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RESEARCH MEMORANDUM

FLIGHT DETERMINATION OF THE LONGITUDINAL STABILITY IN ACCELERATED MANEUVERS AT TRANSONIC SPEEDS FOR THE DOUGLAS D-558-II RESEARCH AIRPLANE INCLUDING THE EFFECTS OF AN OUTBOARD WING FENCE

By Jack Fischel and Jack Nugent

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NATIONAL ADVISORY COMMITTEE
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FLIGHT DETERMINATION OF THE LONGITUDINAL STABILITY IN ACCELERATED MANEUVERS AT TRANSONIC SPEEDS FOR THE DOUGLAS D-558-II RESEARCH AIRPLANE INCLUDING THE EFFECTS OF AN OUTBOARD WING FENCE

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SUMMARY

Flight tests were performed with the Douglas D-558-II research airplane in the clean configuration to investigate the longitudinal stability characteristics of the airplane in accelerated flight at transonic speeds. The airplane was tested in the original configuration and also in a modified configuration (with outboard wing fences at 0.73 wing semispan) in an attempt to alleviate the reduction of stability encountered with the original airplane configuration at moderate lift coefficients.

At moderate values of angle of attack, the airplane experienced a decrease in stability which was accompanied by a rapid uncontrolled increase in the angle of attack and normal acceleration (termed "pitch-up"). The normal-force coefficient for the occurrence of the reduction in stability was found for the original airplane configuration to decrease from a value of 0.91 to 0.47 as the Mach number increased from 0.52 to 0.94. The incorporation of outboard fences appeared to provide only a slight improvement in stability over the original airplane configuration.

The pilots reported the airplane to be uncontrollable for a range of normal acceleration of 1 g to $1\frac{1}{2}$g after the pitch-up had started but appeared to be slightly more controllable in this region with outboard fences on the wing. In either configuration the behavior was extremely undesirable and would prevent precision flight in this region.

Because the reported flights were performed at reasonably high altitudes, no excessive airframe loads were encountered; however, at lower altitudes, the possibility and danger of such excessive loads are apparent.

INTRODUCTION

The use of sweptback wings on current aircraft has introduced a problem of longitudinal stability and control which manifests itself by a sizable decrease in static stability as the airplane angle of attack increases. The decrease in airplane stability may be stick-fixed or stick-free, or both, and results in a pitching of the airplane to higher angles of attack. The uncontrolled pitching of the airplane (pitch-up) is extremely undesirable because it interferes with precise controlled flight. This is true even if sufficient control is available to recover from the pitch-up; whereas if the pitching is uncontrollable by the pilot it may lead to excessively large structural loads on the aircraft and hence is dangerous.

The longitudinal pitch-up encountered by the Douglas D-558-II airplane at maneuvering lift coefficients at subsonic and transonic speeds has been reported previously in references 1 and 2. Similar behavior for another swept-wing airplane at transonic speeds has also been discussed in references 3 and 4.

In order to extend the data reported in reference 1 to higher values of lift and Mach number, an investigation was performed on an identical airplane and some of the results obtained are reported herein. The Douglas D-558-II research airplane used in the present investigation was procured for the National Advisory Committee for Aeronautics by the Bureau of Aeronautics, Department of the Navy, for use in the joint Air Force-Navy-NACA transonic flight research program. Data were obtained during accelerated longitudinal maneuvers up to high values of normal-force coefficient and at speeds up to a Mach number of approximately 0.96. From these data, a normal-force-coefficient—Mach number boundary for the occurrence of the decay in longitudinal stability was determined and is presented herein. The effects of an outboard wing fence, developed by a wind-tunnel investigation for improving the longitudinal stability in the clean condition (ref. 5), were also determined.

SYMBOLS

δ_e elevator deflection with respect to stabilizer, deg

i_t stabilizer setting with respect to fuselage center line, positive when leading edge of stabilizer is up, deg

F_e elevator control force, lb

n	normal acceleration, g units
g	acceleration due to gravity, ft/sec^2
C_{N_A}	airplane normal-force coefficient, nW/qS
W	airplane weight, lb
q	free-stream dynamic pressure, lb/sq ft
S	wing area, sq ft
b	wing span, ft
c	wing chord, ft
M	free-stream Mach number
h_p	pressure altitude, ft
α	angle of attack of airplane center line, deg
$\dot{\theta}$	pitching velocity, radians/sec
t	time, sec

AIRPLANE

The Douglas D-558-II airplanes have sweptback wing and tail surfaces and were designed for combination turbojet and rocket power. The airplane used in the present investigation (BuAero No. 37975 or NACA 145) is equipped with a Westinghouse J-34-WE-40 turbojet engine, exhausting out the bottom of the fuselage between the wing and the tail, and with a Reaction Motors, Inc. LR8-RM-6 rocket engine, exhausting out the aft end of the fuselage. The airplane is air-launched from a Boeing B-29 mother airplane. A photograph of the airplane is shown as figure 1 and a three-view drawing is shown as figure 2. Pertinent airplane dimensions and characteristics are listed in table I.

Wing slats, which spanned the outboard section of each wing panel, were incorporated in the original airplane configuration; however, for the investigation reported herein, the wing slats were locked in the closed position. Inboard wing fences at 0.36 wing semispan were incorporated in the original airplane configuration to improve the longitudinal stability characteristics of the airplane at high angles of attack

($\alpha > 10^{\circ}$) when the wing slats were open (ref. 5). A modified configuration of the airplane also tested incorporated outboard wing fences at 0.73 wing semispan in addition to the inboard fences. The outboard fences were similar to the optimum fence configuration developed in the wind-tunnel investigation of reference 5 for improving the longitudinal stability characteristics at high angles of attack in the airplane clean configuration and started at the 48.5-percent-chord station and extended around the wing leading edge. Figures 3 and 4 illustrate the wing and fence configurations investigated.

The airplane is equipped with an adjustable stabilizer. No aerodynamic balance or control-force booster system is used on the elevator. Hydraulic dampers are installed on all the control surfaces to aid in the prevention of control-surface "buzz."

INSTRUMENTATION

Standard NACA recording instruments were installed in the airplane to measure the following quantities which were pertinent to this investigation:

Airspeed
Altitude
Elevator wheel force
Normal acceleration
Pitching velocity
Angle of attack
Stabilizer and elevator positions

All of the instruments were synchronized by means of a common timer.

The elevator position was measured at the inboard end of the control surface. The elevator positions presented were measured with respect to the stabilizer and the stabilizer position was measured with respect to the fuselage center line at the plane of symmetry. All control positions were measured perpendicular to the control hinge line.

An NACA high-speed pitot-static tube (type A-6 in ref. 6) was mounted on a boom $4\frac{3}{4}$ feet forward of the nose of the airplane. The vane used to measure the angle of attack was mounted on the same boom about $3\frac{1}{2}$ feet forward of the nose of the airplane. The angle-of-attack data have not been corrected for the effects of upwash ahead of the nose of the airplane nor for the effects of airplane pitching velocity. The

maximum error attributable to the effects of pitching velocity was of the order of 0.8°. The airspeed system was calibrated up to M = 0.80 by the "fly-by" method and at speeds in excess of M = 0.80 by the NACA radar phototheodolite method (ref. 7).

TESTS, RESULTS, AND DISCUSSION

The longitudinal stability characteristics of the D-558-II airplane were determined in the clean condition (flaps and landing gear up, slats locked) in turning flight for a range of Mach number from about 0.5 to 0.96 for both the original configuration and the configuration incorporating outboard wing fences. The data were obtained in the altitude range from 19,000 to 36,000 feet and for airplane center-of-gravity locations from 24.8 to 26.1 percent of the wing mean aerodynamic chord. The turns were performed by the use of the elevator alone, the stabilizer remaining stationary during the maneuvers. The stabilizer settings ranged from 1.3° to 2.9° for maneuvers with the original airplane configuration; whereas, the stabilizer setting for maneuvers with the airplane equipped with outboard wing fences was 2.1°.

Data obtained in several turns in the original airplane configuration are plotted in the form of time histories in figure 5 and as functions of angle of attack in figure 6. Corresponding plots for the configuration incorporating the outboard fences are shown in figures 7 and 8.

Original Airplane Configuration

Inspection of the data of figure 5 reveals that the airplane is stable up to moderate values of normal-force coefficient, since an up movement of the elevator produced an almost proportional increase in the airplane angle of attack and normal-force coefficient. At higher values of C_{N_A}, however, a substantially constant elevator deflection or continued up movement of the elevator at the same rate as at low values of C_{N_A} resulted in a rapid pitching of the airplane to high angles of attack and also to large normal accelerations. An example of this is shown in figure 5(a), where a rapid increase of the angle of attack appears to start at slightly above 18 seconds, although the rate of increase of elevator deflection is relatively constant. Subsequent to the start of the pitch-up, the stick force lightened and the pilot reversed the elevator control in an attempt to stop the uncontrolled maneuver, but the airplane angle of attack and the value of C_{N_A} continued to increase to higher levels before recovery was effected.

These effects are more clearly shown in figure 6, where an almost linear variation of δ_e with α is observed for the low values of α, indicating a region of almost constant apparent longitudinal stability. At angles of attack above this linear region, the slope of the curve of δ_e against α is reduced, indicating a reduction in stability as the pitch-up occurs. The slope $d\delta_e/d\alpha$ does not indicate the airplane stability in this region because of the high pitching velocities obtained. The angle of attack at which the reduction in stability occurs is indicated in figure 6 by the flagged symbol and is seen to vary with Mach number. The high angle of attack and large values of C_{N_A} obtained after the pitch-up occurred, even though the up-elevator deflection was reduced, indicate the uncontrollable nature of the maneuver.

Airplane Configuration With Outboard Wing Fences

Inspection of the data of figures 7 and 8 indicates that the behavior of the airplane with outboard fences was similar to that of the airplane in the original configuration (figs. 5 and 6). Although the data show that the maximum values of α attained were slightly smaller in this configuration than in the original airplane configuration, little difference was shown by the data between the two airplane configurations.

Boundary for the Decay in Airplane Stability

From data shown in figures 5 to 8 and similar data for other Mach numbers, the normal-force coefficient corresponding to the value of α at which the reduction of stability occurs has been determined for the original airplane configuration and for the configuration with outboard wing fences and is presented as a function of Mach number in figure 9. For the original airplane configuration the value of C_{N_A} for the decay in airplane stability is seen to decrease from approximately 0.91 at $M = 0.52$ to approximately 0.47 at $M = 0.94$. Addition of the outboard fences appeared to provide only a slight improvement over the basic airplane configuration.

For comparative purposes, peak values of C_{N_A} obtained during the reported maneuvers are also shown in figure 9. It is felt that in some instances these peak values of C_{N_A} may correspond to maximum values attainable at the given Mach number. As may be noted, the difference between peak values of C_{N_A} and the values of C_{N_A} for the decay in stability tends to increase as M increases, particularly at $M > 0.75$.

This would tend to increase the magnitude and potential danger of the stability problem as M increases.

The stability problem would be aggravated for airplanes having high wing loadings and for flight at high altitude, because level flight would necessarily be performed at higher angles of attack and normal-force coefficients. This would allow for little or no maneuvering lift margin prior to experiencing the pitch-up, and, in some cases, pitch-up may be encountered in level flight which would be both intolerable and dangerous.

Because the reported flights were performed at reasonably high altitudes, no excessive airframe loads were encountered; however, at lower altitudes, the possibility and danger of such excessive loads are apparent.

Pilots' Impressions

Although the pilots reported that they could control the pitch-up slightly better with the outboard fences installed, the behavior was considered undesirable in either airplane configuration.

In the pilots' opinion, the airplane is uncontrollable for a range of normal acceleration of about 1 g to $1\frac{1}{2}$g above the value at which the reported change in stability occurs; this behavior is very objectionable. At low speeds, if the pilot does not check the pitch-up by use of the elevator as soon as it is noticed, the angle of attack increases rapidly and violent rolling and yawing motions are experienced at large values of α. At high speeds the pitch-up appeared to be more severe and more abrupt.

Throughout the speed range covered, the occurrence of a reduction in stick-free stability almost simultaneously with the reduction in stick-fixed stability tended to accentuate the pitch-up to the pilot. The pilot felt that even with improved control, as would result from an all-movable tail, flight above the stability boundary would not be sufficiently steady for gunnery or other precise maneuvering.

CONCLUSIONS

Results of a longitudinal-stability investigation of the swept-wing Douglas D-558-II research airplane at high Mach numbers give the following conclusions:

1. At moderate values of angle of attack, a reduction of longitudinal stability was experienced as evidenced by a rapid uncontrolled increase in the angle of attack and normal acceleration (pitch-up).

2. The point at which the pitch-up occurred varied from a value of normal-force coefficient of about 0.91 at a Mach number of 0.52 to a value of about 0.47 at a Mach number of 0.94 for the original airplane configuration.

3. The addition of wing fences at 0.73 wing semispan appeared to provide only a slight improvement over the orginal configuration, inasmuch as the pitch-up occurred at only slightly higher values of normal-force coefficient for the modified airplane configuration.

4. In the pilots' opinion, the airplane is uncontrollable for a range of normal acceleration of 1 g to $1\frac{1}{2}$g after the stability has decayed and the airplane is pitching up but appeared to be slightly more controllable in the pitch-up region with outboard fences on the wings. In either configuration, the behavior was extremely undesirable and would prevent precision flight in this region.

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3. Anderson, Seth B., and Bray, Richard S.: A Flight Evaluation of the Longitudinal Stability Characteristics Associated With the Pitch-Up of a Swept-Wing Airplane in Maneuvering Flight at Transonic Speeds. NACA RM A51I12, 1951.

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7. Zalovcik, John A.: A Radar Method of Calibrating Airspeed Installations on Airplanes in Maneuvers at High Altitudes and at Transonic and Supersonic Speeds. NACA Rep. 985, 1950. (Supersedes NACA TN 1979.)

TABLE I

PHYSICAL CHARACTERISTICS OF THE

DOUGLAS D-558-II AIRPLANE

Wing:	
Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63_1-012
Total area, sq ft	175.0
Span, ft	25.0
Mean aerodynamic chord, in.	87.301
Root chord (parallel to plane of symmetry), in.	108.51
Tip chord (parallel to plane of symmetry), in.	61.18
Taper ratio	0.565
Aspect ratio	3.570
Sweep at 0.30 chord, deg	35.0
Incidence at fuselage center line, deg	3.0
Dihedral, deg	-3.0
Geometric twist, deg	0
Total aileron area (aft of hinge), sq ft	9.8
Aileron travel (each), deg	±15
Total flap area, sq ft	12.58
Flap travel, deg	50
Horizontal tail:	
Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63-010
Area (including fuselage), sq ft	39.9
Span, in.	143.6
Mean aerodynamic chord, in.	41.75
Root chord (parallel to plane of symmetry), in.	53.6
Tip chord (parallel to plane of symmetry), in.	26.8
Taper ratio	0.50
Aspect ratio	3.59
Sweep at 0.30 chord line, deg	40.0
Dihedral, deg	0
Elevator area, sq ft	9.4
Elevator travel, deg	
Up	25
Down	15
Stabilizer travel, deg	
Leading edge up	4
Leading edge down	5

TABLE I.- Concluded

PHYSICAL CHARACTERISTICS OF THE

DOUGLAS D-558-II AIRPLANE

Vertical tail:	
Airfoil section (normal to 0.30 chord)	NACA 63-010
Area, sq ft	36.6
Height from fuselage center line, in.	98.0
Root chord (parallel to fuselage center line), in.	146.0
Tip chord (parallel to fuselage center line), in.	44.0
Sweep angle at 0.30 chord, deg	49.0
Rudder area (aft of hinge line), sq ft	6.15
Rudder travel, deg	±25
Fuselage:	
Length, ft	42.0
Maximum diameter, in.	60.0
Fineness ratio	8.40
Speed-retarder area, sq ft	5.25
Engines:	
Turbojet	J-34-WE-40
Rocket	LR8-RM-6
Airplane weight, lb:	
Full jet and rocket fuel	15,131
Full jet fuel	11,942
No fuel	10,382
Center-of-gravity locations, percent M.A.C.:	
Full jet and rocket fuel (gear up)	23.5
Full jet fuel (gear up)	25.2
No fuel (gear up)	27.0
No fuel (gear down)	26.4

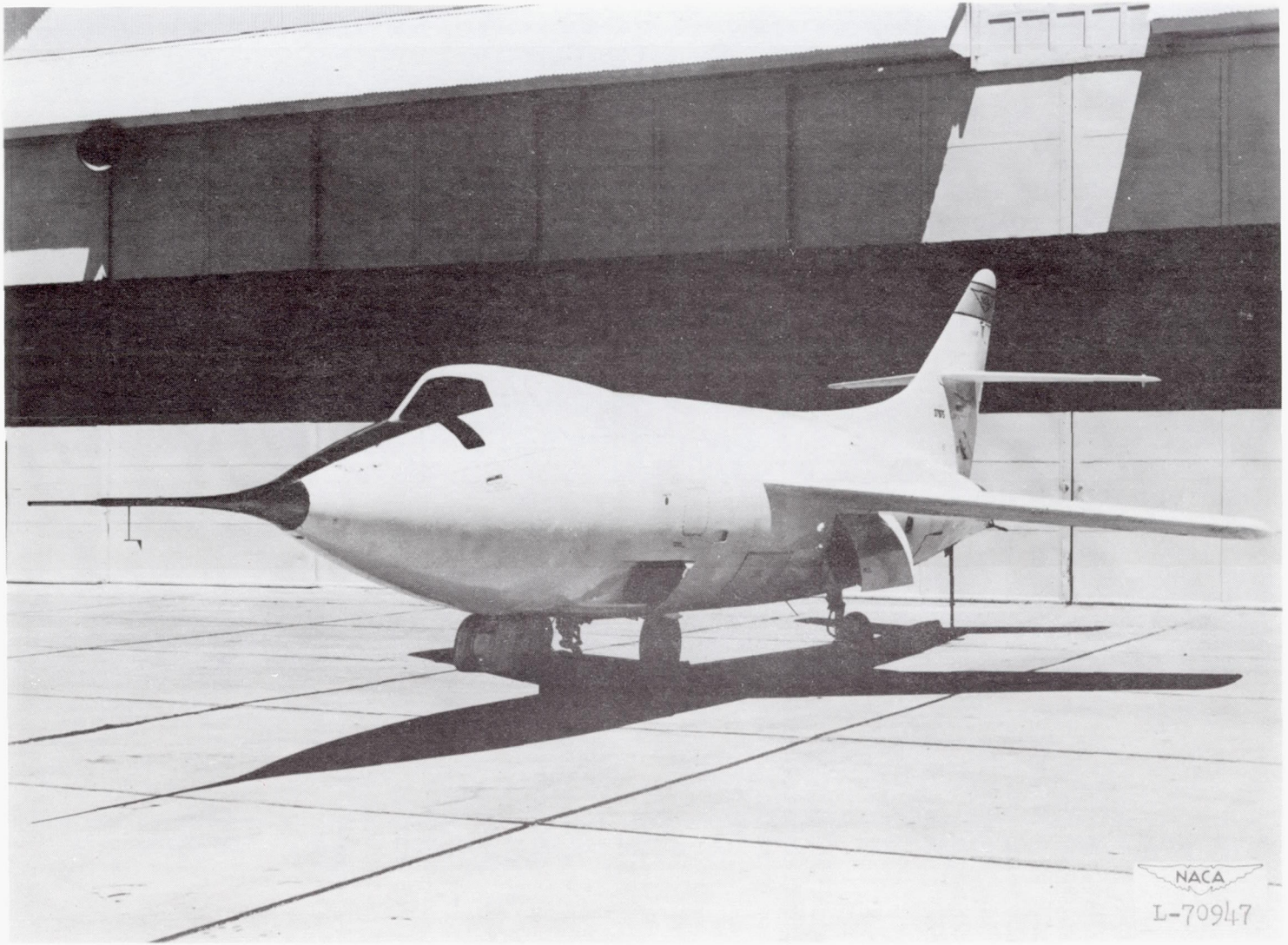


Figure 1.- Three-quarter front view of Douglas D-558-II airplane.

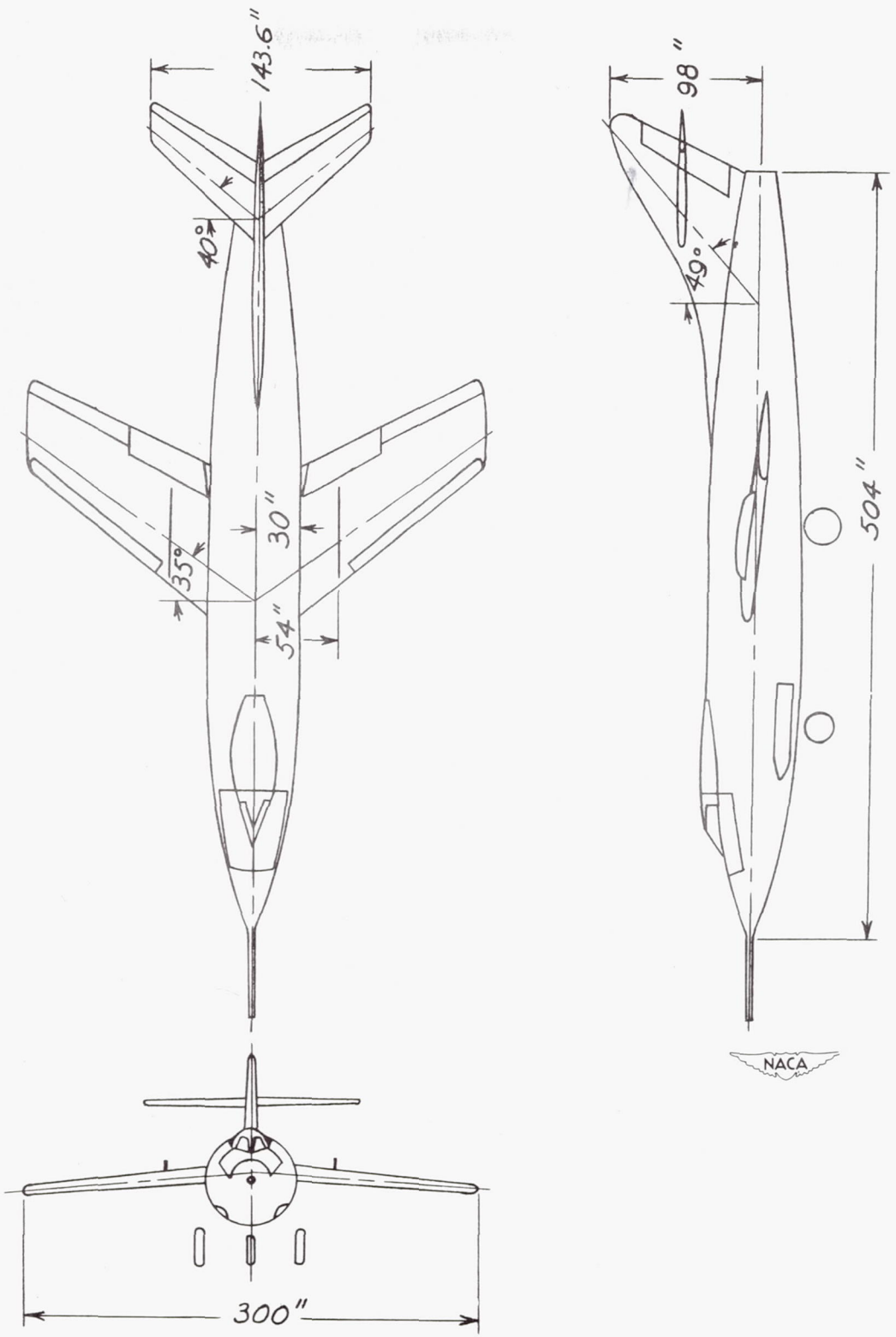


Figure 2.- Three-view drawing of Douglas D-558-II (NACA 145) research airplane.

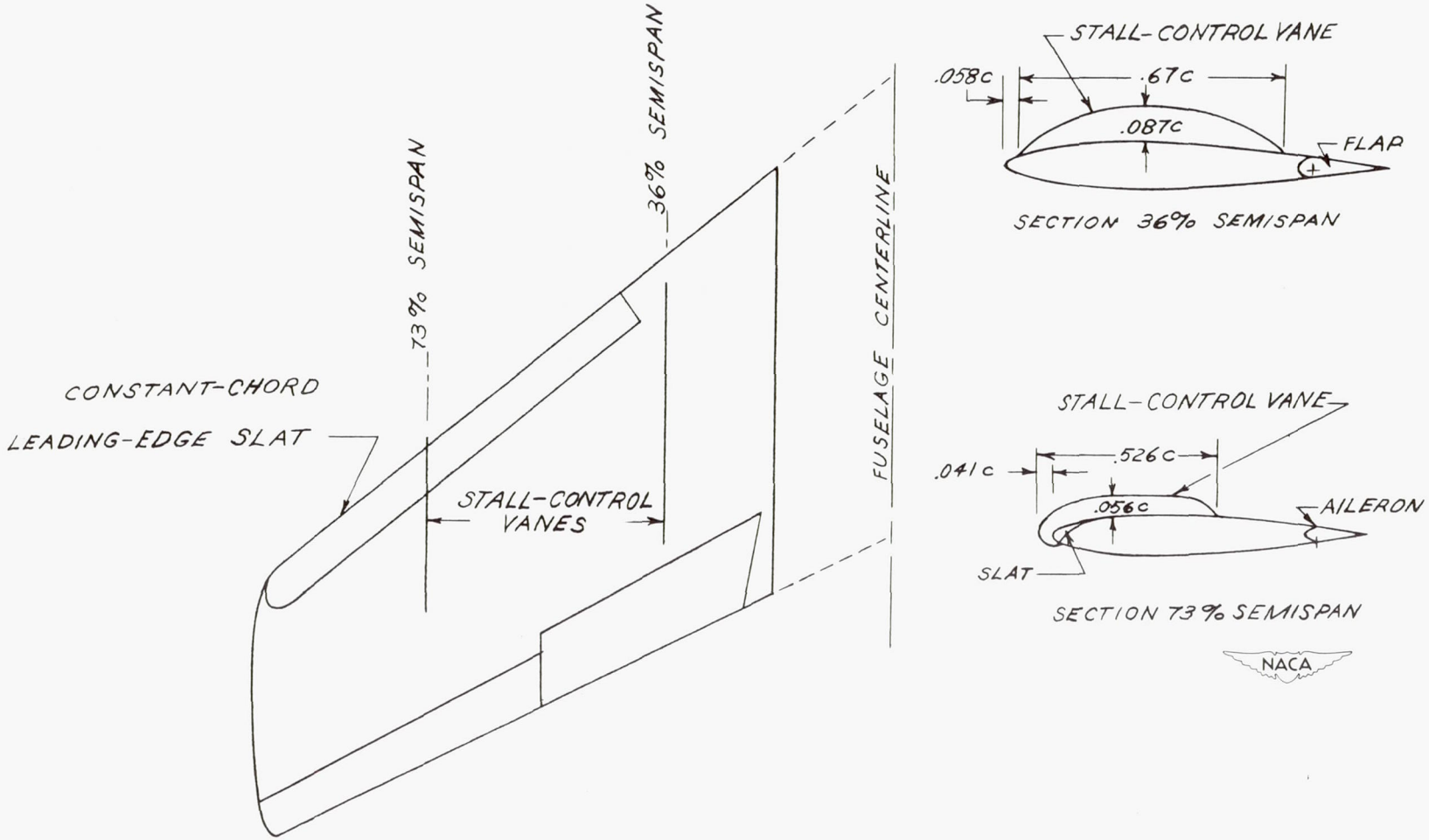


Figure 3.- Plan form and sections of the wing of the Douglas D-558-II airplane showing the location and shape of wing fences (stall-control vanes) used in the investigation.

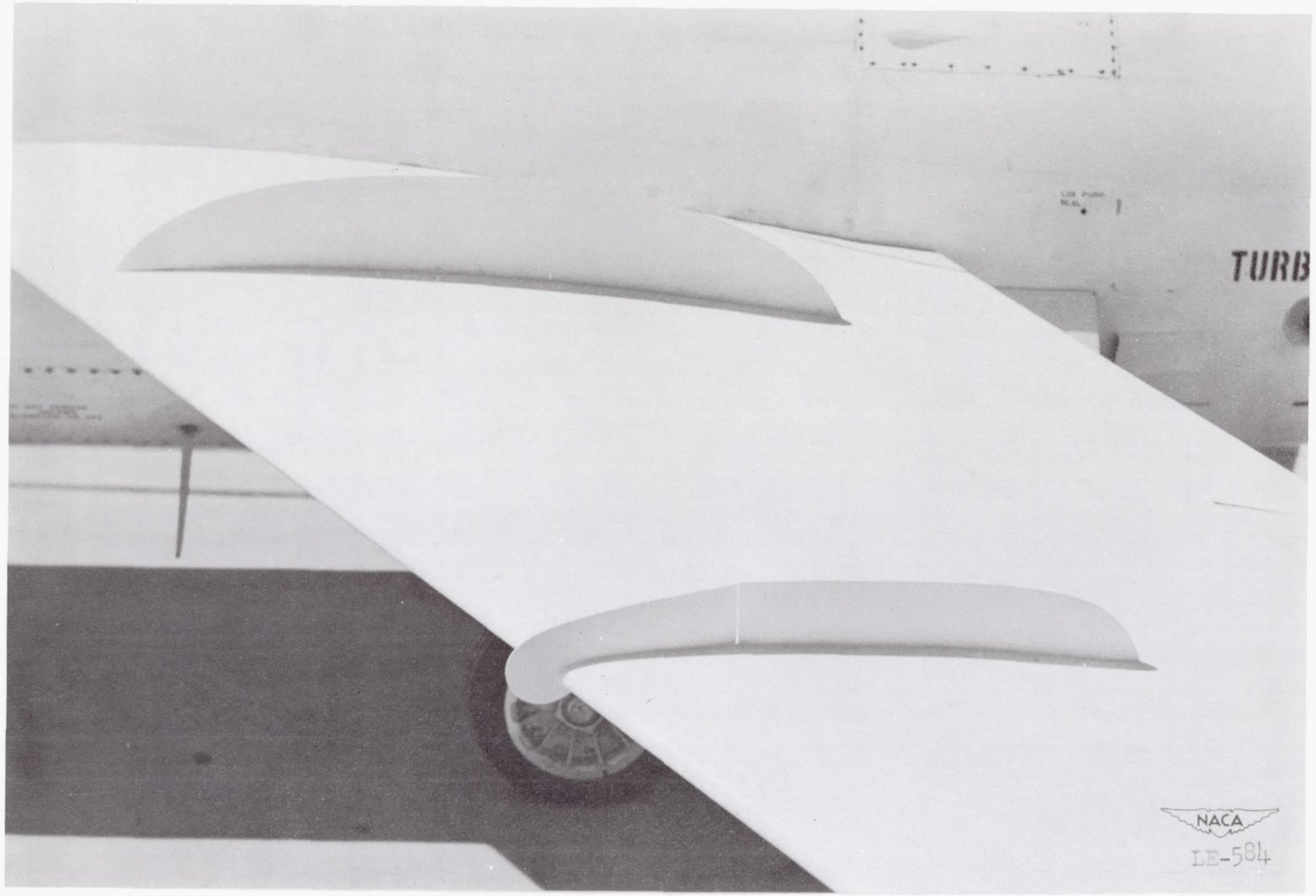
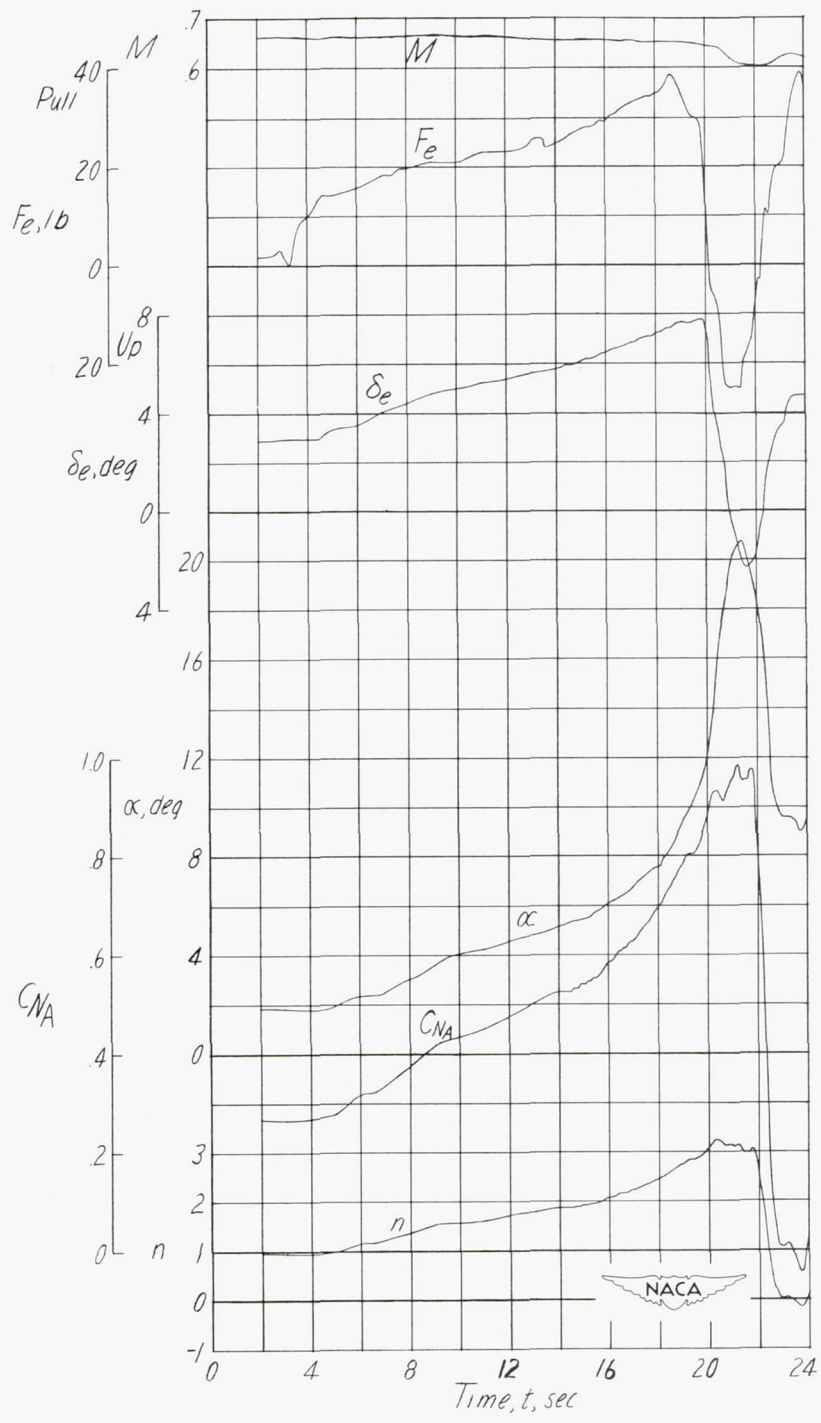
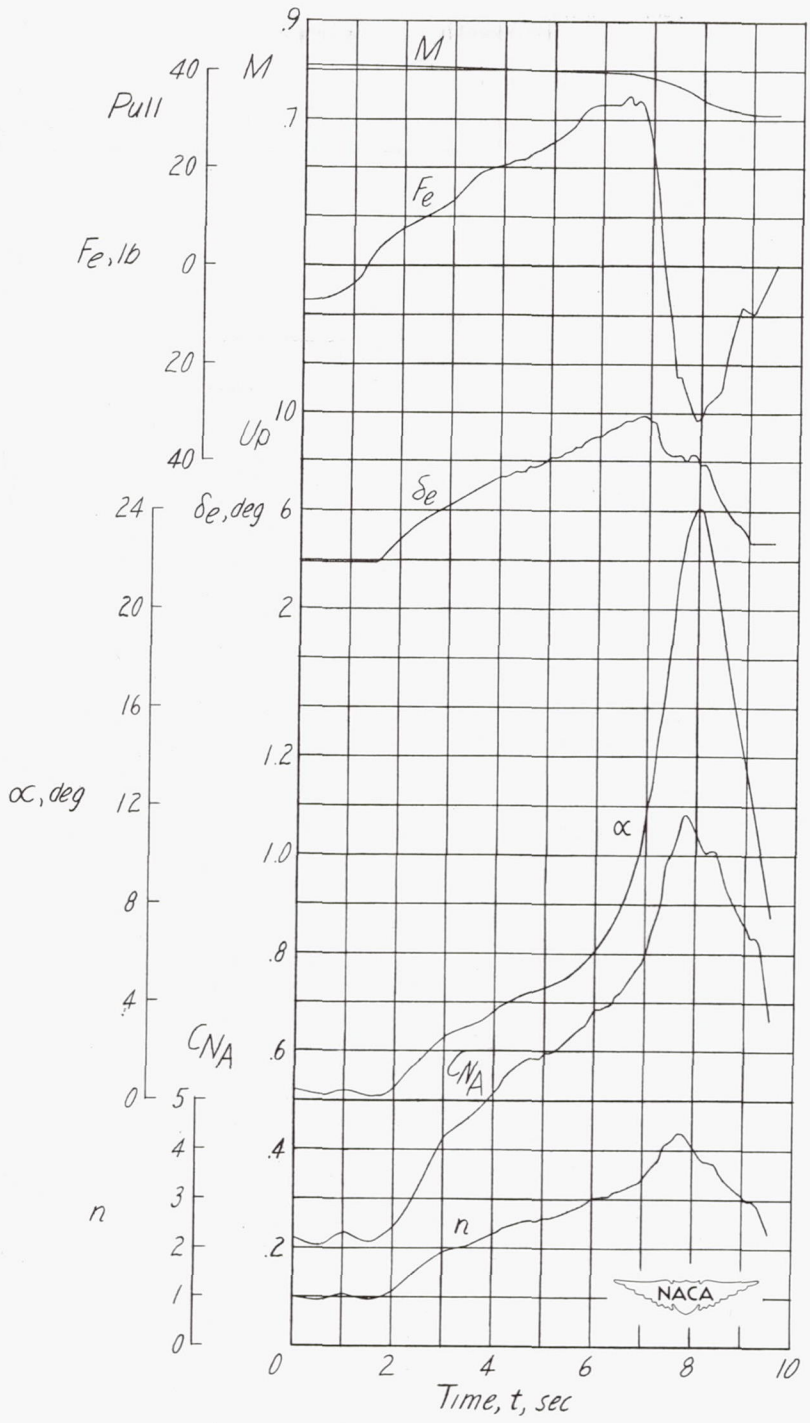


Figure 4.- Photograph of the D-558-II wing showing the inboard and outboard fences (stall-control vanes) on the wing.



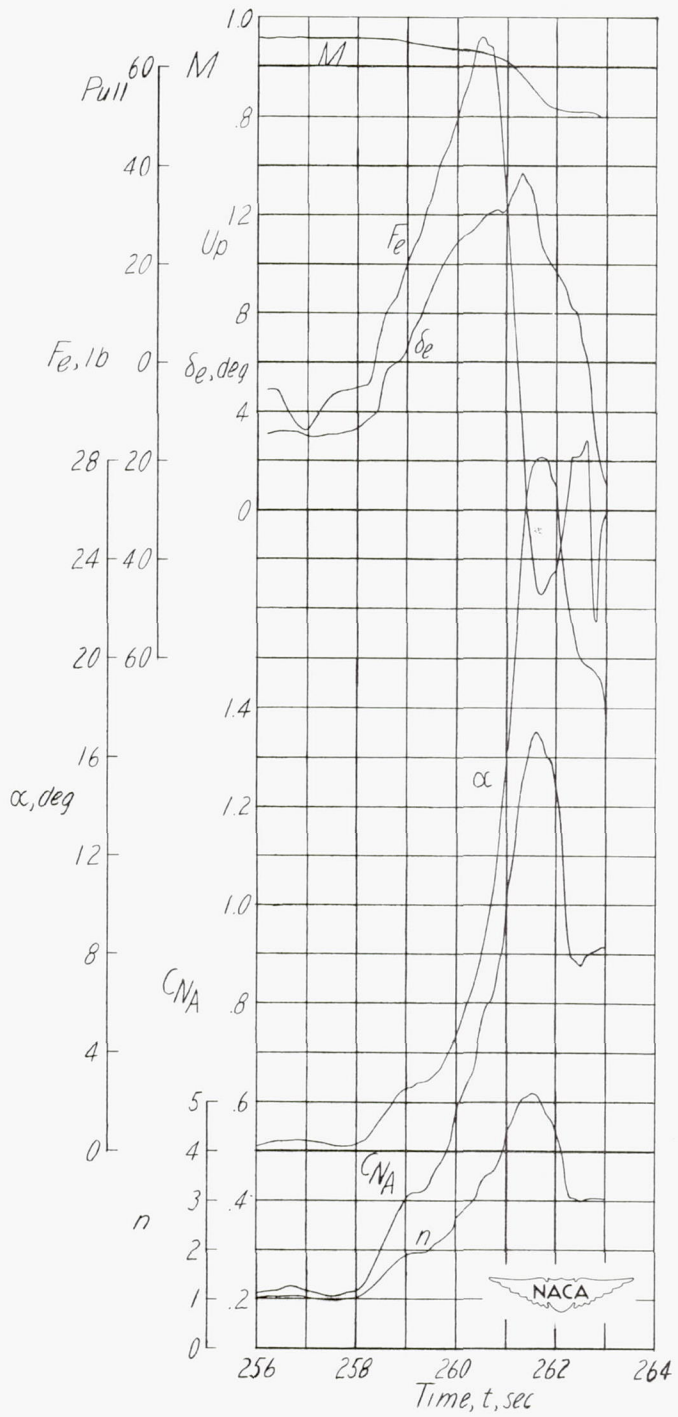
(a) $h_p \approx 25{,}500$ feet; $i_t = 2.3^\circ$; center of gravity at 25.8 percent mean aerodynamic chord.

Figure 5.- Time histories of wind-up turns with the Douglas D-558-II research airplane in the original airplane configuration.



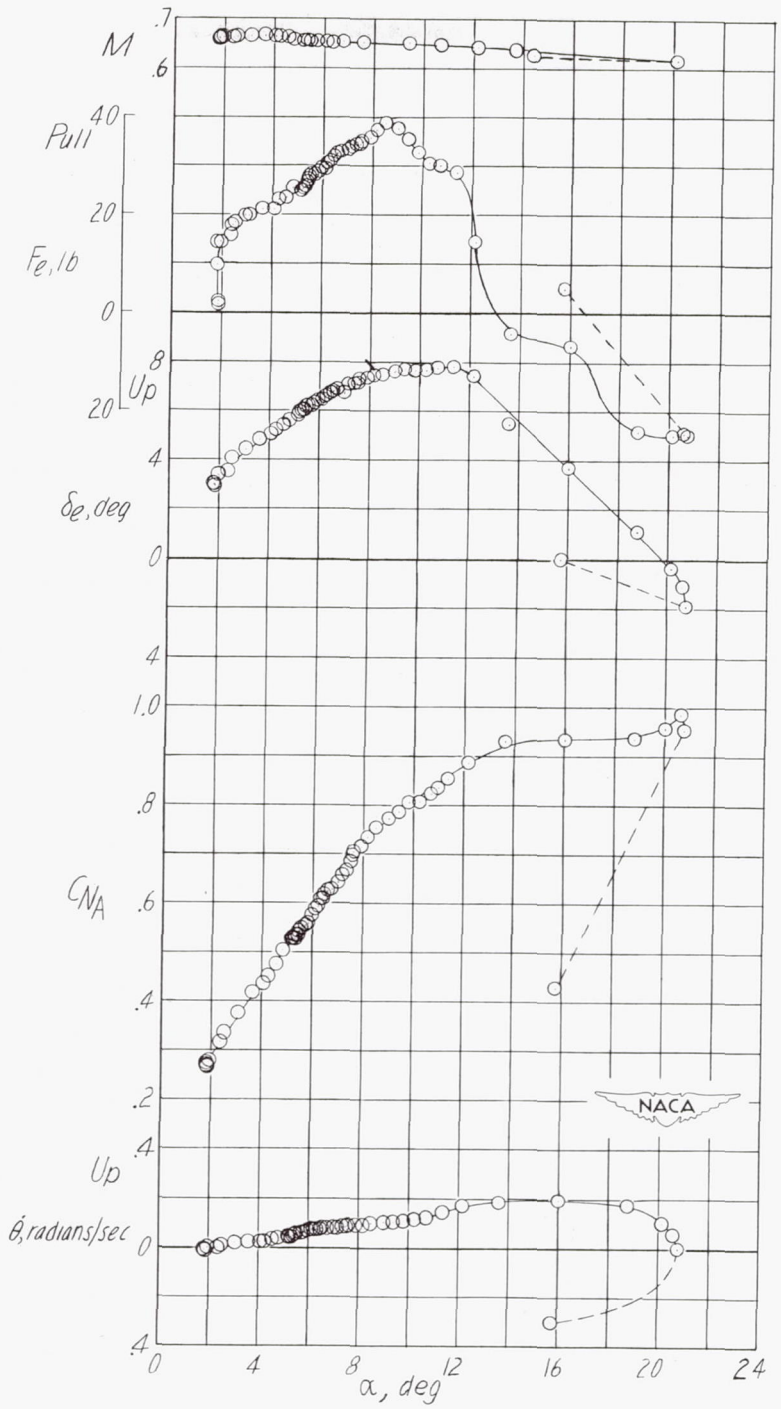
(b) $h_p \approx 28{,}700$ feet; $i_t = 2.1^\circ$; center of gravity at 25.3 percent mean aerodynamic chord.

Figure 5.- Continued.



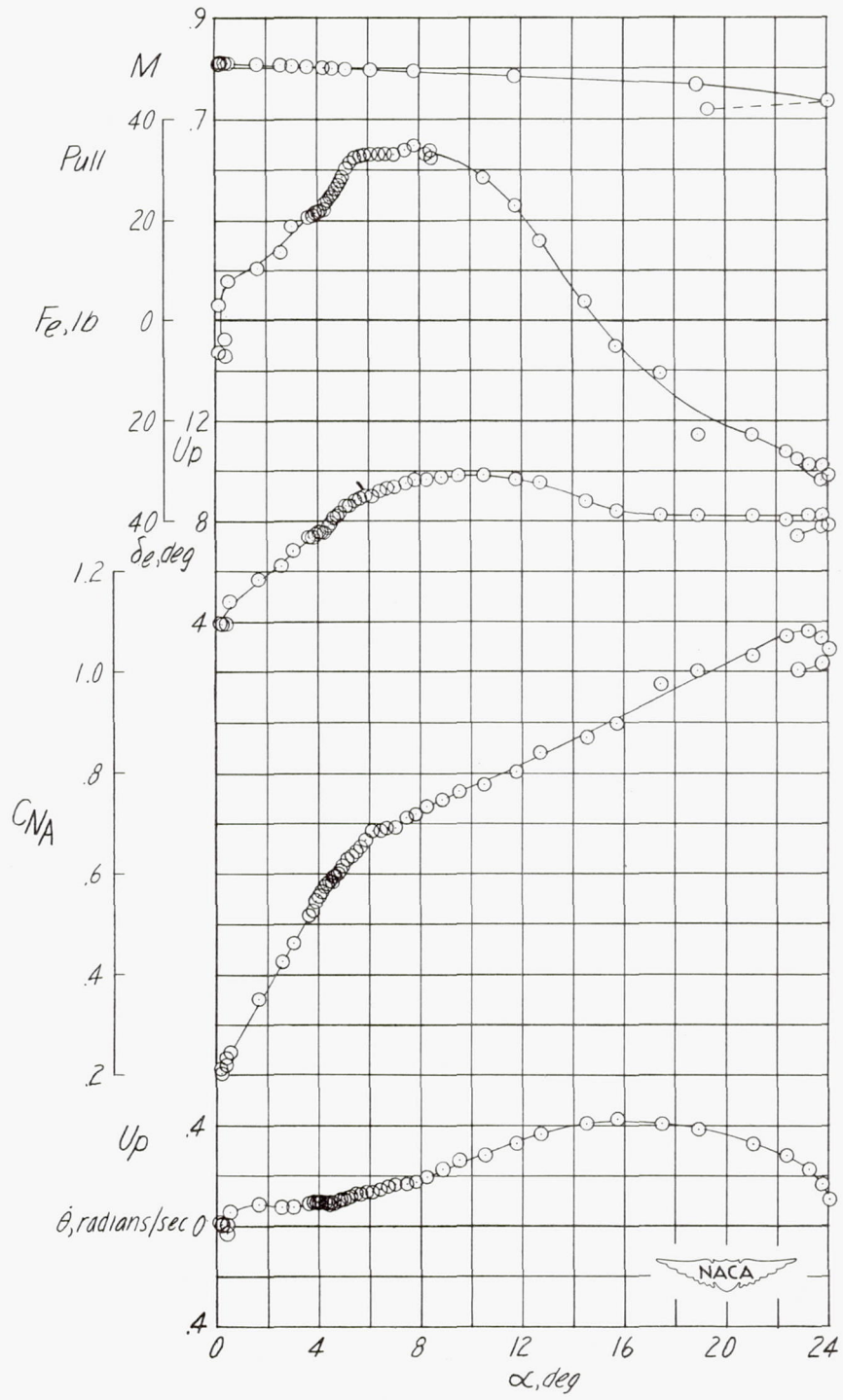
(c) $h_p \approx$ 34,800 feet; $i_t = 1.6^\circ$; center of gravity at 26.1 percent mean aerodynamic chord.

Figure 5.- Concluded.



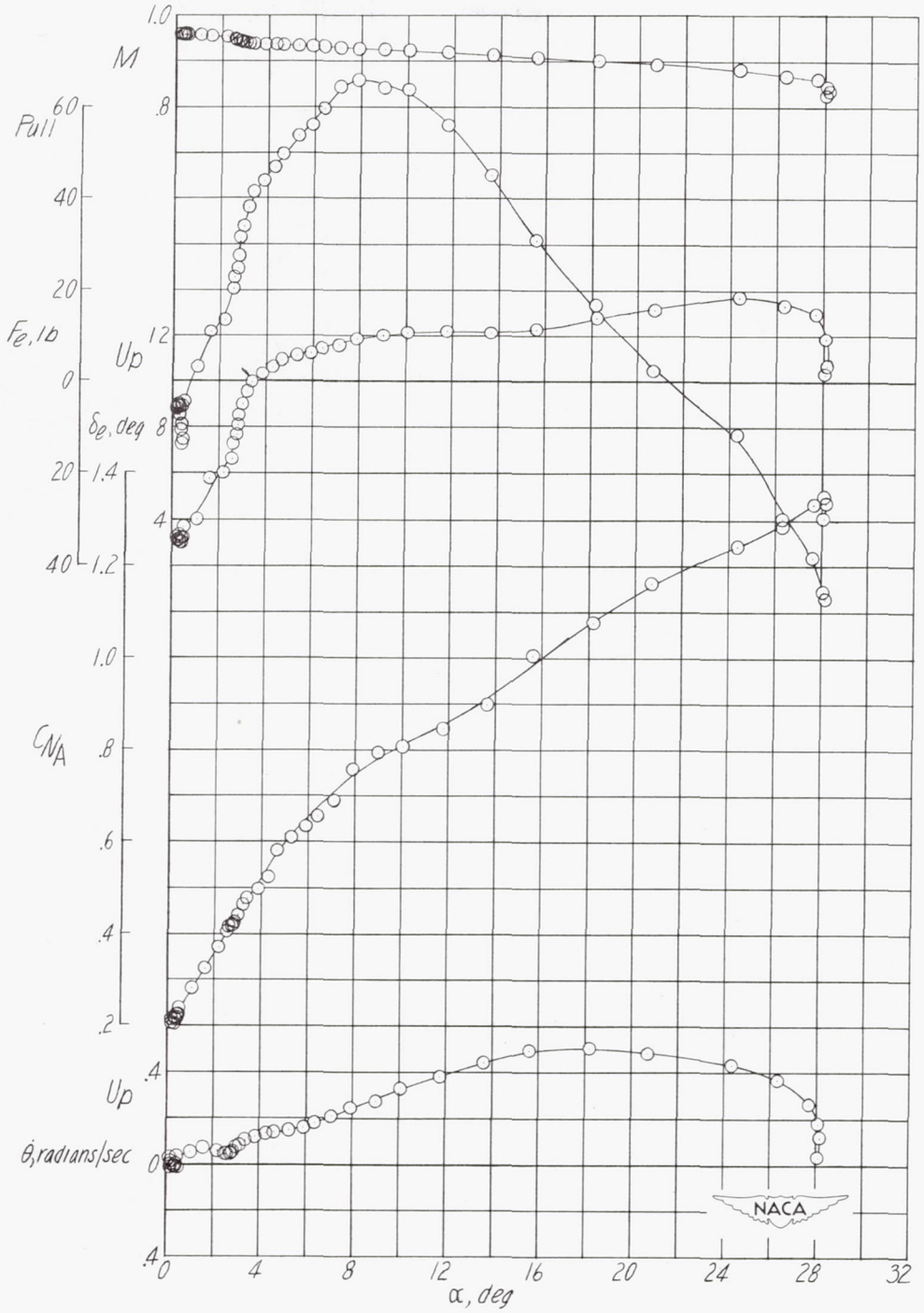
(a) $h_p \approx 25{,}500$ feet; $i_t = 2.3^\circ$; center of gravity at 25.8 percent mean aerodynamic chord.

Figure 6.- Longitudinal stability characteristics of the Douglas D-558-II research airplane in the original configuration in turning flight.



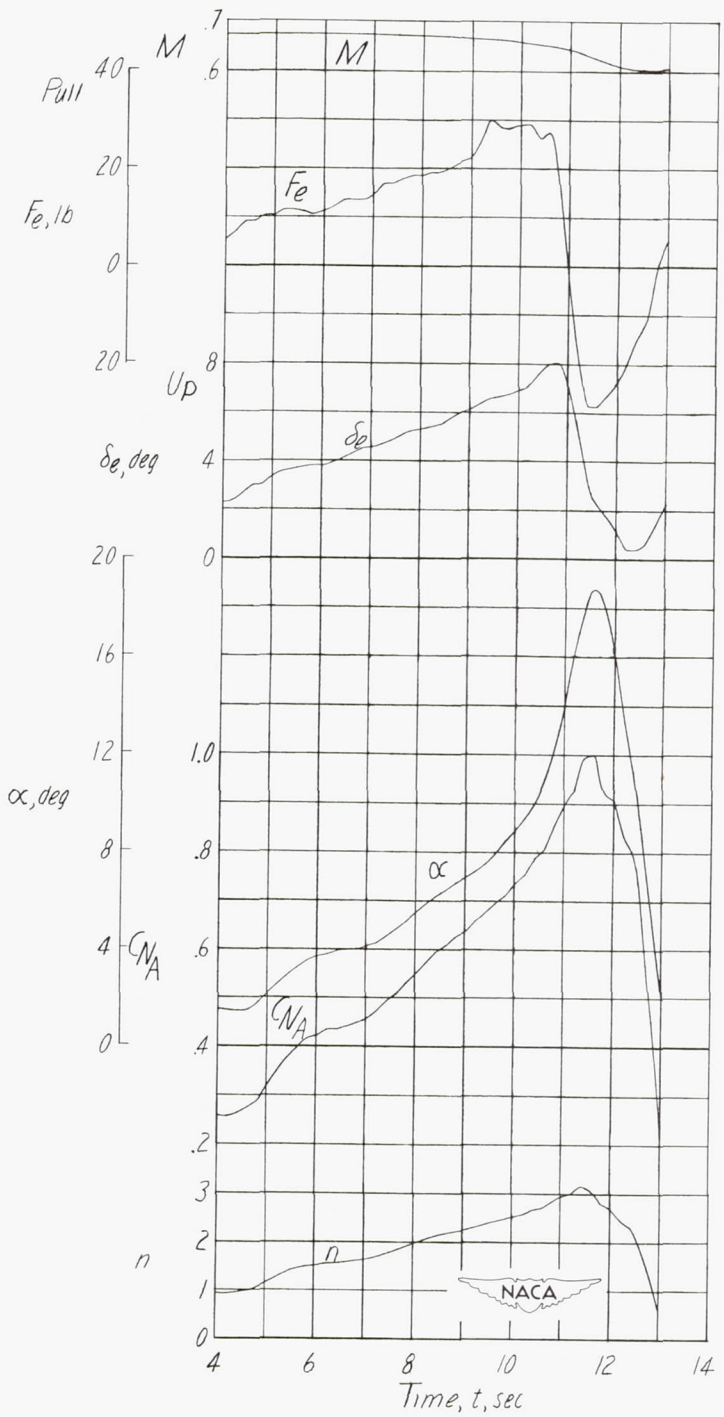
(b) $h_p \approx 28{,}700$ feet; $i_t = 2.1^\circ$; center of gravity at 25.3 percent mean aerodynamic chord.

Figure 6.- Continued.



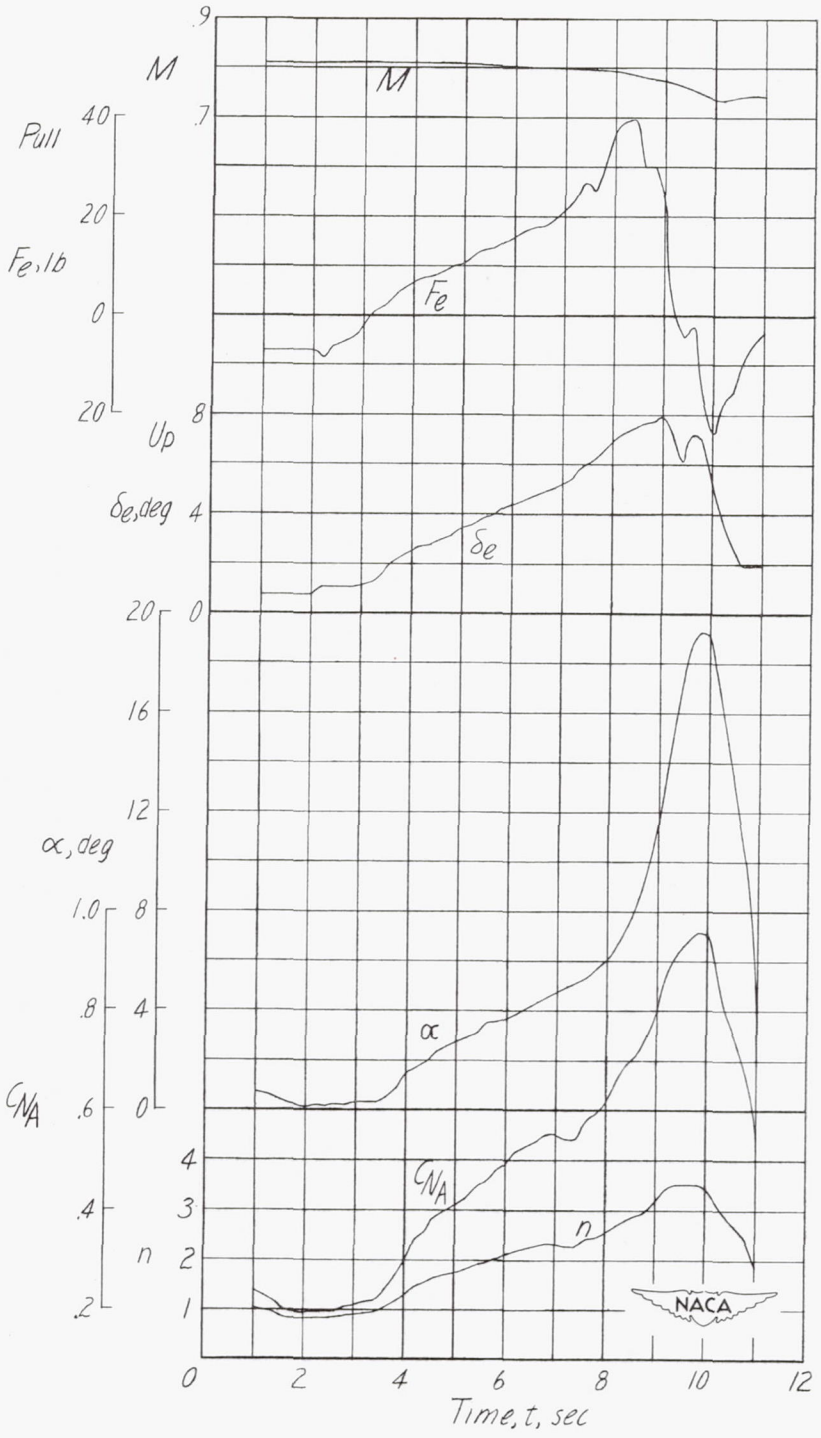
(c) $h_p \approx 34{,}800$ feet; $i_t = 1.6^\circ$; center of gravity at 26.1 percent mean aerodynamic chord.

Figure 6.- Concluded.



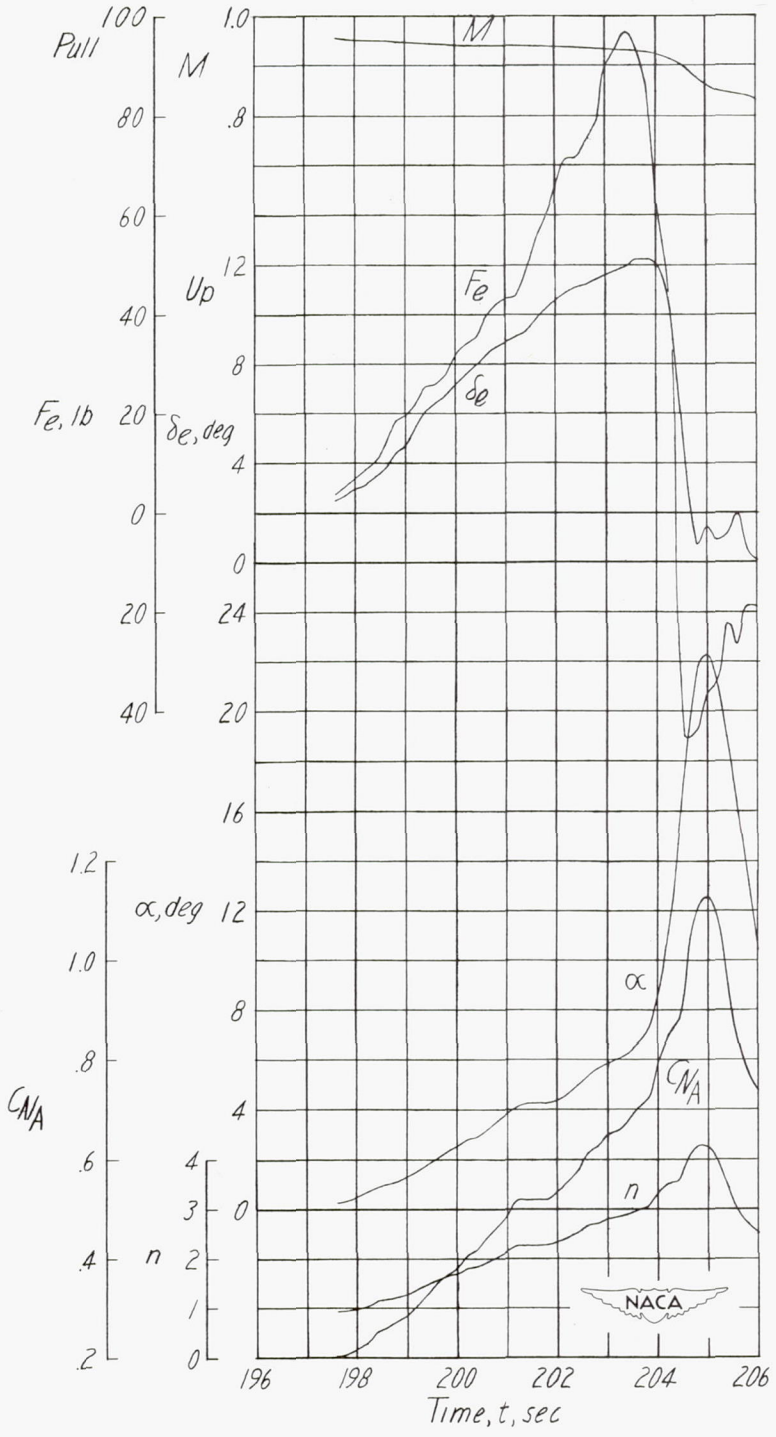
(a) $h_p \approx 26{,}200$ feet; $i_t = 2.1^\circ$; center of gravity at 26.1 percent mean aerodynamic chord.

Figure 7.- Time histories of wind-up turns with the Douglas D-558-II research airplane with outboard wing fences at 0.73 wing semispan.



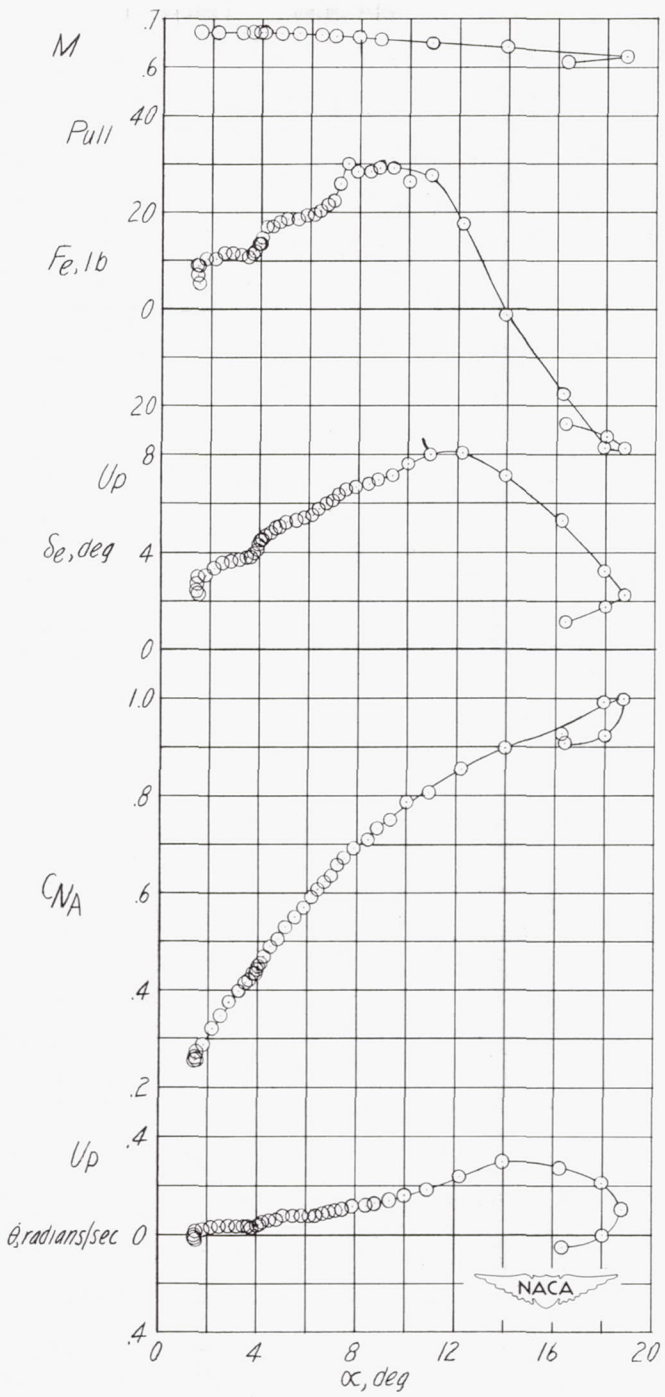
(b) $h_p \approx 30{,}400$ feet; $i_t = 2.1^\circ$; center of gravity at 26.0 percent mean aerodynamic chord.

Figure 7.- Continued.



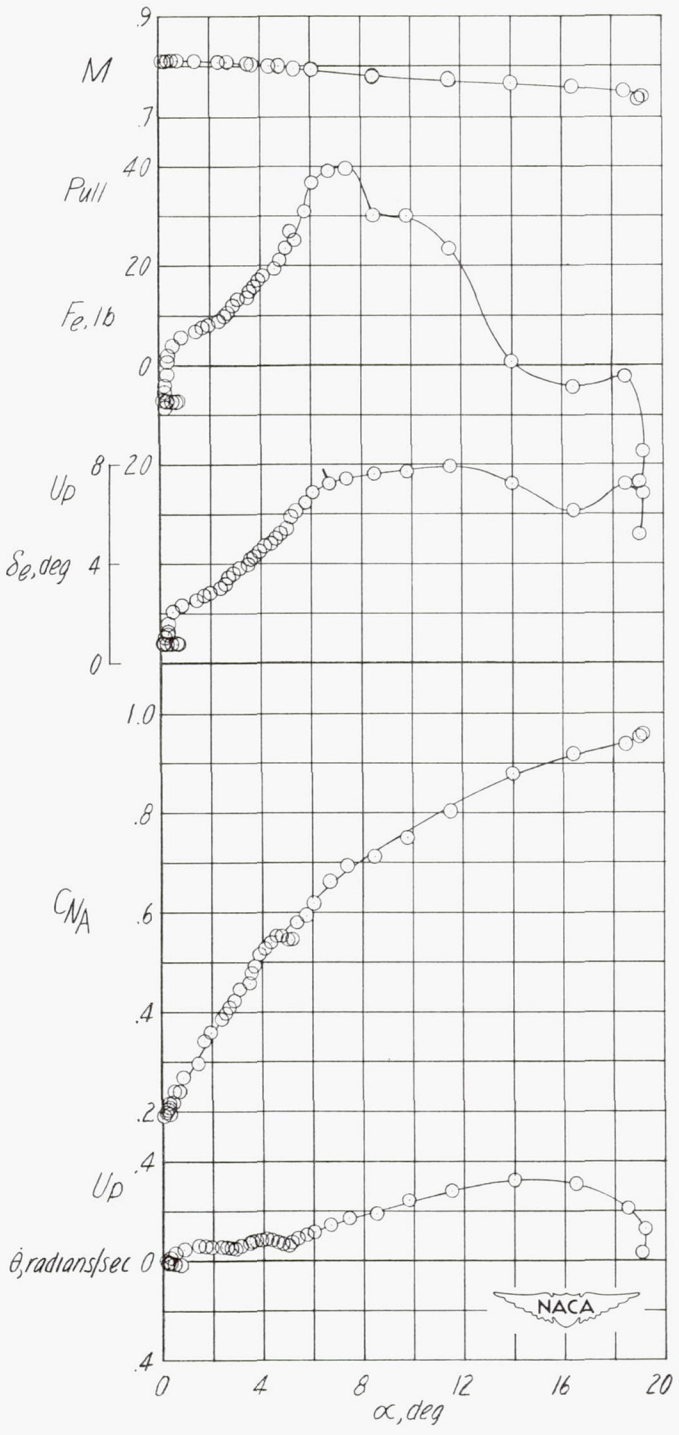
(c) $h_p \approx 35{,}600$ feet; $i_t = 2.1^\circ$; center of gravity at 24.8 percent mean aerodynamic chord.

Figure 7.- Concluded.



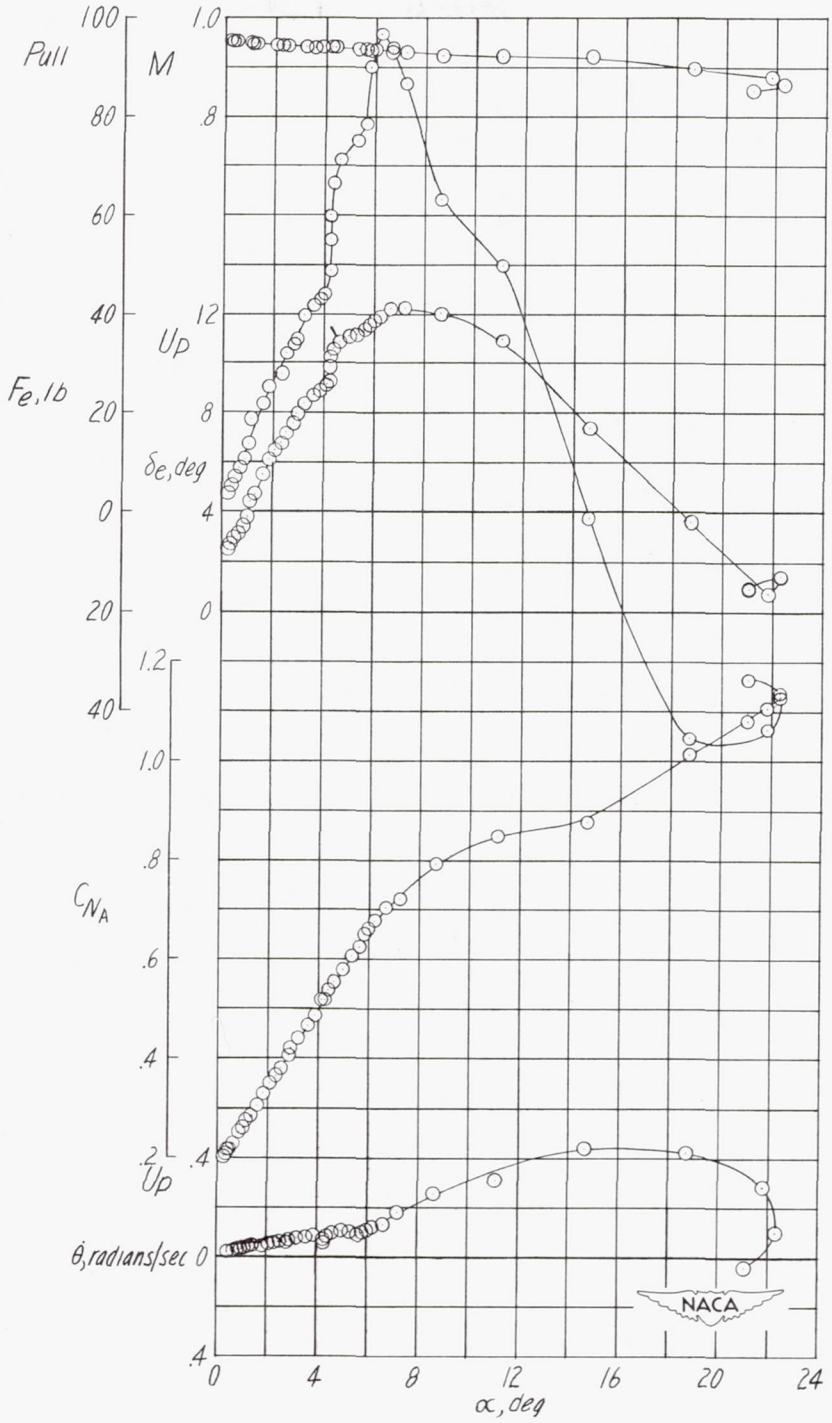
(a) $h_p \approx 26{,}200$ feet; $i_t = 2.1^\circ$; center of gravity at 26.1 percent mean aerodynamic chord.

Figure 8.- Longitudinal stability characteristics of the Douglas D-558-II research airplane with outboard wing fences at 0.73 wing semispan in turning flight.



(b) $h_p \approx 30{,}400$ feet; $i_t = 2.1^\circ$; center of gravity at 26.0 percent mean aerodynamic chord.

Figure 8.- Continued.



(c) $h_p \approx 35{,}600$ feet; $i_t = 2.1^\circ$; center of gravity at 24.8 percent mean aerodynamic chord.

Figure 8.- Concluded.

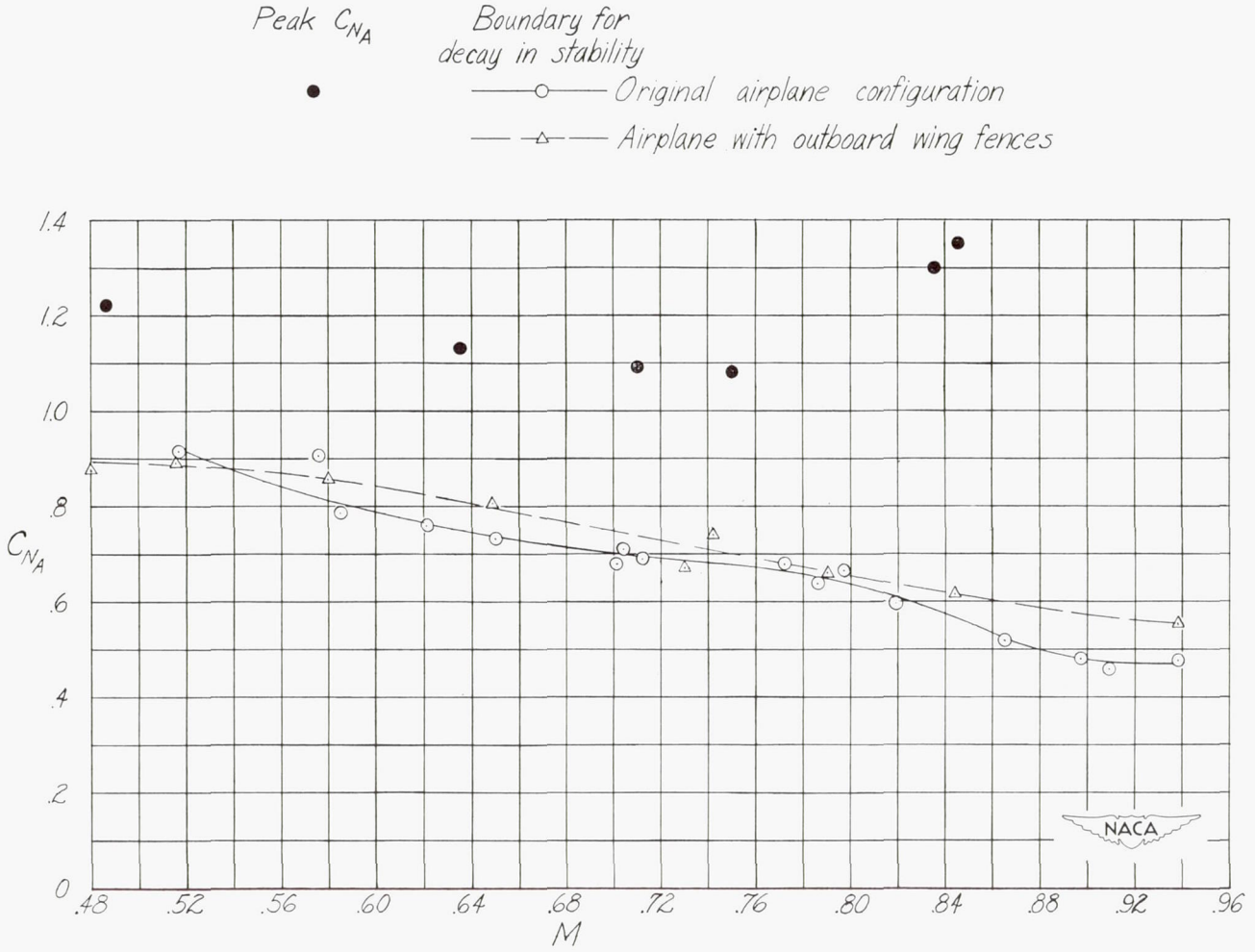


Figure 9.- Variation of normal-force coefficient with Mach number for the decay in airplane longitudinal stability and the onset of pitch-up for both the original airplane configuration and the configuration incorporating outboard wing fences.

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