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SUMMARY

The low-speed characteristics of a delta-wing aircraft modified to an Ogee plan form were investigated in flight and in the Ames 40- by 80-Foot Wind Tunnel. The flight results showed the aircraft had good flying qualities with improved lateral-directional control characteristics. The flight characteristics of the aircraft were sufficiently improved that the pilot was willing to lower the approach speed 10 knots.

INTRODUCTION

Supersonic transport configurations that employ fixed-geometry wings of low aspect ratio have been found to provide performance competitive with that of other designs. Some small-scale wind-tunnel tests (ref. 1) have indicated that one variation of this type of wing, the Ogee, exhibits better low-speed or landing characteristics than some other plan forms of low aspect ratio. These benefits result from a stable vortex flow which is established over the wing by the high sweep angle at the wing root of the Ogee plan form. This vortex system enables the wing to develop higher lift at angles of attack used for landing and take-off. To fully document the characteristics of the Ogee plan form, it was tested in flight and in a full-scale wind tunnel. The specific objective of the tests was to determine whether these benefits of vortex flow are obtainable in flight and whether flight maneuvers would destroy the vortex system so that the pilot could not utilize the static lift capabilities of the wing.

For this investigation, the delta wing of a Douglas F5D-1 aircraft was modified to incorporate an Ogee wing plan form. This modification was first tested in the Ames 40- by 80-Foot Wind Tunnel to determine the static aerodynamic data before the configuration was flight tested. Following the tunnel tests the modifications were made flight-worthy and the low-speed flight characteristics were investigated.

This report describes the flight-measured static and dynamic aerodynamic characteristics of the test airplane with the Ogee wing. Some of the results of the 40- by 80-foot wind tunnel tests are compared with the flight data where applicable.

NOTATION

C_D	drag coefficient, $\frac{\text{drag}}{qS}$
C_L	lift coefficient, $\frac{\text{lift}}{qS}$
q	dynamic pressure, lb/sq ft
S	wing area, sq ft
α	angle of attack, deg
β	angle of sideslip, deg
δ_E	elevon deflection, deg
δ_R	rudder deflection, deg
$\dot{\theta}$	pitching velocity, radians/sec
$\dot{\varphi}$	rolling velocity, radians/sec
$\dot{\psi}$	yawing velocity, radians/sec

DESCRIPTION

Test Airplane

The aircraft used in this investigation was the Douglas F5D-1, a single-place, jet-propelled, delta-wing fighter. The highly swept delta plan form of this aircraft served as a convenient base for the modifications required to produce the Ogee plan form. A photograph of the F5D-1 as modified for these tests is shown in figure 1. Figure 2 presents a two-view drawing of the airplane; pertinent dimensions are presented in table I and in figure 3. The plan form for the basic F5D-1 is shown on figure 2 for comparison. The wing extension was constructed of wood which was attached to the original wing with metal sheets and glass fiber material.

The weight of the aircraft during these flights varied from 25,000 to 21,000 pounds and the center of gravity was 32 percent of the mean aerodynamic chord. Structural limitations prevented ballasting to a more forward center-of-gravity position.

INSTRUMENTATION

Recording instruments were installed to record simultaneously measurements of airspeed, altitude, normal and longitudinal acceleration, angles of attack and sideslip, and tail-pipe total pressure. Control position transducers were mounted at the control surfaces, and angular turnmeters were installed to document the trim and stability characteristics and unsteady phenomena. To minimize the errors in the airspeed and angle-of-attack measuring systems, a boom 10 feet long was mounted on the nose of the aircraft. This installation was not calibrated, but a similar installation used in the tests described in reference 2 indicated the errors to be small.

A motion picture camera mounted on the vertical tail photographed the wing tufts and vortex patterns.

RESULTS AND DISCUSSION

Longitudinal Characteristics

The static longitudinal aerodynamic characteristics of the test configuration, as measured during this flight investigation, are shown in figures 4, 5, and 6 in the form of angle of attack, drag coefficient, and pitching-moment variation with lift coefficient. For comparison, the 40- by 80-foot wind-tunnel data are plotted on the appropriate figures. The variations of angle of attack and drag coefficient with lift coefficient for the gear-up configuration are presented in figure 4, and for the gear-down configuration in figure 5. These data were obtained in steady flight at different airspeeds at the lower angles of attack, and during continuous maneuvers with slowly decreasing airspeed at the higher angles of attack. The equations for determining lift coefficient, drag coefficient, and thrust are described in reference 3. The tests to measure these quantities were conducted at an altitude of about 10,000 feet.

Pitching-moment variations with lift coefficient are presented in figure 6. The flight data were obtained from the measured variation of longitudinal control deflection with airspeed and were converted to pitching moment by use of the value of control effectiveness as measured in the wind-tunnel tests. The data on this figure indicate that for the test center-of-gravity location of 32 percent of the mean aerodynamic chord, the static longitudinal stability was nearly neutral. The mild instability shown in this figure at a lift coefficient of about 0.5 was also measured during the wind-tunnel tests and was apparent to the pilot during flight tests. The magnitude of this effect was small and as shown in figure 6(b) was of the order of 1° change in control surface deflection and did not cause the pilots to limit the flight envelope of the vehicle.

Flights at high angles of attack are characterized by slight buffetting, and although this disturbance does not increase significantly as angle of attack is increased above 15°, it is considered to indicate the limiting angle for landing approach. The pilots report that during flight at high angles of attack, the primary problem is controlling pitch attitude, and that small elevator inputs are continually required to keep the aircraft from wandering. The increased longitudinal control activity results from the nearly neutral stability of the aircraft at the center-of-gravity location flown. The shaded area on figure 6(b) at the high angles of attack illustrates the magnitude of this control activity.

Lateral-Directional Characteristics

The static directional stability was investigated at four airspeeds, 180, 130, 120, and 100 knots, corresponding respectively to angles of attack of 7°, 12°, 15°, and 23°, and the results are presented in figure 7. It had been speculated that nonlinear stability characteristics might result in sideslips from the vortex changing location with respect to the wing leading edge. As shown in figure 7, within the sideslip angles which could be obtained in flight, the variations of differential elevon angle and rudder angle with steady sideslip angle for the gear-up and gear-down configurations are indicated generally to be smooth and linear for the lower angles of attack. Some nonlinearity in the dihedral effect is becoming evident at the test angle of attack of 15° (fig. 7(b)), but the magnitude shown did not evoke any critical comments from the pilot.

The aircraft and control surface motions during a rapid rudder release maneuver from maximum left sideslip angle of the two lowest airspeeds are presented in figures 8 and 9. These data indicate positive directional damping. These data, and data from similar rudder releases, have been analyzed, and the period and damping are presented in figure 10. The data on this figure show only a minor change in damping characteristics for angles of attack up to approximately 24°.

The pilot felt that the directional stability and control characteristics at high angles of attack were superior to those of any delta-wing aircraft he had previously flown. The aircraft exhibited no tendency to develop abrupt changes in stability and control.

Vortex Characteristics

The vortex system can, under centain atmospheric conditions, produce visible condensation trails over the wing. Figure 11 shows the vortex, photographed from the chase aircraft during a landing approach. It was not possible to document the vortex characteristics completely either with the camera on the aircraft or in the chase aircraft, so some of the information about the vortex behavior was obtained from the visual observations of the pilots of both aircraft. The characteristics of the vortex, both observed and photographed, agree with the vortex behavior measured during the water tunnel tests on an Ogee plan form described in reference 4 regarding the changes due to angle-of-attack and angle-of-sideslip variations. A set of sketches of the tuft patterns over the wing at various angles of attack, derived from photographs taken by the tail-mounted camera, are presented in figure 12. The first three sketches show the increase in the area of unsteady flow as the angle of attack changes from 7.5° to 15° and then to 18°. The two sketches at 18° angle of attack are included to show the variation in tuft patterns in flight during the onset of mild buffetting and indicate an increase in the area of unsteady flow in figure 12(d). Since changes in tuft patterns between figures 12(c) and 12(d) occurred in about 0.3 second and were continually changing, it was reasoned that flow changes over the outboard section of the wing might be one of the causes for the buffetting disturbance previously noted at angles of attack greater than 15°. It is also possible that some of this disturbance is caused by the effect of the vortex flow on the vertical tail. The pilot of the chase aircraft observed that during flights at these angles the vortex appears to be high off the wing and flows to an area near the tail.

Comparison With Other Data

A comparison of the characteristics of the Ogee wing with the characteristics of the delta wing on the basic F5D-1 aircraft should indicate the effectiveness of the vortex flow in maintaining favorable flow patterns over the wing at high angles of attack. However, no flight data are available for this airspeed range. It is therefore necessary to rely on the opinion of the pilots as to how the characteristics of the aircraft with the Ogee wing compare with those of the basic aircraft. In carrier-type landings, the landing-approach speed of the basic aircraft is limited by the deterioration in lateral-directional characteristics, evidenced largely by low damping and high yaw angles induced by lateral-control inputs. The pilots felt that the lateral-directional characteristics were much improved for the aircraft with the Ogee wing and permitted a reduction in the landing-approach speed of approximately 10 knots. The approach speed of the aircraft with the Ogee wing is limited by poor flight-path control caused by longitudinal instability and by the rapid increase in the power required with decreasing flight speed.

CONCLUDING REMARKS

Flight tests of a delta-wing aircraft modified to incorporate an Ogee wing plan form indicated that over the range of angles of attack and sideslip flown, the vortex produced stable lift characteristics. In the opinion of the pilot the modified aircraft has improved lateral-directional control and damping characteristics. At high angles of attack, greater than about 15°, a slight lateral unsteadiness was noted by the pilot and, although it did not increase significantly at higher angles of attack, it was considered an indication of the limiting angle for landing approach. The lateral-directional flying qualities of the aircraft with the Ogee wing were sufficiently improved to permit a 10-knot reduction in approach speed.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Sept. 2, 1965

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2. White, Maurice D.; and Innis, Robert C.: A Flight Investigation of the Low-Speed Handling Qualities of a Tailless Delta-Wing Fighter Airplane. NASA MEMO 4-15-59A, 1959.

3. Rolls, L. Stewart; and Wingrove, Rodney C.: An Investigation of the Drag Characteristics of a Tailless Delta-Wing Airplane in Flight, Including Comparison With Wind-Tunnel Data. NASA MEMO 10-8-58A, 1958.

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TABLE I.- DIMENSIONAL DATA FOR THE F5D-1 AIRPLANE WITH AN OGEE PLAN-FORM WING

Wing	
Area, sq ft	661
Span, ft	33.5
Aspect ratio	1.70
Mean aerodynamic chord, ft	22.59
Incidence at root, deg	0
Geometric twist, deg	0
Sweep	
Leading edge at root, deg	77
Leading edge, minimum, deg	55.8
Elevon	
Area aft of hinge line (one side), sq ft	24.26
Span, ft	11.79
Inboard elevon (trimmer)	
Area aft of hinge line (one side), sq ft	9.04
Span, ft	2.58
Vertical tail	
Area, sq ft	69.87
Span, ft	9.46
Sweep of 25-percent chord line, deg	48.22
Rudder	
Area aft of hinge line, sq ft	9.29
Span, ft	6.29
Fuselage	
Length, ft	46.83
Maximum depth, ft	4.75
Maximum width, ft	4.75

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Figure 1.- Photograph of the test aircraft in flight.

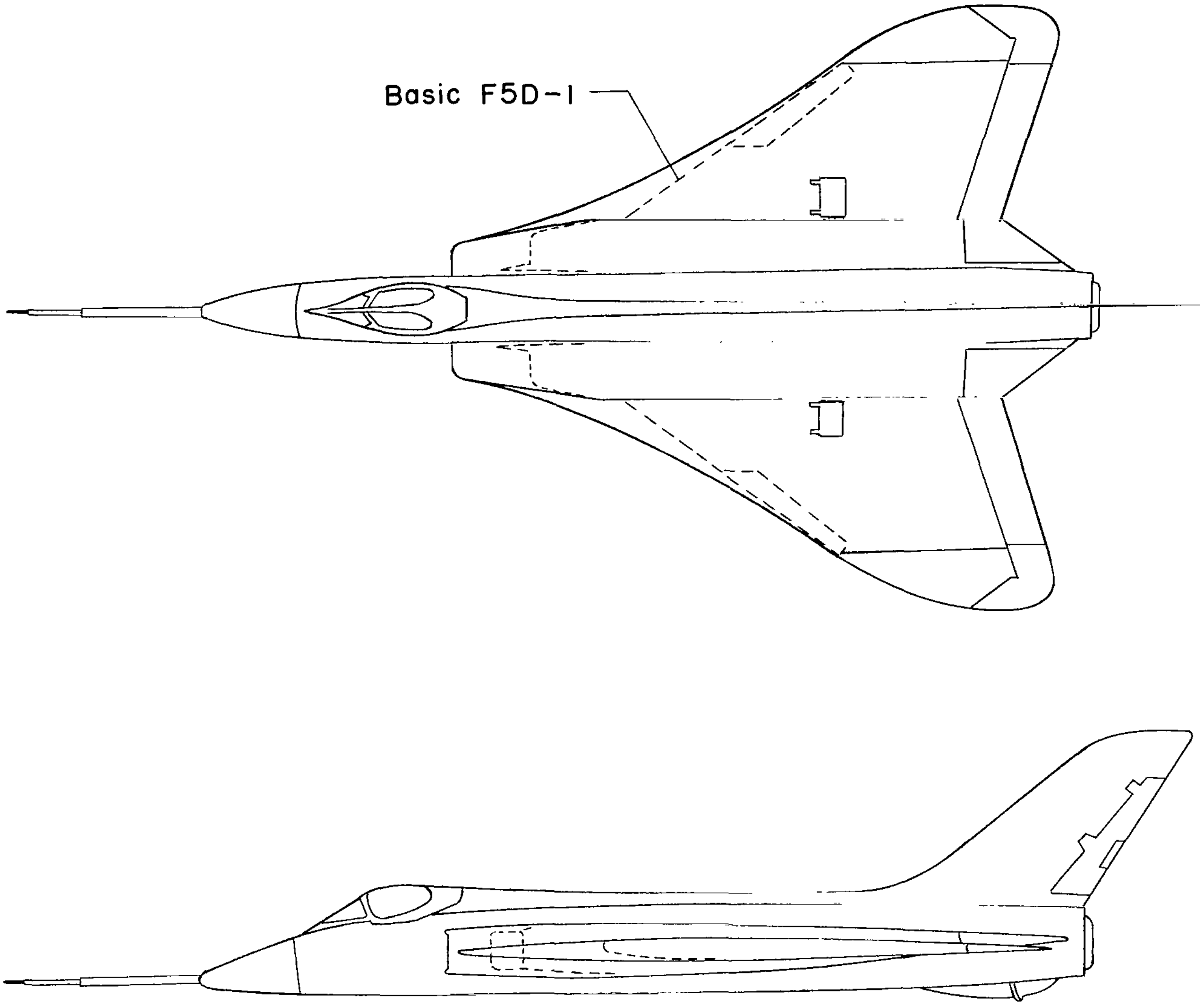
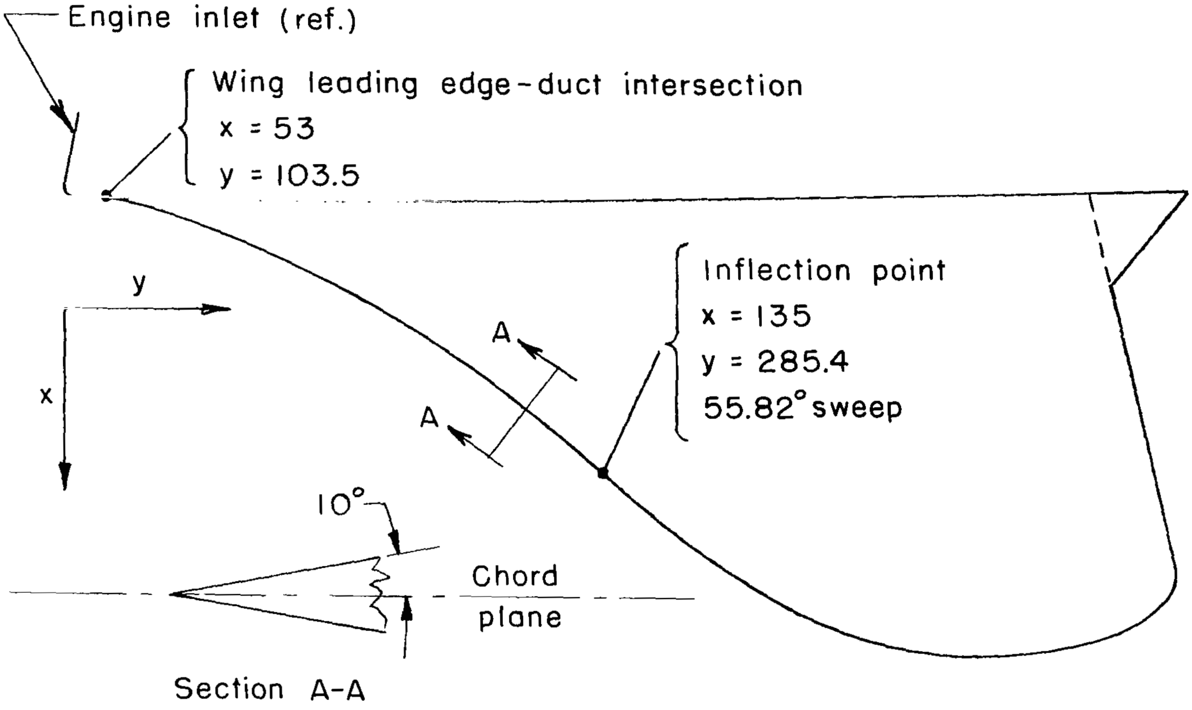


Figure 2.- Two-view sketch of test airplane.



Leading edge

$$y = 475.50 - 100\left[\frac{2290}{x-21} - 12.77\right]^{.3226}$$

Trailing edge

$$y = 426.80 + .30322x$$

Figure 3.- Details of Ogee plan form.

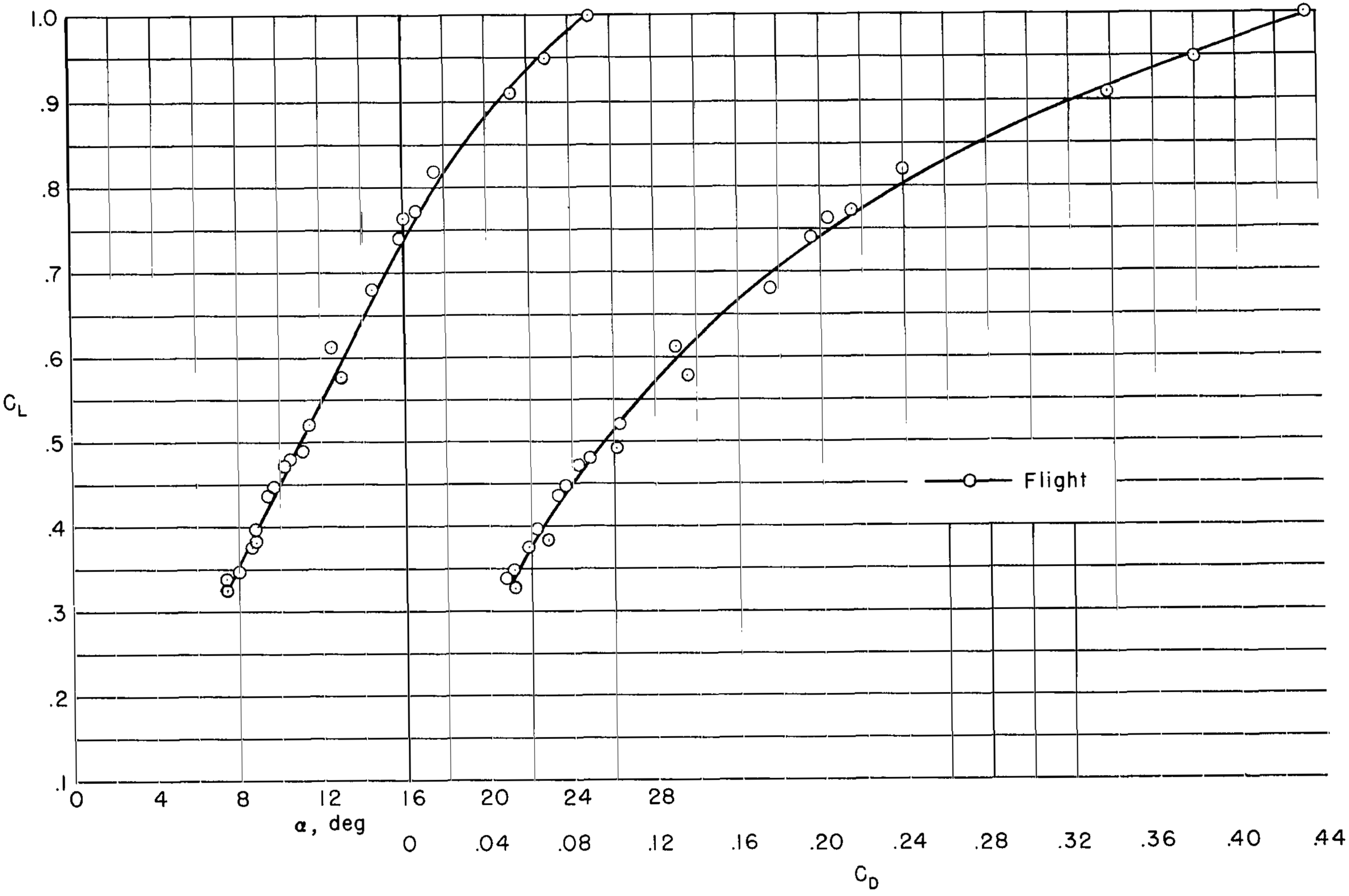


Figure 4.- Variation of angle of attack and drag coefficient with lift coefficient; gear up.

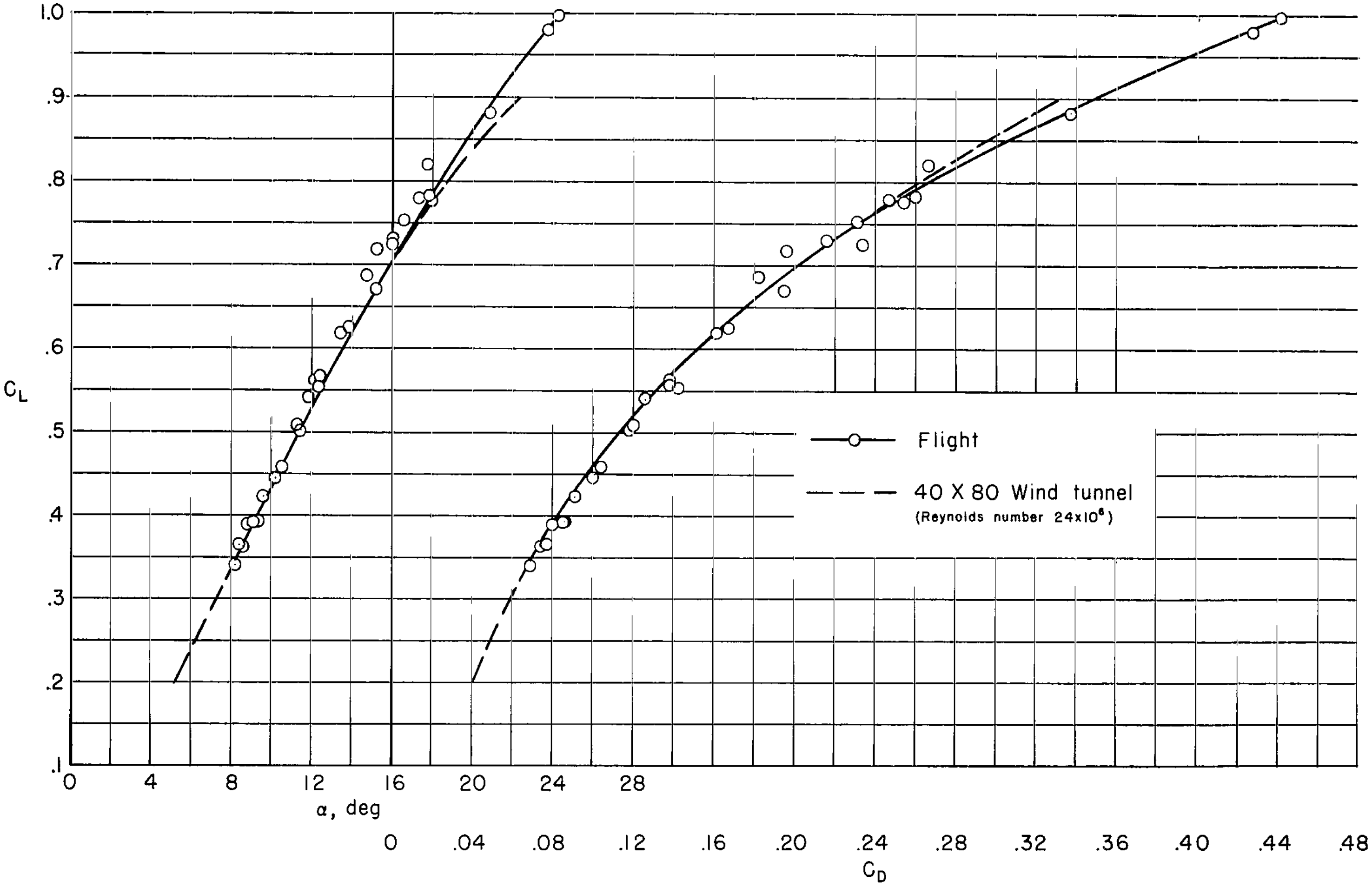
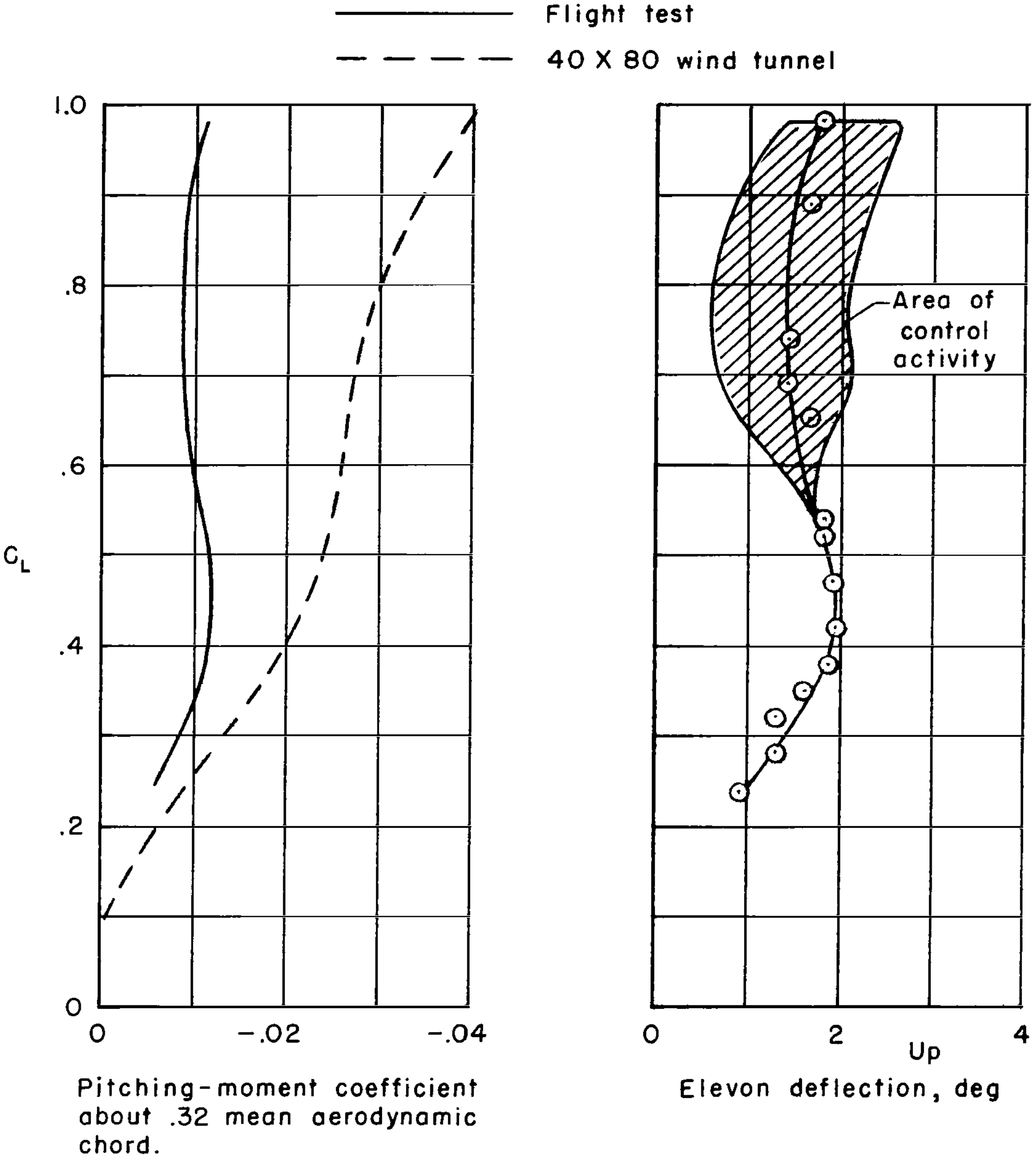


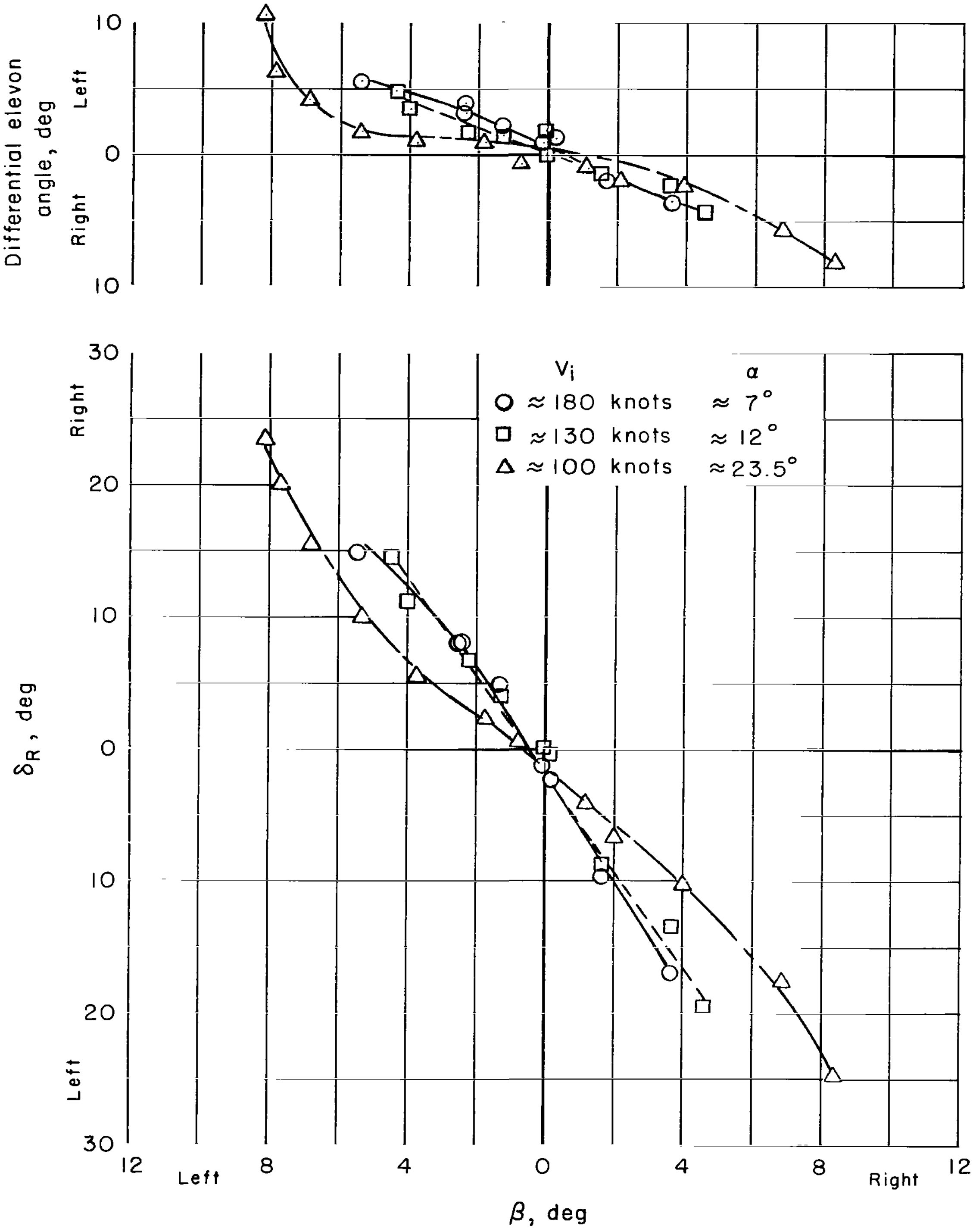
Figure 5.- Variation of angle of attack and drag coefficient with lift coefficient; gear down.



(a) Pitching moment.

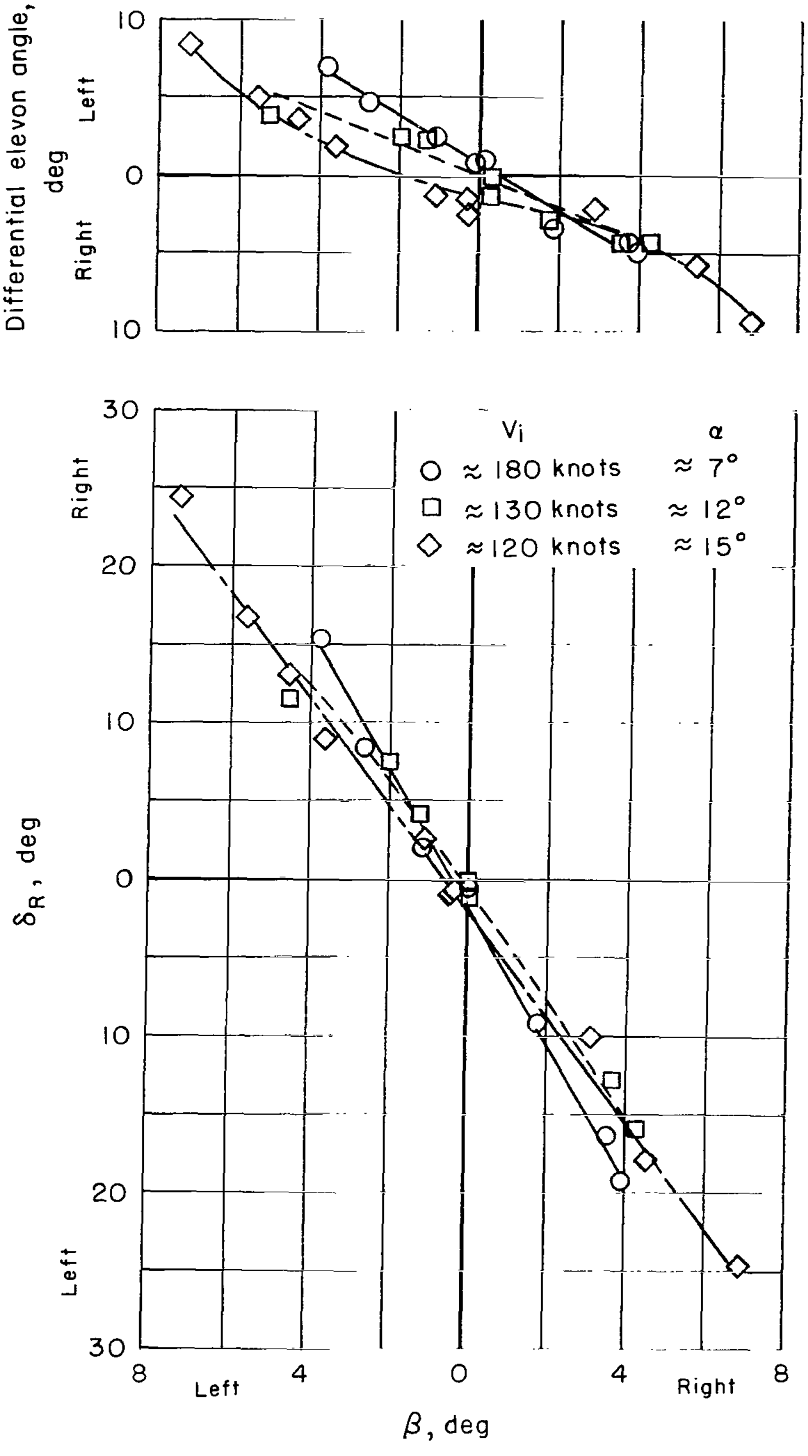
(b) Elevon angle.

Figure 6.- Pitching-moment characteristics in landing-approach condition.



(a) Gear up.

Figure 7.- Variation of rudder and differential elevon angles with steady sideslip.



(b) Gear down.

Figure 7.- Concluded.

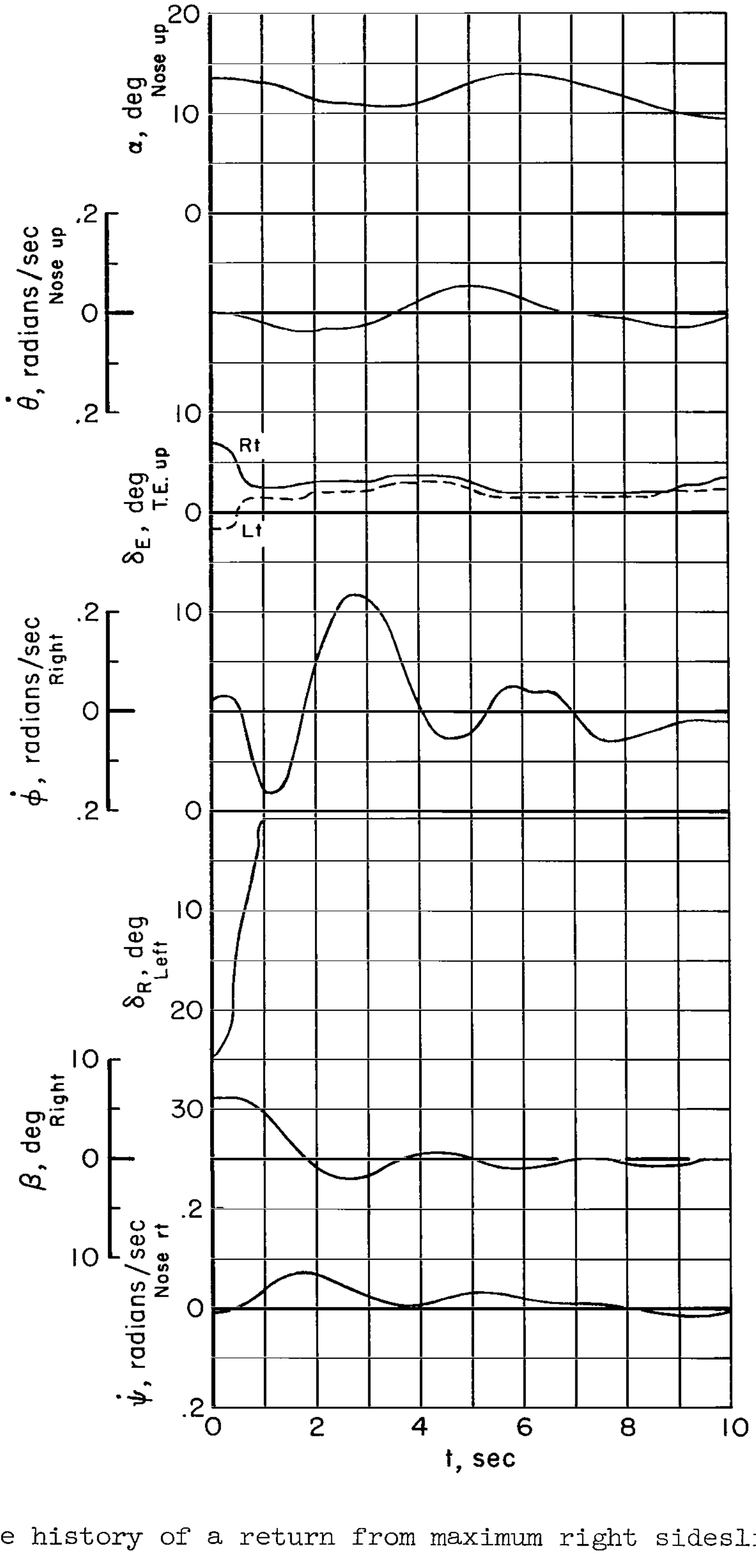


Figure 8.- Time history of a return from maximum right sideslip at 120 knots.

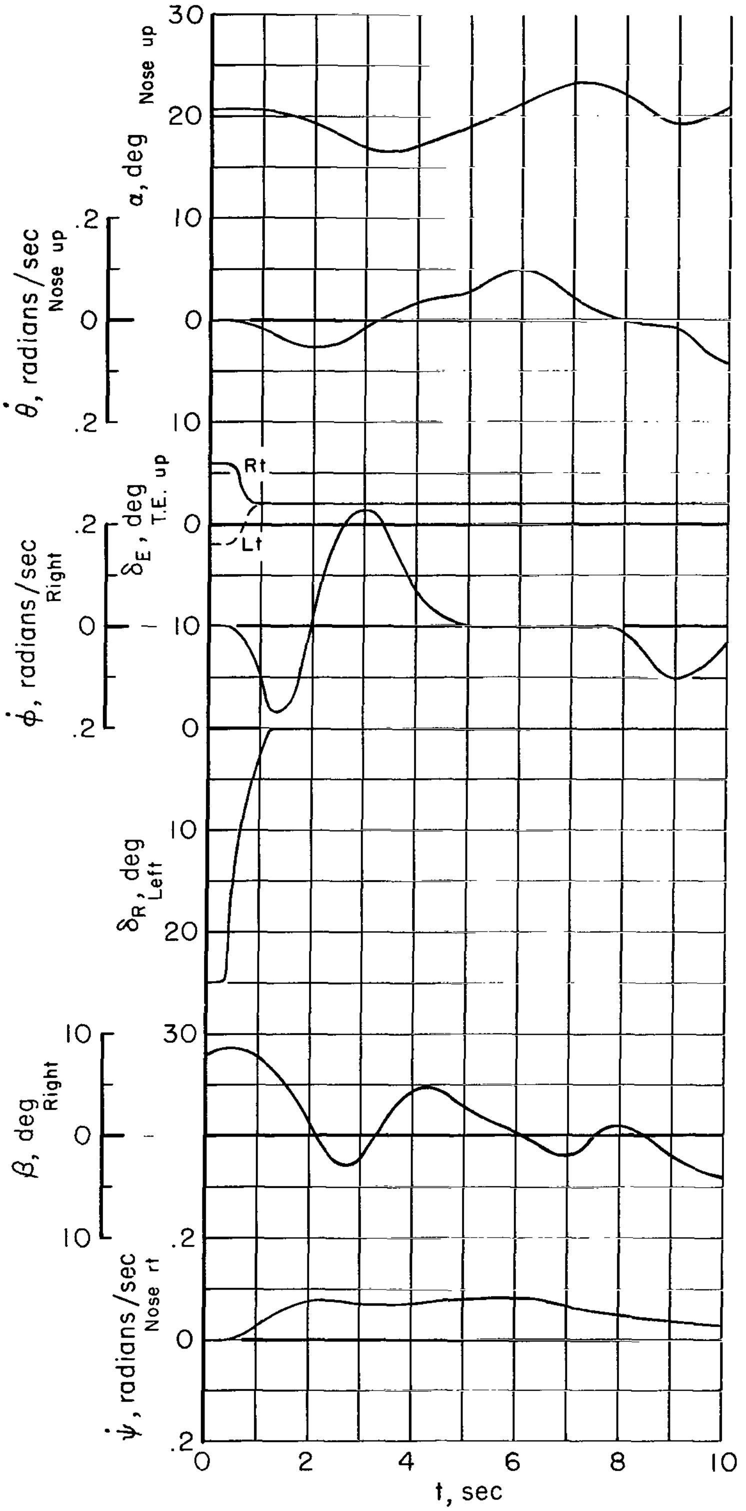


Figure 9.- Time history of a return from maximum right sideslip at 100 knots.

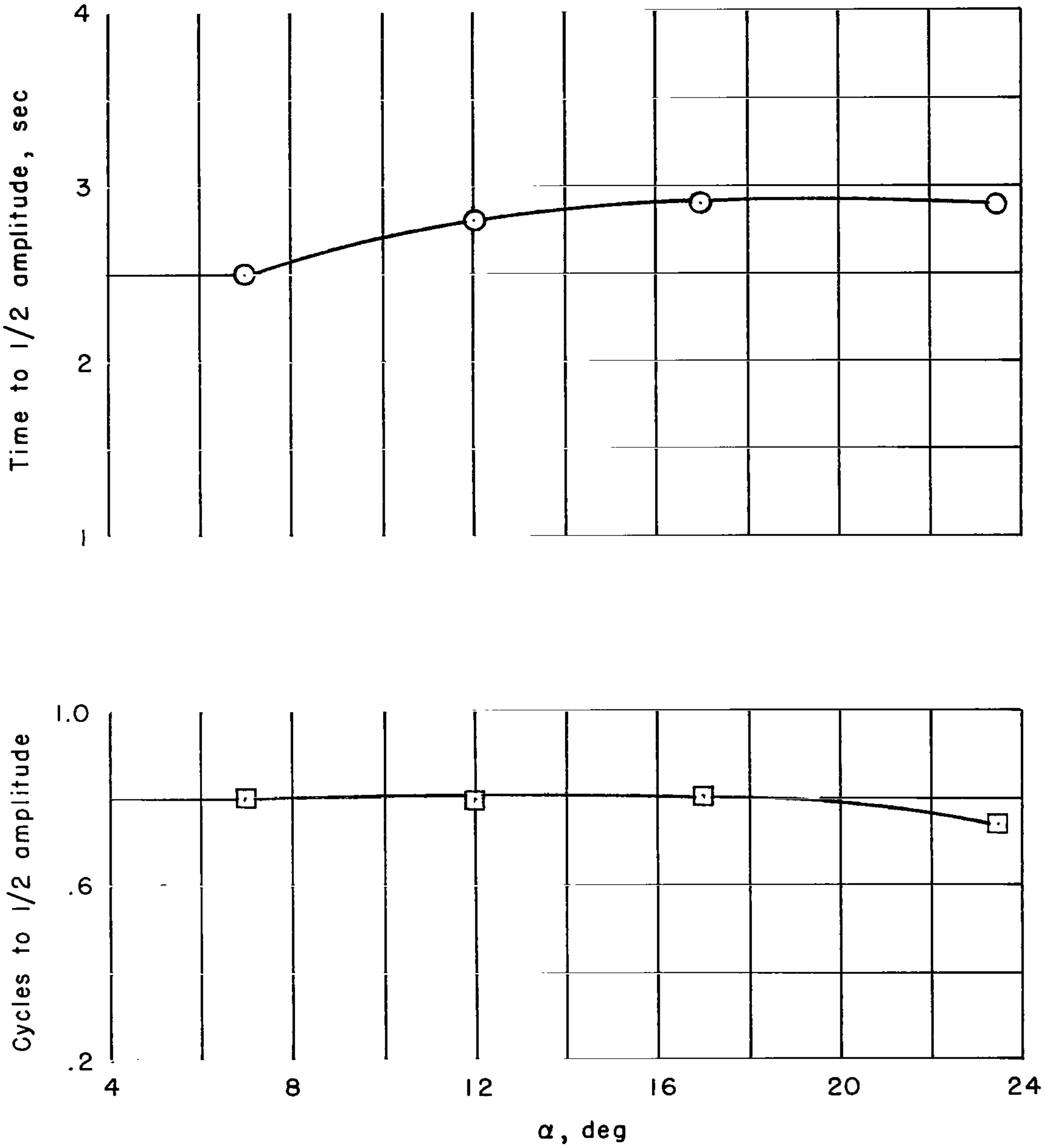


Figure 10.- Directional damping characteristics as a function of angle of attack.

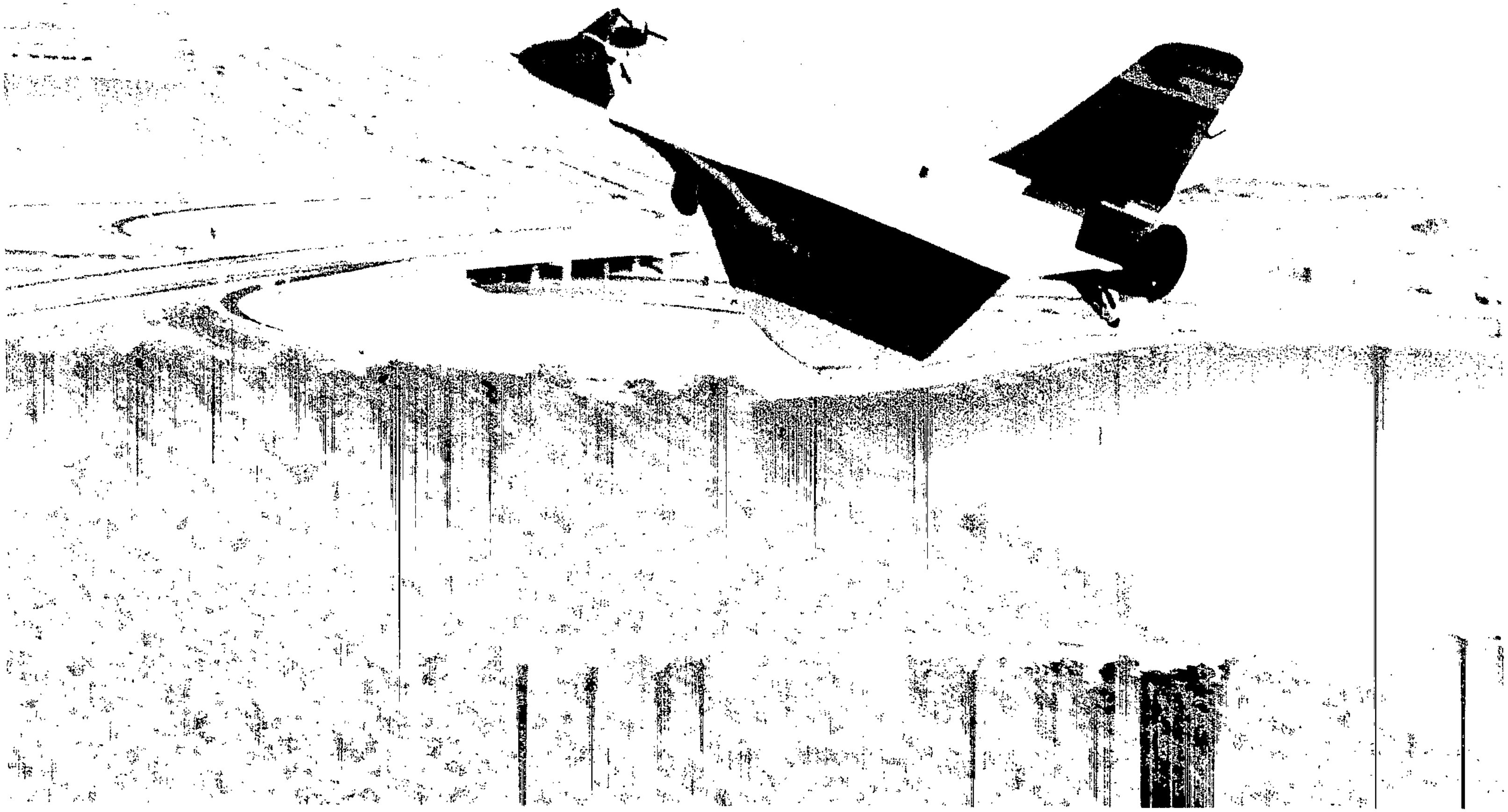


Figure 11.- Photograph of the visible vortex system.

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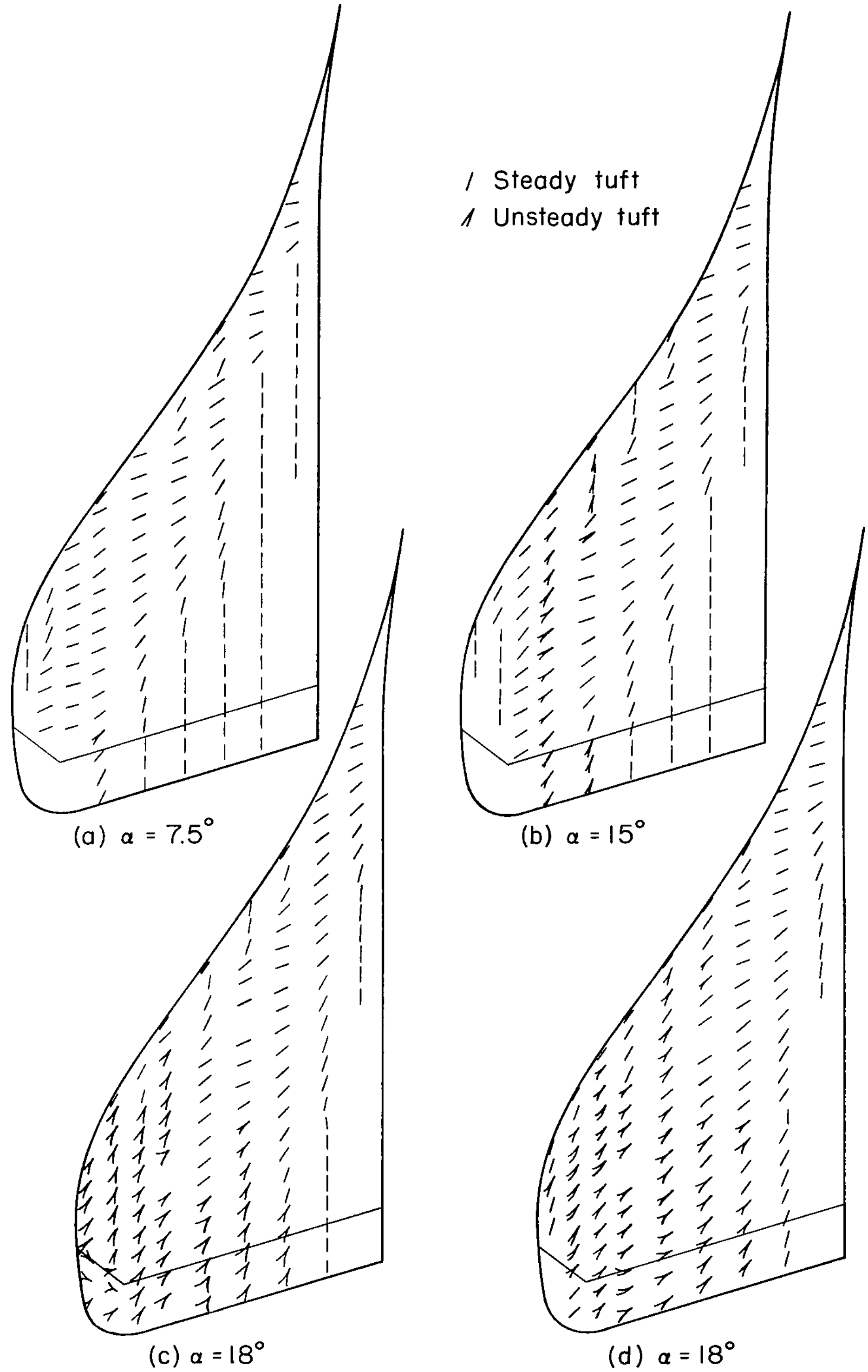

Figure 12.- Tuft patterns at various angles of attack, zero sideslip.

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>
> —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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