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LOW-SPEED FLIGHT INVESTIGATION OF AN AIRPLANE WITH SWEPTBACK WINGS

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Some of the stability parameters of sweptback wings are considerably different from those of conventional straight wings. In order to determine how these different stability parameters would affect the low-speed flying qualities of an airplane, the Navy early in 1946 authorized the Bell Aircraft Corporation to modify two P-63 airplanes to incorporate sweptback wings. The first figure shows a drawing of the modified airplane, which is designated the L-39 airplane. The outer wing panels are swept back 35° along the quarter-chord line. The center section, containing the cooling air intakes, is left unchanged. The main landing gear of the L-39 airplane is fixed. The tail was lengthened after preliminary flight tests at the Bell Company, partly to increase the directional stability but mainly to assist in getting the tail down for landing. The wing leading edge is made of wood and may be modified to incorporate fixed slots covering various portions of the span. Because of the fixed landing gear and the structural features of the wing, the airplane is restricted to an indicated airspeed of 250 miles per hour. Also, because of the fuselage modifications, the sideslip angle is restricted to fairly small values at high speeds. In all cases except those noted, the extension on the ventral fin shown in figure 1 was installed for the flight tests reported herein. Some tests were made with this extension removed, however, to give a condition of reduced directional stability. The flight tests made by the NACA and reported in this paper were all made with the first L-39 airplane, which incorporates conventional airfoil sections, designated NACA 66, 2X116, a = 0.6 measured perpendicular to the quarter-chord line. Tests made by the Bell Aircraft Corporation on this airplane before the NACA investigation are reported in reference 1. The second L-39 airplane had a pointed leading edge, simulating a circular-arc airfoil section 14.3 percent thick. This airplane was tested by the Bell Company but has not been flown by the NACA.

Tests have been made of a 0.22-scale model of the L-39 airplane in the Langley 7- by 10-foot tunnel, so that a comparison between the small-scale wind-tunnel results and the flight results is possible.

Measurements of the longitudinal- and lateral-stability characteristics and stalling characteristics have been completed with

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three slot arrangements. These slot configurations will be referred to as the 0, 40-percent, and 80-percent span slots. The 40-percent span slots covered 40 percent of the span of the sweptback outer panels, starting at 40 percent of the span and extending out to 80 percent of the span. The 80-percent span slots extended from 20 percent of the span to the tip. These slot arrangements are shown in the first figure.

All tests were made with power off, because it was felt that the results would be of most interest for application to jet-propelled aircraft where slipstream effects would be absent.

The main item of interest in connection with the longitudinal stability of a sweptback-wing airplane is the stability at low speeds near the stall, because wind-tunnel tests of many sweptback configurations have shown instability at high lift coefficients.

The longitudinal stability of the L-39 airplane was investigated by recording the elevator angles and forces in steady flight at various speeds with two center-of-gravity positions, 20 and 26 percent of the mean aerodynamic chord. The results of these tests are presented in detail in reference 2. Figure 2 shows the variation of elevator angle with speed for the flaps-down condition with the three slot configurations, with the center of gravity at 26 percent of the mean aerodynamic chord. A negative slope of this curve, corresponding to a larger up-elevator angle for trim at lower speed, represents a stable condition.

The results presented show that without slots the stability became neutral near the stall. The stall occurred at the minimum speed plotted. The stability was large in the normal-flight range, where the neutral point was at about 42 percent of the mean aerodynamic chord. The decrease in stability close to the stall was not objectionable to the pilot, because the elevator angle and stick force variations did not become unstable. There was a slight nosing up tendency at the stall but this could easily be controlled by application of down elevator. In an airplane with a smaller degree of stability in the normal flight range, this much loss in stability would result in more serious instability at the stall, which would probably be very objectionable to the pilot. Tests could not be made with a more rearward center-of-gravity position in the L-39 airplane because of the position of the main landing gear.

The use of slots reduced the tendency toward instability at the stall. The slots also improved the stalling characteristics so that the airplane could be controlled to some extent in flight beyond the stall. In this case the elevator had to be pulled up to prevent the airplane from pitching down when it was in a partially stalled condition. This characteristic is shown by the low-speed end of the curves in figure 2. The pitching moments beyond the stall were, therefore, stable with flaps down when the slots were employed.

The longitudinal stability with flaps up was good all the way to the stall with any of the slot configurations. The tendency toward neutral stability at the stall was not present in this case.

Tuft studies showed that, with flaps up, the wing of the L-39 airplane stalled first at the root, probably because of the leading-edge air intakes and the design of the wing-fuselage juncture. This root stall occurred even without slots in the wing, and probably tended to reduce the unstable pitching tendencies at the stall by reducing the downwash at the horizontal tail at high lift coefficients. With flaps down, the initial stall did not occur at the root.

The most apparent difference expected between the lateral stability characteristics of sweptback and straight wings is the large increase in dihedral effect with lift coefficient for the sweptback wings. The dihedral effect of an airplane is felt by the pilot by the amount of aileron angle required to maintain equilibrium in sideslips. The characteristics of the L-39 airplane in steady sideslips are shown in figure 3. More complete data on the lateral and directional stability characteristics of the L-39 airplane are given in reference 3. This figure shows the total aileron angle and rudder angle as a function of sideslip angle for various values of the airspeed. The variation of rudder angle with sideslip angle was essentially the same for all speeds. At the highest speed tested, 235 miles per hour, a small amount of left aileron angle was required in right sideslips, indicating a slight negative dihedral effect. As the speed was decreased, the dihedral effect became positive and reached a large positive value at 110 miles per hour, the lowest speed tested. At this speed, full aileron deflection was required to hold a steady sideslip with only 8° rudder deflection. Even higher dihedral effect was observed in the flaps-down condition because of the higher lift coefficient which could be reached. The dihedral characteristics in the flaps-up condition for various slot configurations are summarized in figure 4. This figure shows the variation of aileron angle with sideslip as a function of normal-force coefficient for the three slot configurations tested. The effect of slot configuration is not great, but a slightly greater variation of dihedral effect with normal-force coefficient was obtained with the 80-percent span slots.

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Some question has arisen as to the ability of small-scale wind-tunnel tests to predict the characteristics of sweptback wings. In order to obtain a comparison between the flight and wind-tunnel measurements of dihedral effect, the airplane was flown with known asymmetric loadings so that the sideslip angle required to balance a given rolling moment could be measured. The variation of rolling-moment coefficient with sideslip C_{l_β} as a function of normal-force coefficient for the condition of 80-percent span slots is shown in figure 5. The wind-tunnel measurements are also shown in this figure. The small-scale wind-tunnel results showed somewhat smaller values of effective dihedral than the flight-test results, though the trends are similar. The flight results always showed an increase of C_{l_β} all the way to the stall. It should be noted that the maximum value of C_{l_β} was about -0.006 per degree, a value corresponding to 30° effective dihedral in a straight wing.

It had been expected that the large dihedral effect obtained with a sweptback wing might lead to objectionable or dangerous flying qualities. The pilots of the L-39 airplane, however, did not consider any of the flying qualities caused by the large dihedral to be dangerous or objectionable. They had only minor objections to a few characteristics. The main difficulty was the considerable reduction in rolling velocities which could be reached in rudder-fixed aileron rolls as a result of the combined effects of the dihedral and the sideslip developed during the roll. The maximum value of $pb/2V$ obtainable in rolls at speeds approaching the stall with flaps down was 0.035 radians as compared with the value of 0.07 which is considered to be the minimum for satisfactory flying qualities. Also, it was noted that at low speeds the rolling response was oscillatory; that is, the rolling velocity following an abrupt deflection of the ailerons would build up to a maximum and then fall off to zero or even reverse, then build up again.

Although in landing approaches and landings use of the rudder produced large lateral trim changes, this characteristic was not considered dangerous. The pilots considered the slight negative dihedral effect present at low normal-force coefficients to be more objectionable than high dihedral effect present at high normal-force coefficients. The negative dihedral effect leads to an illogical type of control because the rolling velocity due to rudder deflection is in the wrong direction. This is particularly objectionable to the pilot if the airplane changes from a condition of high positive to negative dihedral, so that he cannot become accustomed to either. It appears from these tests that in the design of sweptback-wing airplanes, the use of negative geometric

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dihedral to reduce the effective dihedral at high lift coefficients should not be carried to the point of producing negative effective dihedral at low lift coefficients.

Another feature of sweptback-wing airplanes which it was thought might prove undesirable was the possibility of poorly damped lateral oscillations. The time history of a lateral oscillation of the L-39 airplane started by abruptly deflecting and releasing the rudder is shown in figure 6. In this case the ventral fin extension was removed. The lateral oscillation at this speed had a period of about 5 seconds and required 1.5 cycles to damp to half amplitude. The oscillations were satisfactorily damped in this case although the rolling motions associated with the oscillation were relatively large in comparison with those of conventional airplanes. The pilot had no objections to the lateral oscillations because he could easily control them. The type of control motions used in recovery from an oscillation is shown in figure 7. It is shown by this figure that, following an abrupt rudder kick, the airplane rolled 35° and started to return to its original attitude. As it was returning, the pilot applied coordinated rudder and aileron control to bring the airplane to the level attitude and then applied a small amount of control in the opposite direction to prevent overshooting. The speed at which the oscillation damped out indicates that an oscillation of such a long period is not likely to cause any difficulty, even if it should be poorly damped or undamped.

The application of the results of the L-39 tests to airplanes of higher wing loading or different size will be considered briefly. The dynamic-stability characteristics of an airplane of similar type will be the same if the value of the relative density factor μ is the same. For the L-39 airplane, the value of μ (based on wing span) was 14. An approximately equal value of μ might be obtained on a larger airplane with higher wing loading. In this case, the damping characteristics of the lateral oscillations in terms of the number of cycles to damp to half amplitude would be the same at a given lift coefficient, but the period of the oscillations would be increased as the square root of the linear dimension. It would be expected that the pilot would have less difficulty in controlling these oscillations than those of the L-39 airplane. If the airplane had the same size as the L-39 but a heavier wing loading, or flew at a higher altitude, the value of μ would be increased, As a result, the damping of the lateral oscillations would probably be decreased but the period of these oscillations in flight at a given lift coefficient would be the same. As mentioned previously, reduced damping would probably not be serious for an oscillation of this period.

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The L-39 results give a good indication of the amount of directional stability that should be provided on an airplane with sweptback wings. With the ventral fin installed, the value of C_{n_β} at high lift coefficients was 0.00195 per degree. With this amount of directional stability, the characteristics were fairly satisfactory, as noted previously. This value is about twice that usually present in conventional straight-wing fighter airplanes. With the ventral fin extension removed, the value of C_{n_β} was about 0.001 per degree. In this case, the pilot considered the airplane difficult to fly because of the large lateral trim changes produced in any maneuver when inadvertent sideslipping occurred and because of the reversal in rolling velocities in rudder-fixed rolls. In the case of the L-39 airplane, with the fin extension removed, the variation of rudder angle with sideslip in steady sideslips was practically zero even though the directional stability measured in the wind tunnel was comparable with that of a conventional airplane. The loss of stability in steady sideslips is caused by the destabilizing effect of the aileron yawing moments when the ailerons are deflected to offset the high dihedral effect. The pilot's impression of directional stability is obtained from the variation of rudder angle with sideslip. In this case, therefore, the pilot felt that the directional stability was very small.

A larger value of directional stability is therefore required on sweptback-wing airplanes than on straight-wing airplanes for two reasons: First, to maintain adequate aileron effectiveness in rolls, and second, to offset the destabilizing effect of the aileron yawing moments in steady sideslips.

Complete studies of the stalling characteristics of the L-39 airplane were made with flaps up and flaps down and with all slot configurations. Without slots, the stalling characteristics were very undesirable. Figure 8 shows a time history of the rolling velocity during a stall with the flaps up and no slots. Also shown for comparison is a similar record obtained with the 80-percent-span slots. Without slots, there was a small amount of stall warning given by preliminary motion of the airplane but, at the stall, the airplane rolled abruptly because of almost instantaneous stalling of a complete wing panel. With either the 40-percent or 80-percent-span wing slots, the airplane performed increasing lateral oscillations at the stall. The stalling characteristics were considered good with either the 40-percent- or the 80-percent span slots installed. The rate of increase of the oscillations at the stall was considerably greater when the ventral-fin extension was removed.

In order to obtain a comparison with the wind-tunnel measurements of the lift characteristics of the L-39 model, flight measurements of the angle of attack of the L-39 airplane were made during stall approaches. The angle of attack was measured by means of a vane located on a boom ahead of the wing tip. The position error of this installation was determined by tests of a similar vane on the wind-tunnel model. A comparison of the flight and wind-tunnel measurements of the variation of normal force coefficient with angle of attack is given in figure 9. These results, which are representative of all the conditions tested, show that the agreement was good.

The maximum lift coefficient of the L-39 airplane without slots with flaps up was 1.20 and with flaps down was 1.51. The original P-63 airplane with the unswept wing had essentially the same values of maximum lift. The maximum lift coefficient of the L-39 airplane with slots installed was slightly less than without slots. Tuft studies indicate that this unexpected effect was caused by premature separation of the flow inside the inboard end of the slot. With the plain wing, the stall occurred abruptly over the whole wing at the same instant and therefore steady flight was possible right up to the maximum lift coefficient. With the slots installed, however, the premature separation of flow near the inboard end of the slot caused rolling and pitching motions of the airplane so that higher values of maximum lift coefficients which might have been obtained at high angles of attack were not usable in steady flight.

Though no NACA flight tests have been made on the second L-39 airplane with simulated circular-arc wing sections, a brief summary of the Bell flight test results may be of interest. No quantitative data from the Bell flight tests are available, and these statements are based on pilot's comments. It was found that the longitudinal instability at the stall was somewhat worse than that of the L-39 airplane with normal wing sections. The lateral stability characteristics were similar, but no measurements are available at high lift coefficients. The stalling characteristics were good in that there was no tendency to roll off at the stall. Flow separation started near the leading edge of the wing at speeds below 180 miles per hour, and at 140 miles per hour the flow was turbulent over the entire upper surface of the wing. Control could be maintained to 110 miles per hour, resulting in a normal value of maximum lift coefficient. The drag was very high at low speeds, however, and power-off landings at low speeds were dangerous because of the excessively steep gliding angle and high sinking speed.

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2. Sjoberg, S. A., and Reeder, J. P.: Flight Measurements of the Longitudinal Stability, Stalling, and Lift Characteristics of an Airplane Having a 35° Sweptback Wing Without Slots and with 40 Percent Span Slots and a Comparison with Wind-Tunnel Data. (Prospective NACA paper)

3. Sjoberg, S. A., and Reeder, J. P.: Flight Measurements of the Lateral and Directional Stability and Control Characteristics of an Airplane Having a 35° Sweptback Wing with 40-Percent-Span Slots and a Comparison with Wind-Tunnel Data. (Prospective NACA paper)

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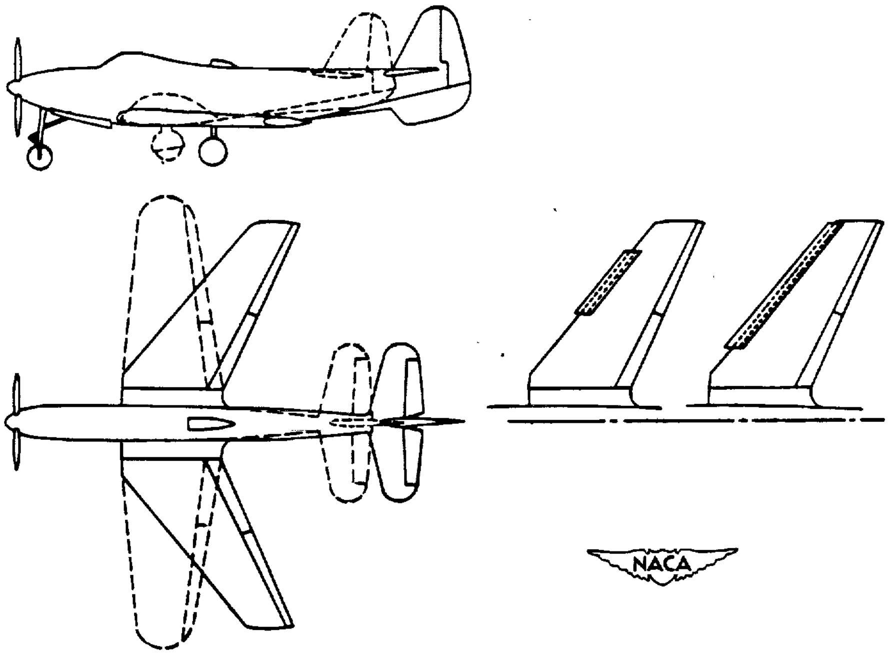
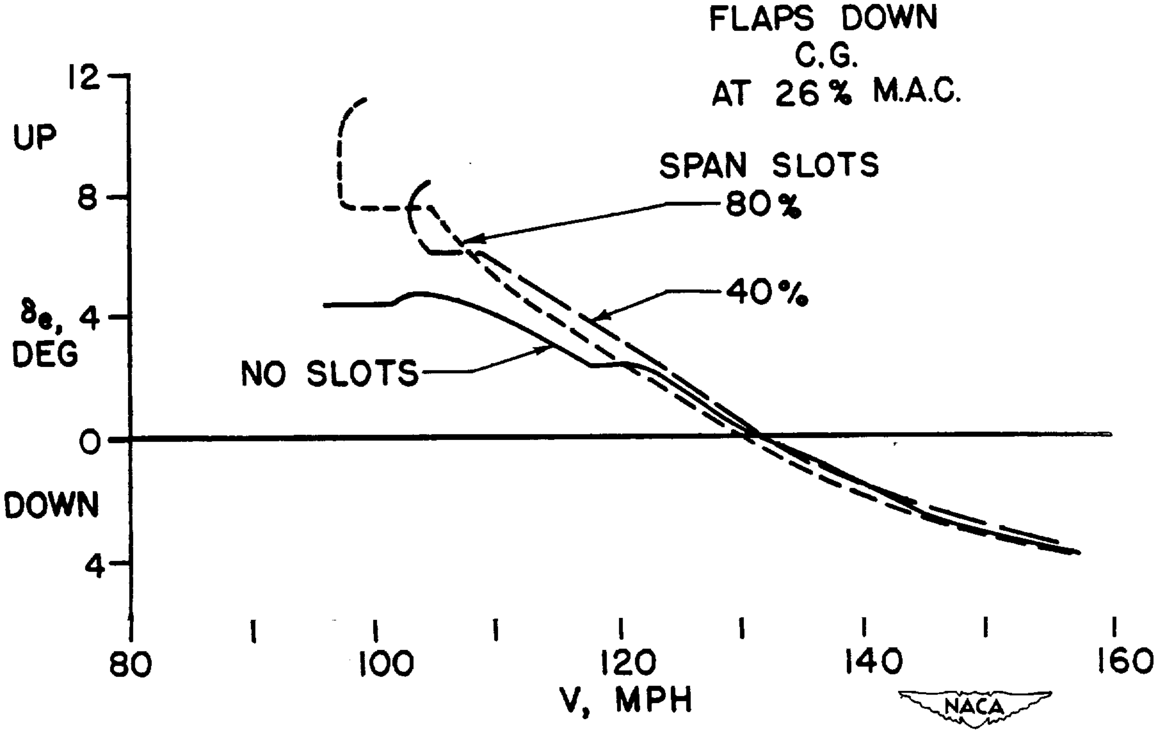


L-39 AIRPLANE

Figure 1.



LONGITUDINAL STABILITY

Figure 2.

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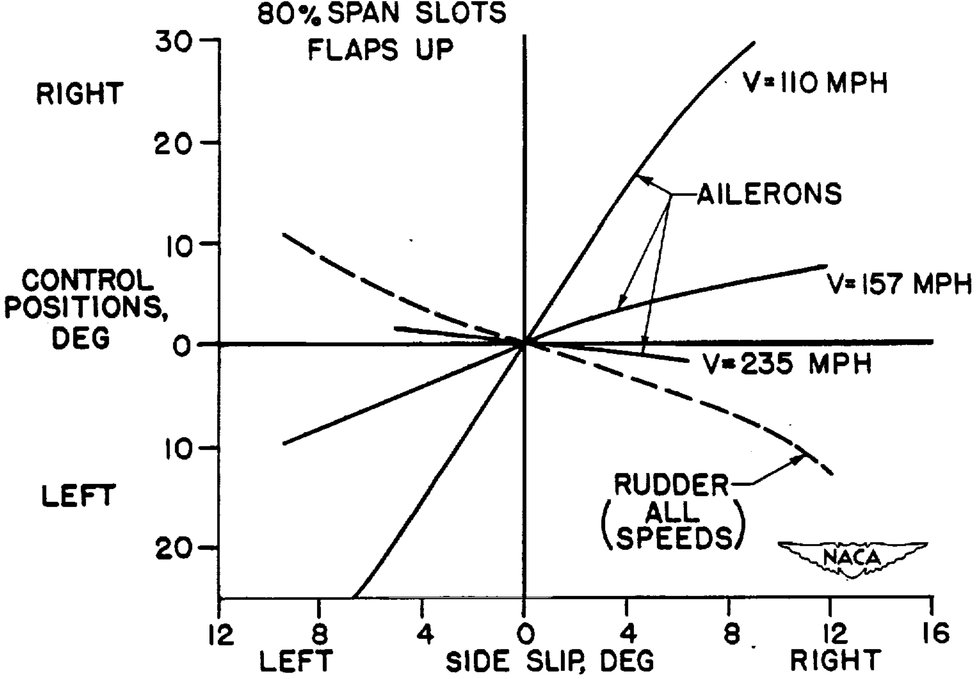
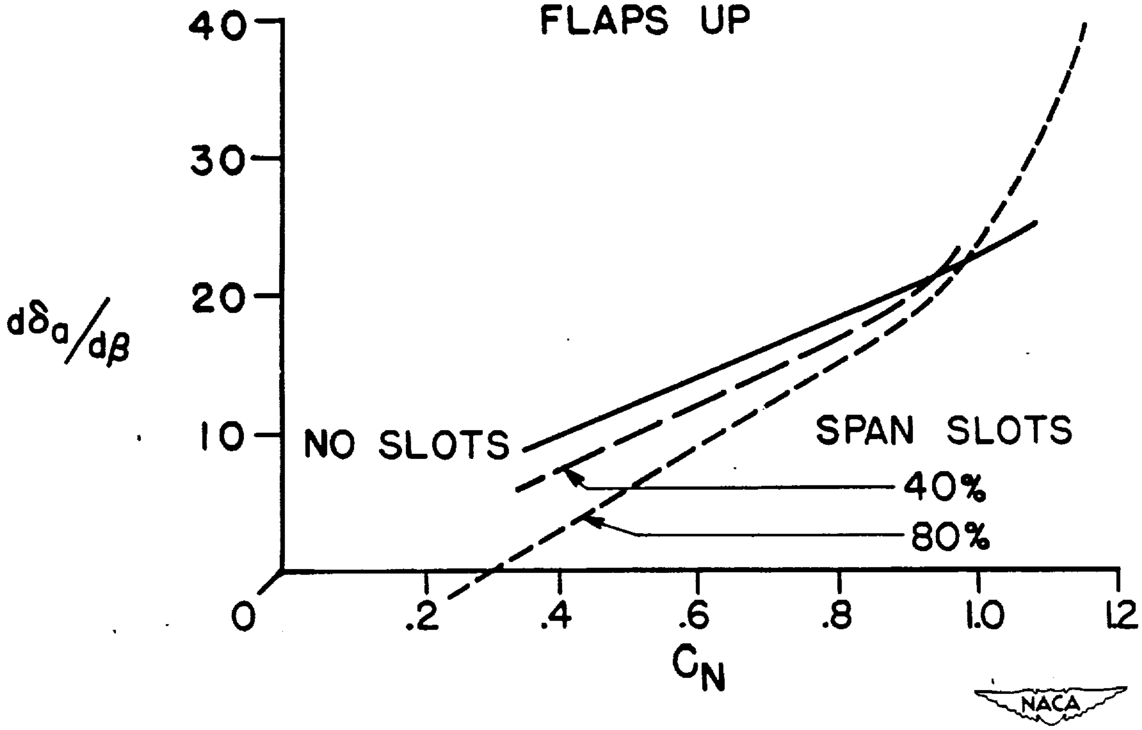


STEADY SIDE SLIP CHARACTERISTICS

Figure 3.



DIHEDRAL EFFECT

Figure 4.

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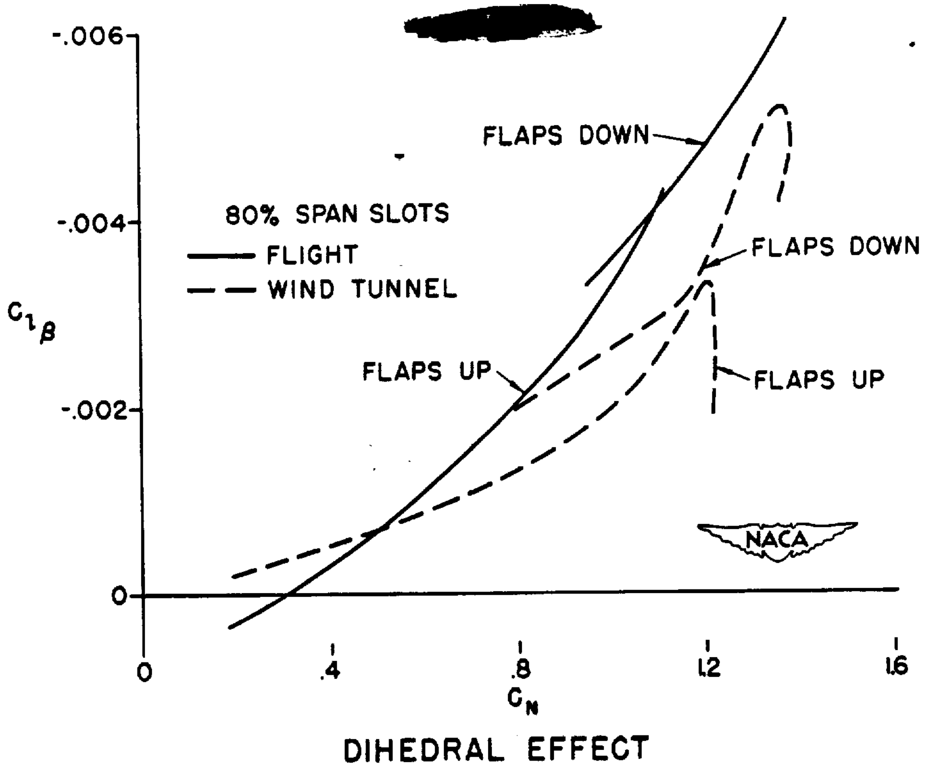

Figure 5.

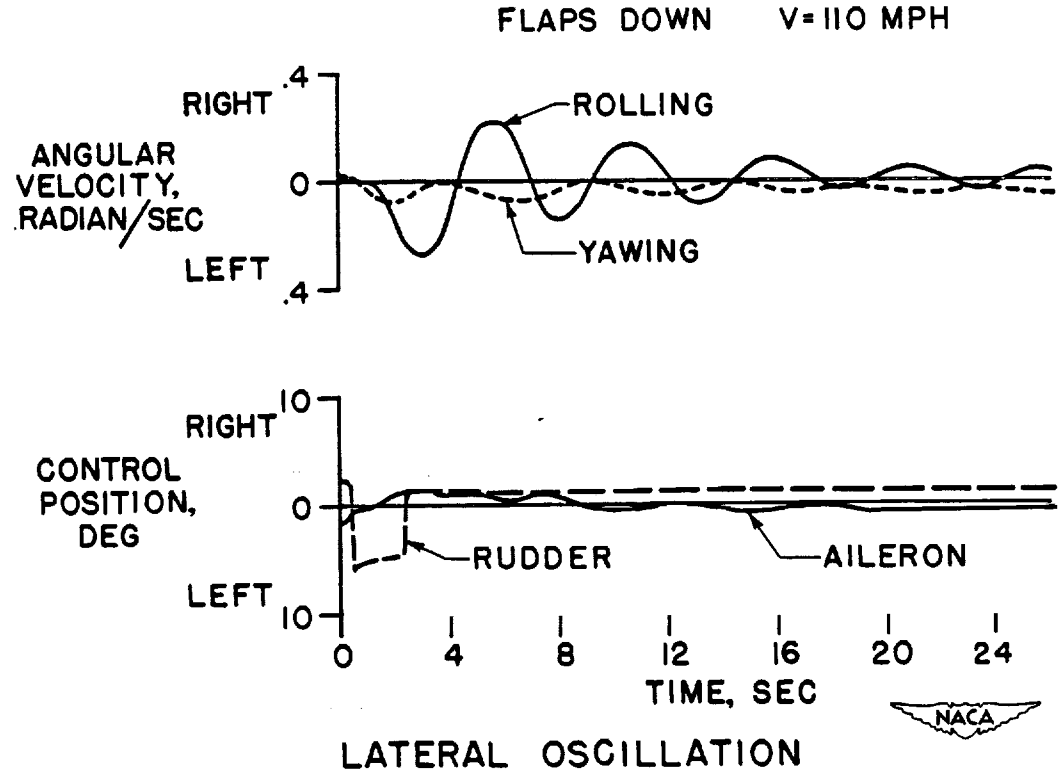

Figure 6.

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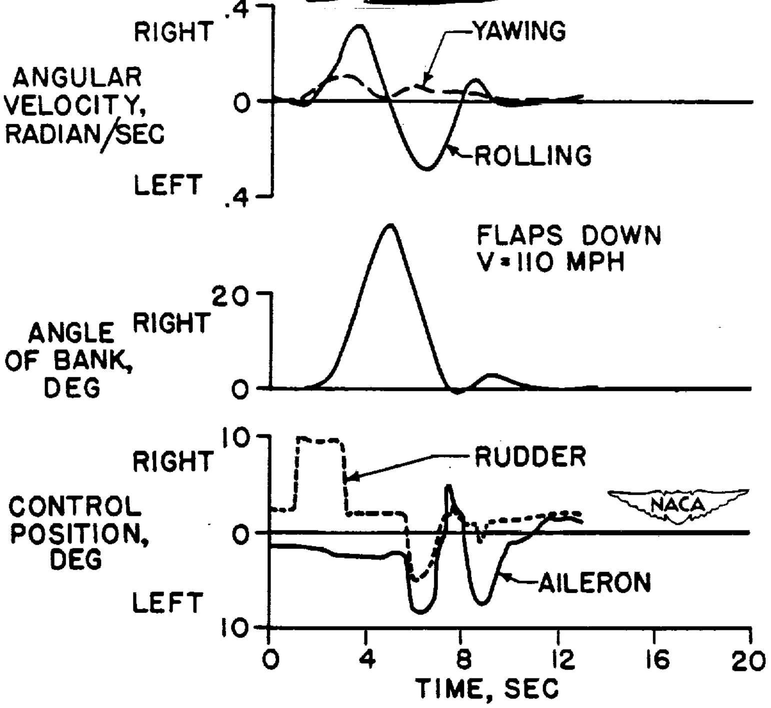
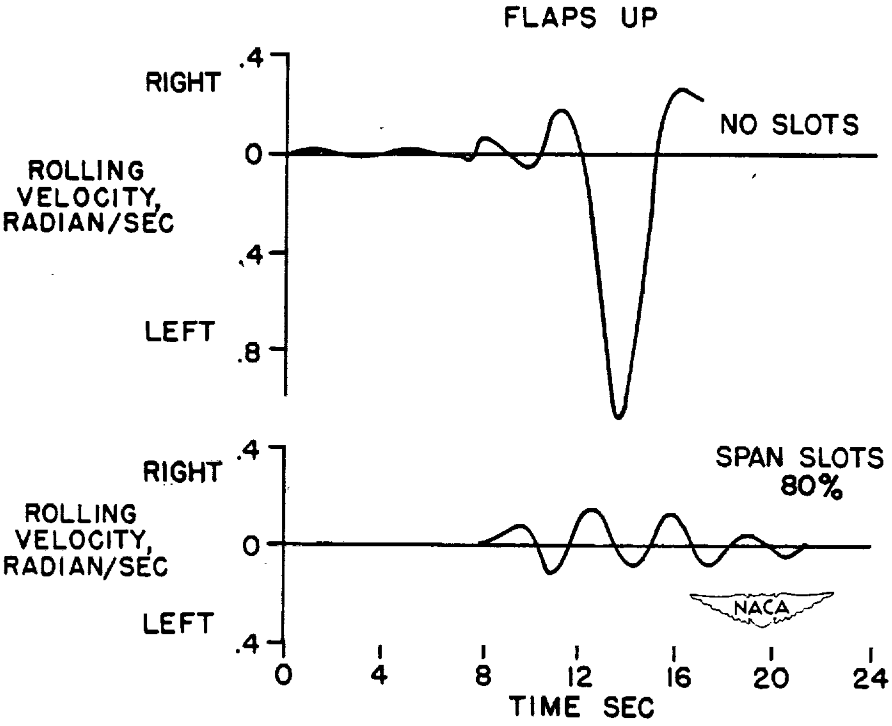


CONTROLLED LATERAL OSCILLATION

Figure 7.



STALLING CHARACTERISTICS

Figure 8.

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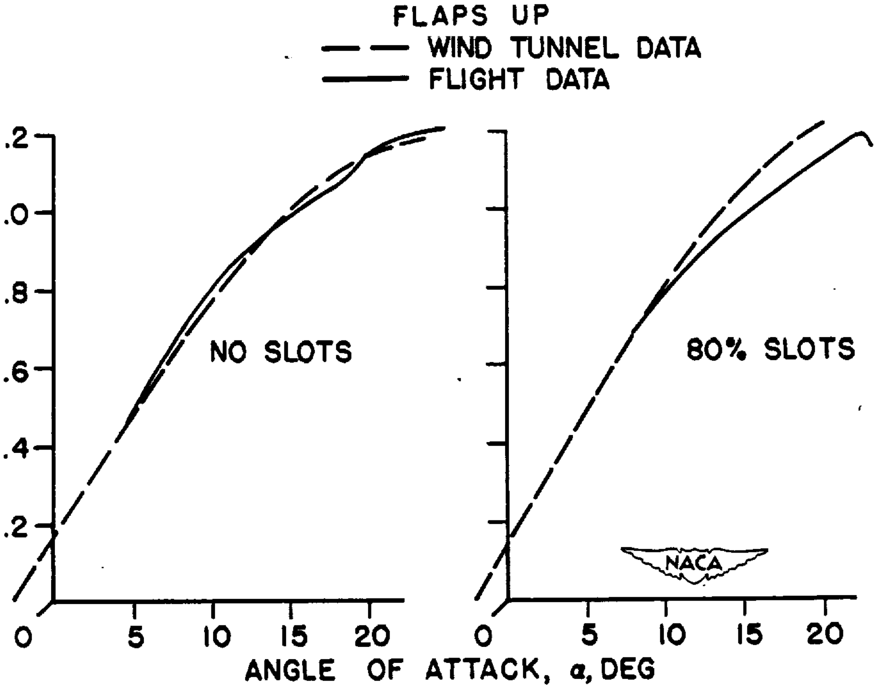

NORMAL FORCE COEFFICIENT CURVES

Figure 9.

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