D8

[redacted]

NACELLES FOR HIGH CRITICAL SPEEDS ON STRAIGHT AND SWEPT WINGS

By Robert E. Dannenberg

Ames Aeronautical Laboratory

The development of a large high-speed airplane utilizing jet engines normally requires that the engines be enclosed in nacelles attached to the wing. In order to achieve high flight velocities, it is necessary to design the nacelle so that not only is the air ducted to the jet engine in an efficient manner but also so that the air flow over the nacelle does not detrimentally affect the high-speed drag characteristics of the airplane. The combination of the wing and nacelle give rise to interference effects (particularly on the drag and critical speed of the wing-nacelle combination) that are controlled through the design of the nacelle contour and its position on the wing.

The Langley Laboratory has recently made high-speed wind-tunnel measurements on the interference effects of nacelles on straight wings (reference 1). As shown in figure 1, the simulated nacelle for these tests, an NACA 111 body of fineness ratio 6, was mounted in various vertical positions on a two-dimensional straight wing having an NACA 65-210 section. This figure shows the effects of the vertical position of the nacelle located 66-percent-chord length ahead of the wing, as shown by the corresponding lines, on the nacelle drag coefficient based on the frontal area C_{D_F} as a function of Mach number M.

In the underslung position (shown by the solid-line curves), the drag increment at the maximum available test Mach number of 0.7 indicated a smaller tendency to increase at an angle of attack α of 0° than in the other positions. At an angle of attack of 2.5°, the underslung-nacelle drag variation was similar to that of the plain wing, whereas the positions above the wing showed large drag rises. The fact that these interference drags arise from the increased velocities provided by the nacelle over the midchord section of the wing is confirmed by the pressure-distribution studies.

At an angle of attack of 0°, the peak suction pressures of the nacelles are located near the midchord section of the wing. For the nacelle in the underslung position, these pressures combine with the lower surface pressures of the wing. The pressures over the upper surface remained essentially the same as over the undisturbed wing. Raising the nacelles from the low position increased the velocities over the wing adjacent to the nacelles and resulted in a decreased Mach number at which the severe drag rises occurred. This effect is even more pronounced at higher angles of attack.

[redacted]

[redacted]

Figure 2 shows the influence of horizontal position on the drag characteristics of the underslung nacelle. Although little drag variation was noted at an angle of attack of 0° up to the maximum test Mach number, the drag coefficients decreased with forward nacelle location at an angle of attack of 2.5°. Little change was noted on the wing pressures from varying the nacelle position horizontally; however, the forward position resulted in an appreciable loss in lift of the wing-nacelle combination. Giving the nacelle (shown by the solid-line curve) either positive or negative incidence reduced the Mach number at which the drag rise occurred.

The Ames Laboratory has made wind-tunnel studies of the interference effects of a nacelle with internal air flow as shown in figure 3. This research covered nacelle types for conventional-wing high-speed bombers, powered with four jet engines housed either in two dual-unit nacelles, which also enclose the landing wheel, or in four single-unit nacelles. Tests were made for the nacelles underslung beneath the wing and for nacelles centrally located on the wing. Figure 4 shows the internal arrangement of the dual-unit nacelles. The jet engines were placed well forward on the wing to aid in providing proper balance to the airplane. Retracting the landing wheel into a forward position of the nacelle allowed the cusp-type afterbody to taper more gradually and kept the frontal and surface areas as small as possible. The forebody shape ahead of the wing was designed to have no localized velocity peaks over the lips. The general body lines were selected to give constant cross-sectional area for the central portion of the nacelle to minimize the additional interference velocities produced by the nacelle in the region of the wing.

The dual-unit nacelles as shown in figure 4 and the single-unit nacelles were developed in a low-speed wind-tunnel investigation on a $\frac{1}{4}$-scale model (reference 2). The nacelles showed desirable aerodynamic characteristics. Satisfactory internal pressure recoveries were obtained. The drag of each nacelle based on the frontal area was approximately 0.05. Negligible adverse interference effects on the maximum lift and pitching-moment characteristics were experienced. Locating the nacelle underslung beneath the wing resulted in a slight increase of the angle of zero lift. The predicted critical compressibility speed for the combination of the wing and each nacelle above an inlet-velocity ratio of 0.5 was above that of the plain wing except in the wing-nacelle juncture.

The high-speed characteristics of the dual-unit nacelles were obtained with a $\frac{9}{100}$-scale model of the wing, fuselage, and two nacelles (references 3 and 4). The external-drag coefficient of

[redacted]

the underslung and central dual nacelles, based on the frontal area, were 0.06 and 0.044, respectively, at zero lift and at a Mach number of 0.74. The variation in pitching moment and angle of attack for zero lift with Mach number was slight up to drag divergence.

Pressure studies at high speeds showed satisfactory distribution over the nacelle except in the wing-nacelle juncture. This was similar to the results predicted from the low-speed tests. Normally, the critical Mach numbers are compared as an indication of whether the Mach number for drag divergence of the wing-nacelle combination is equal or below that of the plain wing. Figure 5 shows the predicted critical Mach number M_{cr} as a function of the angle of attack α of the various sections of the dual underslung nacelle. The critical Mach number of the upper center line, the lip section, the half-breadth, as well as the upper and lower junctures, are presented inasmuch as they are representative of the type encountered with an underslung nacelle. The lower wing-nacelle juncture, although filleted, was critical over a small angle range (fig. 5). These predicted critical Mach numbers were based on the peak suction pressures occurring at the juncture leading edge. Basing the predicted Mach number on the juncture pressure at the midchord section would result in a value above that of the wing. Centrally located nacelles exhibit similar characteristics except that the critical pressures usually occur in the upper-surface juncture at the maximum thickness of the wing.

The high-speed drag characteristics of the dual nacelles are presented in figure 6. In this figure the drag coefficient C_D of the wing and fuselage with two nacelles are presented as a function of Mach number M and are shown by the corresponding lines for lift coefficient C_L of 0 and 0.2. The presence of either type nacelle had no appreciable effect on the Mach number of drag divergence compared to the basic wing-fuselage combination other than to steepen the rise of the drag curves after the divergence Mach number was reached. It is interesting to note that the predicted Mach number as set by the leading-edge-juncture pressures was well below that obtained by actual test. This would indicate that a predicted critical Mach number, based on the very localized suction pressure occurring in a wing-nacelle juncture, is evidently quite conservative. Extensive pressure surveys made in the wing-fuselage juncture revealed that the critical pressures were contained in a very small region adjacent to the nacelle that extended but $\frac{1}{100}$-chord length along the span. Outboard of this region the pressures were satisfactory.

When the problem of nacelle design on a sweptback wing is considered, it is desired that the interference effects resulting

 [redacted]

from the addition of the nacelles on the swept wing will not reduce the divergence Mach number. Any reduction will tend to nullify the advantages gained through the use of sweepback.

Before proceeding with the problem of the design of an air-flow nacelle, it was necessary to obtain information relative to the interference effects of a jet nacelle body on a sweptback wing. For this purpose, a nacelle was mounted at various positions along the 31-percent semispan station of a sweptback wing as shown in figure 7. The nacelle was simulated by a prolate ellipsoid of fineness ratio 5 mounted on an NACA 64-212 wing swept 35°.

The nacelles were investigated at low speed at the central locations shown in figure 7: (1) a forward position 40-percent-chord length ahead of the wing leading edge, (2) a leading-edge position coincident with the wing leading edge, and (3) an aft position coincident with the 40-percent wing-chord line. The nacelle was also mounted in an underslung position 40-percent-chord length ahead of the wing leading edge and on a strut below the wing as it was believed that such a position may be necessary to reduce the interference effects. The nacelle was located ahead and coincident with the wing leading edge on different length struts.

The experimental results of the low-speed investigation (reference 5) showed that the nacelle in the above locations had negligible effect on the maximum lift and pitching-moment characteristics. Locating the nacelle beneath the wing and on the struts slightly increased the angle of zero lift. The external-drag coefficient based on the frontal area was approximately 0.05. Practically the only effect of the nacelle position was on the pressure distribution. All the wing-mounted nacelles produced a velocity distribution over the center lines which were less than the maximum velocities over the basic swept wing. The lowest velocity distribution was obtained over the center line of the nacelle having the minimum pressure point farthest aft of the minimum pressure point of the wing (that is, the nacelle in the aft position). The application of a wing-leading-edge entrance with such a nacelle position is indicated.

The pressure distribution along the inboard wing-nacelle juncture varied with nacelle location. With the nacelle in the forward position, the peak suction pressures at the jucture leading edge were well above those of the wing. In the leading-edge position, the pressures were generally of the same magnitude as the pressures along the midchord of the wing. Locating the nacelle in the aft position reduced the juncture pressures well below those of the wing.

[redacted]

The pressure distribution along the outboard junctures were satisfactory for all nacelle positions.

The pressure distribution over the nacelle mounted on the strut of lengths 20-percent and 30-percent chord below the wing were satisfactory; however, the strut junctures at the nacelle and particularly at the wing showed the formation of high localized velocities over the inboard surface. These high velocities were due in part to the suction pressures of the strut and lower wing surface being coincident at the same chordwise station. Undoubtedly these velocities could be reduced by changing the location of the strut peak pressure with respect to that of the wing.

The Langley Laboratory (reference 6) investigated the effect of a central nacelle located ahead of the leading edge of a sweptback wing where the angle of sweep Λ is equal to 45° as shown in figure 8. Up to the maximum available test Mach number of 0.61, the addition of the nacelle had but little effect on the lift, drag, and moment characteristics. The pressure-coefficient contours over the upper surface of the wing and nacelle are shown in figure 8 for a Mach number of 0.61 and a lift coefficient of 0.20. The pressures over the nacelle are less than those over the midchord section of the basic wing except for a very small region at the inboard-juncture leading edge. A possible detrimental interference effect due to the nacelle is the shifting of the constant pressure lines along the plain wing from a position parallel to the wing leading edge to one normal to the flight path. Further research at high speeds is necessary to evaluate this effect on the drag characteristics. Similar results were obtained with the same nacelle location but with the wing swept forward 45°, except that the leading-edge peak suction pressures shifted to the outboard juncture.

In summary, the design of a high-critical-speed wing-nacelle combination is primarily dependent on the location of the nacelle such that the peak suction pressures of the nacelle and wing do not coincide at the same chordwise position or unite in an area that is largely influenced by the lift additional of the wing. The low-speed or basic drag of the combination depends upon the contours of the nacelle and its location on the wing. It is greatest when the wing-nacelle components intersect in such a way that regions of adverse pressure gradients face each other upon their surfaces. Early drag rises resulted for a wing-nacelle combination on a straight wing in which the pressures coincide in the midchord section of the wing, particularly with the nacelle in a central position. Satisfactory drag characteristics were obtained for the nacelle design in which the peak suction pressures were located behind those of the wing. High-speed drag results showed that the localized peak suction pressures at the leading edge of the wing-nacelle juncture on a conventional wing did not contribute to a reduction in the critical speed of the combination.

REFERENCES

1. McLellan, Charles H., and Cangelosi, John I.: Effect of Nacelle Position on Wing Nacelle Interference. (Prospective NACA paper)

2. Dannenberg, Robert E.: The Development of Jet-Engine Nacelles for a High-Speed Bomber Design. NACA RM No. A7D10, 1947.

3. Pengal, Joseph R., and Butterworth, Keith L.: High-Speed Characteristics of Nacelles for Jet-Propelled Aircraft - An Underslung Nacelle Housing a Landing Wheel and Two Jet Engines. NACA MR No. A6A28, Army Air Forces, 1946.

4. Pengal, Joseph R., and Butterworth, Keith, L.: High-Speed Characteristics of Nacelles for Jet-Propelled Aircraft - A Centrally Located Nacelle Housing a Landing Wheel and Two Jet Engines. NACA MR No. A6D04, Army Air Forces, 1946.

5. Hanson, Frederick H., and Allison, George E.: Effect of Streamline Body Location on the Aerodynamic Characteristics of a Sweptback Wing. (Prospective NACA paper)

6. Heiser, Gerald, and Whitcomb, Charles F.: Investigation of the Effects of Sweep on a Wing and Wing-Nacelle Combination. (Prospective NACA paper)

Dannenberg

[redacted]

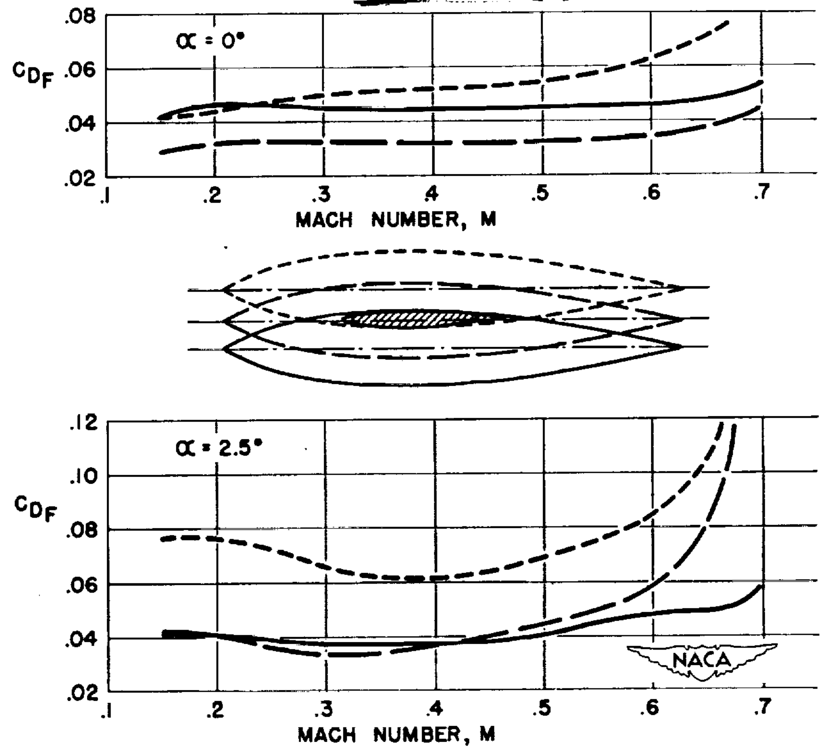

Figure 1.- The effect of vertical nacelle position on the drag coefficient.

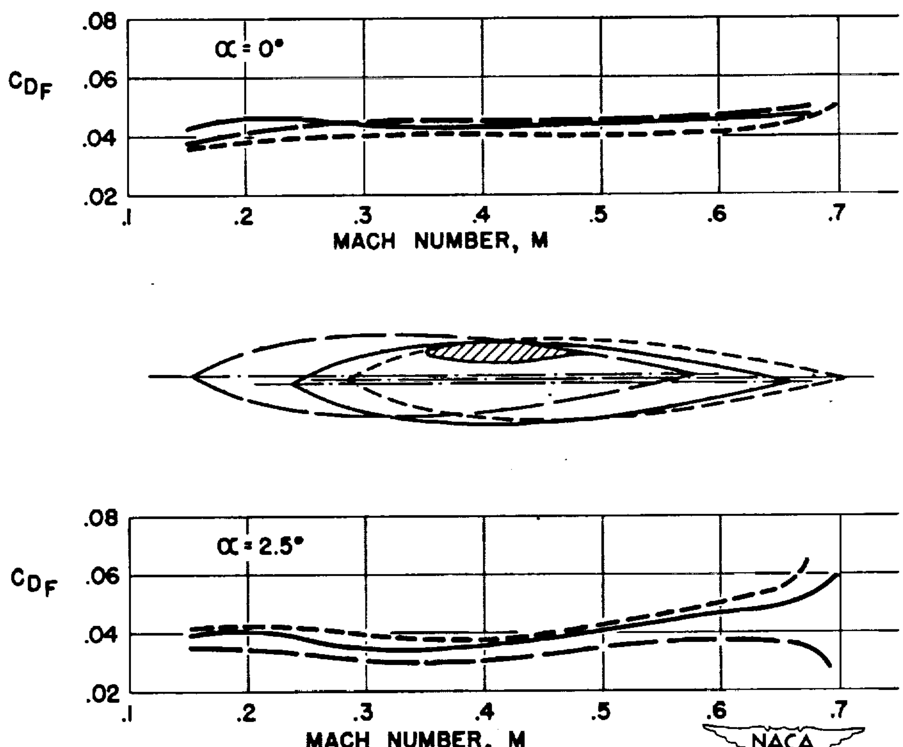

Figure 2.- The effect of horizontal nacelle position on the drag coefficient.

[redacted]

[redacted]

Dannenberg

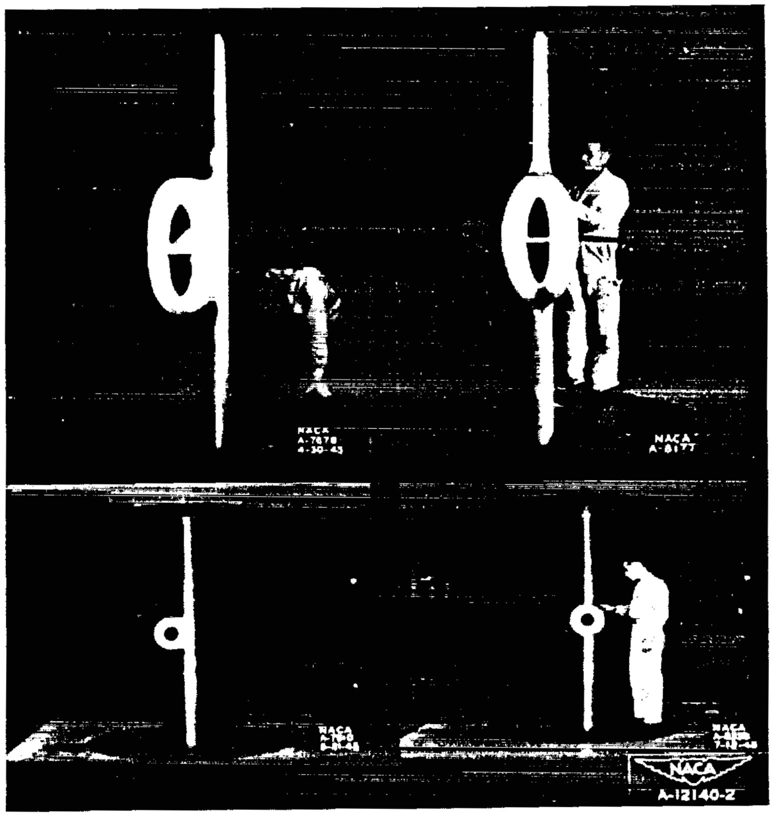

Figure 3.- Jet-engine nacelles mounted on the wing panel.

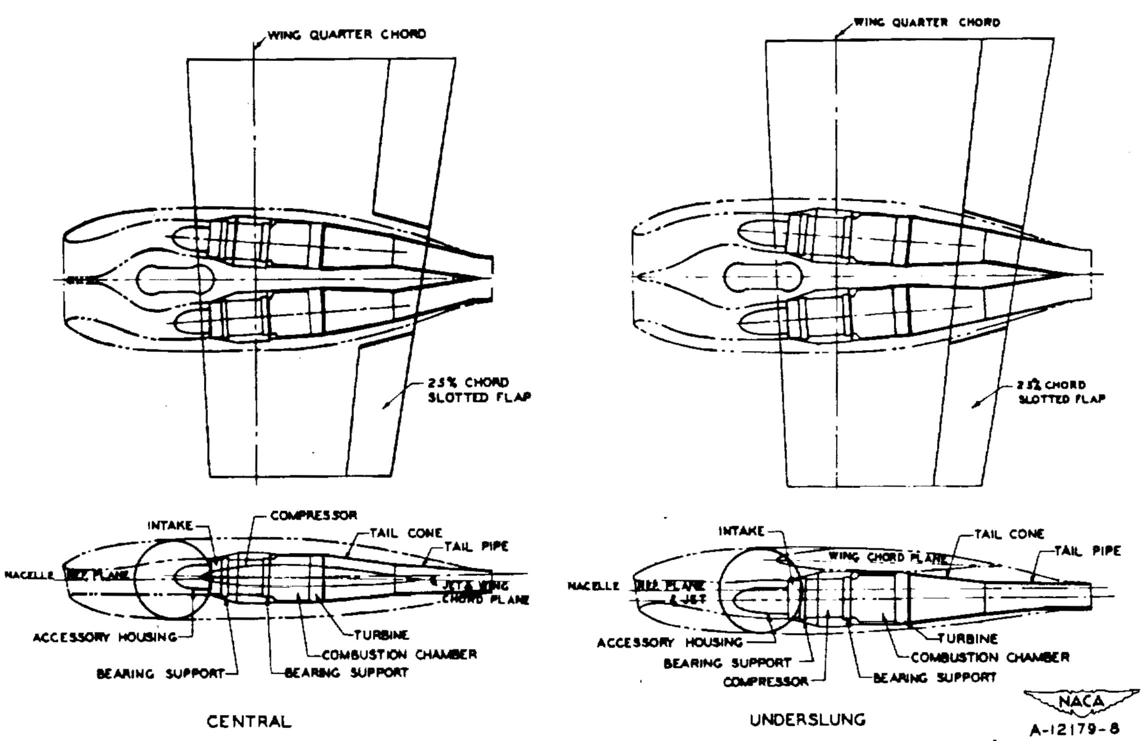

Figure 4.- Internal arrangement of the dual jet-engine nacelles.

[redacted]

Dannenberg

[redacted]

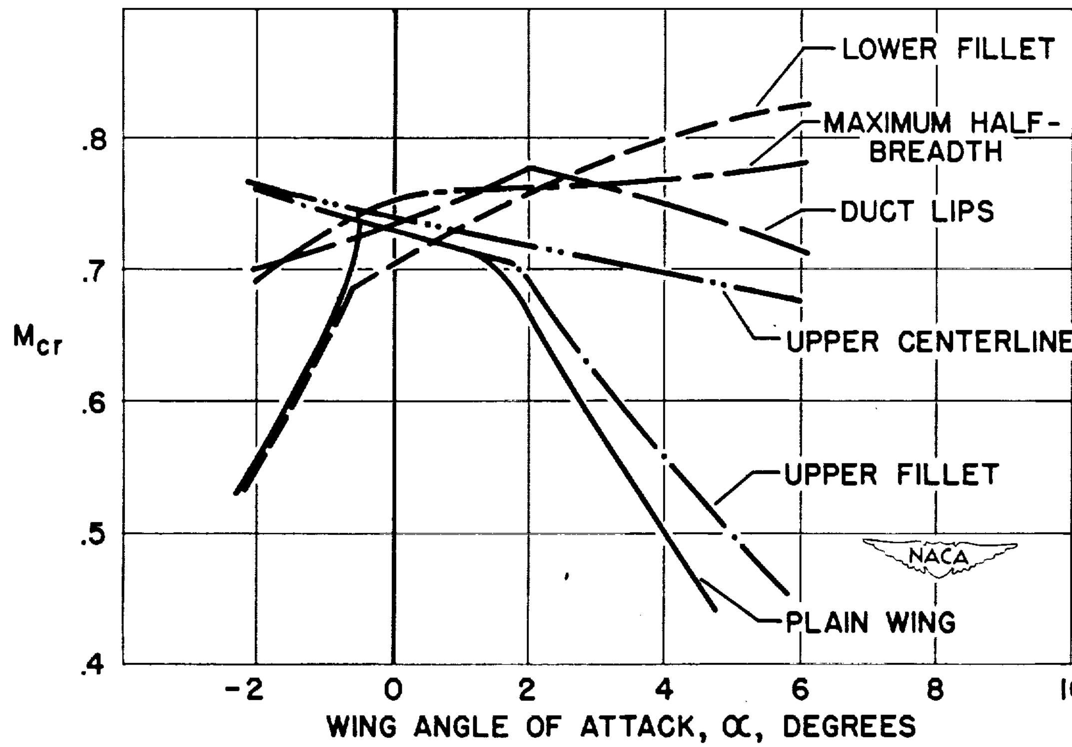

Figure 5.- Critical Mach number characteristics of the underslung nacelle at an inlet-velocity ratio of 0.8.

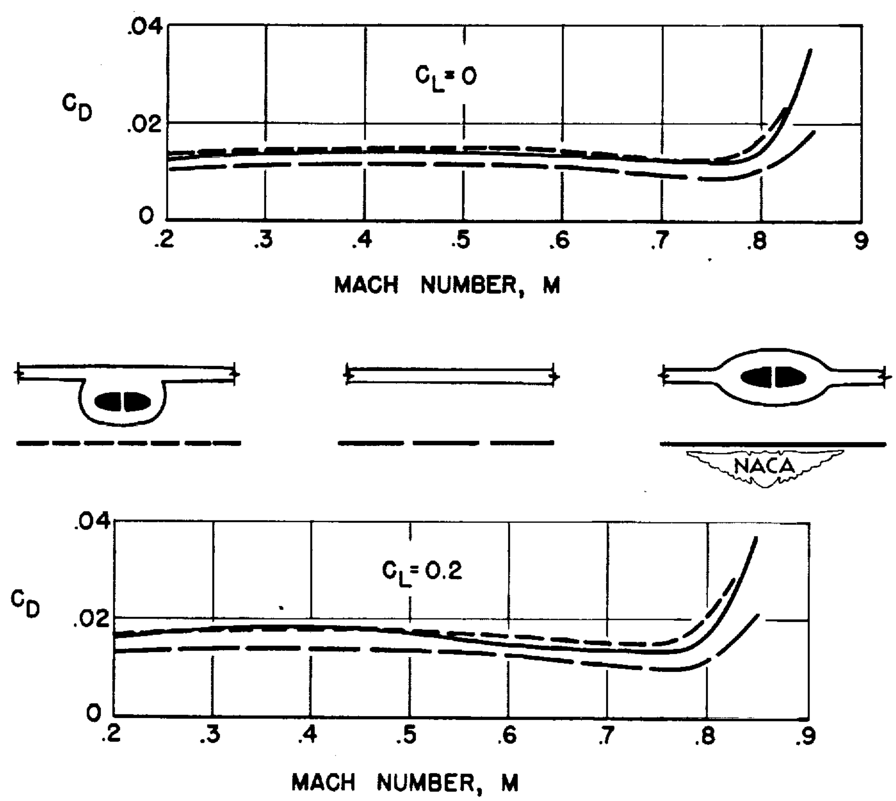

Figure 6.- High-speed drag characteristics of the wing and fuselage with two dual nacelles.

[redacted]

[redacted]

Dannenberg

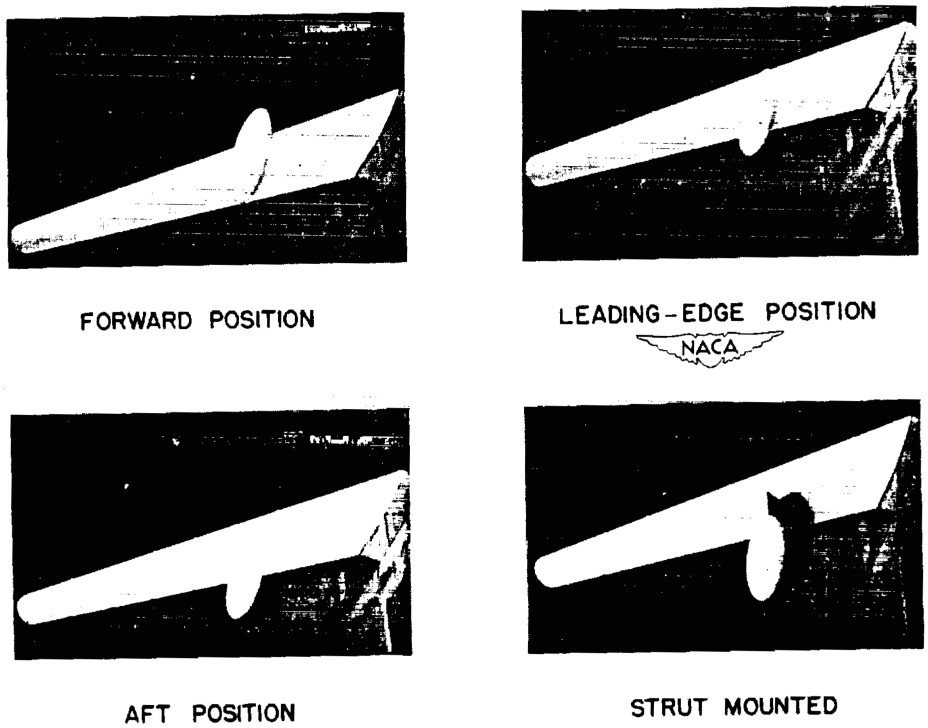

Figure 7.- Nacelle body locations on a 35° sweptback wing.

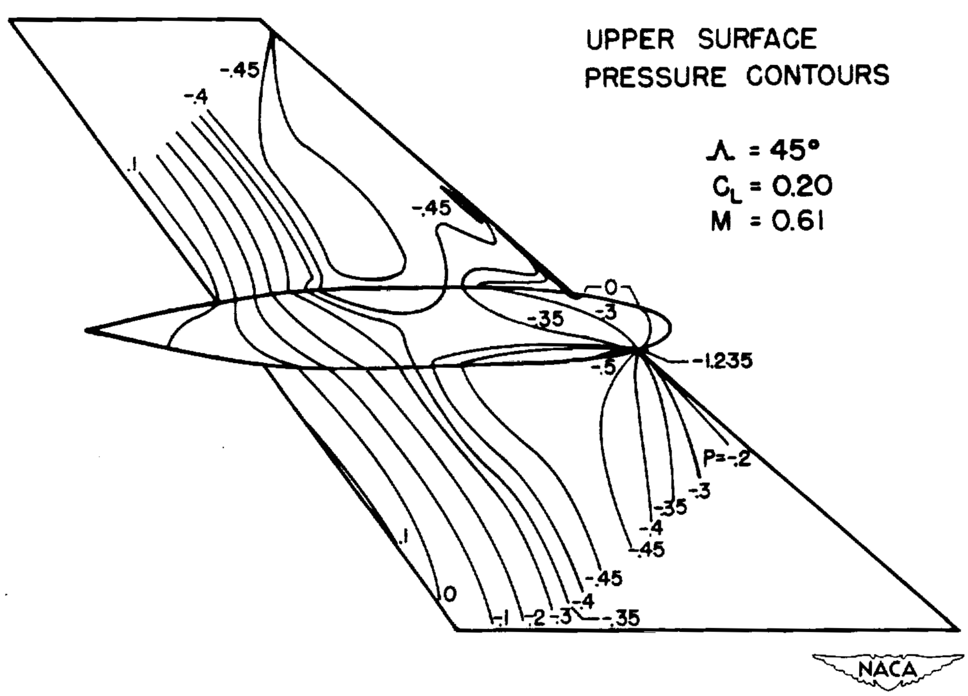

Figure 8.- Pressure-coefficient contours of a centrally located nacelle on a 45° sweptback wing.

[redacted]

64(2.