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NACA

RESEARCH MEMORANDUM

REVIEW OF THE MAXIMUM-LIFT CHARACTERISTICS OF THIN AND SWEPT WINGS

By John G. Lowry and Jones F. Cahill

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RESEARCH MEMORANDUM

REVIEW OF THE MAXIMUM-LIFT CHARACTERISTICS OF THIN AND SWEPT WINGS

By John G. Lowry and Jones F. Cahill

The maximum-lift capabilities of aircraft wings at high speeds are becoming of greater importance as the speeds and altitudes flown by modern aircraft continue to increase. High-speed, high-altitude aircraft fly at rather high lift coefficients and may reach or exceed the angle of attack for maximum lift of the aircraft in maneuvers. The present paper reviews the existing high-speed data on maximum lift of aircraft wings in the clean condition, that is, without high-lift devices. The discussion, which includes the effects of plan form, Reynolds number, airfoil section, thickness, and rate of pitch, should not be considered a design procedure but merely a review of trends that are indicated from the existing data.

For the most part, the discussion is limited to the lift capabilities of wings alone. Figure 1, which presents the normal-force coefficient as a function of angle of attack for the D-558-II airplane (reference 1), shows one of the limitations involved by using wing-alone data. It can be seen that the maximum normal force of the exposed wings, based on exposed area, is about 1.15 while the complete model develops normal forces as high as 1.46. Since the division of loads between the component parts of the airplane is outside the scope of this paper, these data are presented only to point out that airplanes can develop normal-force coefficients considerably higher than the lift capabilities of the wing alone. The effect shown here would be even more pronounced in cases where the fuselage is a lifting surface. Although the maximum lift of the wing determines the maximum load that can be developed on the wing, it does not, necessarily, determine the maneuverability of the airplane and thus the limit loads on other parts of the aircraft.

During the last few years, several investigations have been made to study the lift capabilities of thin unswept and swept wings at both subsonic and transonic speeds (references 1 to 6). Some of the data are given in figure 2 where $C_{L_{max}}$ is plotted against Mach number for three representative wings: a thin (6-percent-thick) unswept wing, a 6-percent-thick 45° sweptback wing, and a 6-percent-thick 60° delta

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wing (references 3, 5, and 6 and unpublished data). Although the data show some scatter, several well-defined trends are shown except in the speed range from $M = 1.1$ to $M = 1.5$ where very few data are available. The data indicate that, at low speeds, the $C_{L_{max}}$ increases as the sweep is increased and the variation with Mach number is much more pronounced for the swept and delta wings. At transonic and supersonic speeds, however, little effect of plan form is noted, all the wings showing an abrupt increase in $C_{L_{max}}$ between $M = 0.9$ and 1.1. The wings tested at supersonic speed are of different plan form than those tested at subsonic and transonic speeds. Since there appeared to be no significant effect of plan form at these speeds, based on tests of some 12 wings (reference 3), it appears justified to extend the curve to the wings investigated at transonic speeds. The dashed line, limit $C_{L_{max}}$, represents the $C_{L_{max}}$ that would be obtained at 45° angle of attack if the upper-surface pressures were absolute zero. (See reference 7.) Since the values of $C_{L_{max}}$ above a Mach number of about 1.1 are about 90 percent of the maximum obtainable, little effect of plan form on the values of $C_{L_{max}}$ would be expected. The angle of attack for maximum lift follows trends very similar to those shown for $C_{L_{max}}$, that is, an abrupt rise near the speed of sound increasing from the low-speed values, 14° for unswept wing and 27° for the delta wing, to about 42° at supersonic speed. In general these data indicate that, although plan form may affect the values of $C_{L_{max}}$ at low speeds, it has little or no effect above a Mach number of about 0.9.

Since most of the data used in figure 2 were obtained at low Reynolds number it would appear advisable to discuss that variable next. Maximum-lift data are shown in figure 3 through a range of Reynolds number from low to moderately high values for three different wings (reference 6 and unpublished data). The several curves at constant Mach number are for a 6-percent-thick 45° sweptback wing of aspect ratio 4 and show no appreciable change in maximum lift coefficient with Reynolds numbers up to Reynolds numbers of 10×10^6. These data are representative of the results obtained with wings of the same thickness and aspect ratio but having sweepbacks of 0°, 30°, and 60°. The other two wings shown, a 4-percent-thick highly tapered unswept wing and a 6-percent-thick delta wing, were tested with a fuselage and do show a noticable increase in $C_{L_{max}}$ as the Reynolds number is increased. At Reynolds numbers beyond the range of figure 3, a small scale effect will probably exist for thin and swept wings since section data (reference 8) indicate that for these airfoil sections the $C_{L_{max}}$ increased by about 0.2 as the Reynolds numbers were increased from 12×10^6 to 25×10^6. In any case, the changes in $C_{L_{max}}$ with Reynolds number are small for thin wings when compared to the large changes associated with the thick unswept wings of yesterday.

Figure 4 shows a comparison of the variation of $C_{L_{max}}$ with Mach number for a thick and a thin wing. The thick wing in this case is 13 percent thick. The results of flight tests (reference 9) using an F-80 airplane show the typical large loss of available lift as the Mach number is increased at low speed. This variation of $C_{L_{max}}$ for the thick unswept wing at low speed is very similar to the variation shown for the swept and delta wings in figure 2. The data for the thin (6-percent-thick) wing shown here is the faired curve of figure 2 and shows little effect of Mach number up to about $M = 0.8$ with an abrupt change in $C_{L_{max}}$ between $M = 0.9$ and 1.1. It would be expected, however, that the thick wing would also show a similar rise if data were available at these speeds.

There are not sufficient data available to give a complete story on the effect of airfoil section on $C_{L_{max}}$ at high speed. Figure 5 shows the results of an investigation where the section of a 45° sweptback wing of aspect ratio 4 was changed radically. The basic wing had NACA 65A006 sections streamwise and the modified wing had a flat-plate section with a rounded leading edge, varying in thickness from $9\frac{1}{2}$ percent at the root to about 16 percent at the tip. The results indicate that, although the round leading edge increased the $C_{L_{max}}$ at low speeds, it had little or no effect at Mach numbers of 1.05. These data and other fragmentary data indicate that although changes in section, twist, or the addition of leading-edge slots give improvements at low speed, little or no improvement can be expected above a Mach number of about 1.1 since the plain wing is developing about 90 percent of the limiting values of $C_{L_{max}}$ in the supersonic speed range.

The trends shown for $C_{L_{max}}$ with Mach number for thin wings at transonic speeds were all obtained from model tests in wind tunnels. The final question is, of course, how does the airplane behave at these speeds? Figure 6 shows the variation of maximum normal-force coefficient with Mach number for two Bell X-1 research airplanes.

The data below a Mach number of 0.6 were obtained on the X-1 with the 10-percent-thick wing (reference 10) and above 0.6 Mach number the data were obtained on the X-1 with 8-percent-thick wing. A few values of $C_{N_{max}}$ were obtained for the 10-percent-thick wing in the speed range above $M = 0.6$ and agree with the values obtained from the 8-percent-thick wing. The flight tests show the same trends as the wind-tunnel data, that is, little change in the subsonic speed range and an abrupt rise near Mach number 1.0. These data do not, however, go to high enough Mach numbers to show any leveling off at supersonic speeds. It would appear, therefore, that the trends shown by the wind-tunnel data will be applicable to aircraft flying at or near the speed of sound.

Since the maximum lift at high speeds and high altitudes can very easily be obtained during a manuever, either planned or inadvertent, the effect of changes in rate of pitch on maximum lift are of importance. Figure 7 shows $C_{L_{max}}$ for different rates of pitch for a thick unswept wing (reference 11), a model of the P-47 airplane, and the X-1 research airplane with 10-percent-thick wings (reference 10). The static $C_{L_{max}}$ curve for the thin unswept wings is included for reference only. The rate-of-pitch parameter $\frac{\bar{c}}{V}\frac{d\alpha}{dt}$ represents the change in angle of attack in radians per chord traveled. The data for the model of the P-47 airplane show considerable increases in $C_{L_{max}}$ as rate of pitch is increased in the low-speed range. This marked effect of pitch decreases as the speed is increased until for this case it disappears at a Mach number of 0.6. The flight tests of the X-1 airplane with the 10-percent-thick wing, however, are not so complete. The abrupt stall represents maneuvers where angle of attack was increased as rapidly as possible with values of $\frac{\bar{c}}{V}\frac{d\alpha}{dt}$ from 0.0025 to 0.005 and the gradual stall represents the conditions where the stall was approached slowly. These data, as did the P-47 data, show that the effect of rate of pitch decreases as the speed is increased. Since the maximum lift of thin wings is about 90 percent of the limit $C_{L_{max}}$ at supersonic speeds, little or no benefit of rate of pitch should be realized at these speeds. It would appear from the data shown here that the effect of rate of pitch would tend to decrease as the speed is increased and, for thin wings, no effect of rate of pitch is to be expected above a Mach number of 1.1.

RÉSUMÉ

The net result of the discussion on lift capabilities of thin and swept wings at high speed seems to be that, although considerable variation in the values of $C_{L_{max}}$ may be possible at low speed due to Reynolds number, plan form, section, and so forth, little or no increase in the value of $C_{L_{max}}$ appears possible at speeds greater than the speed of sound.

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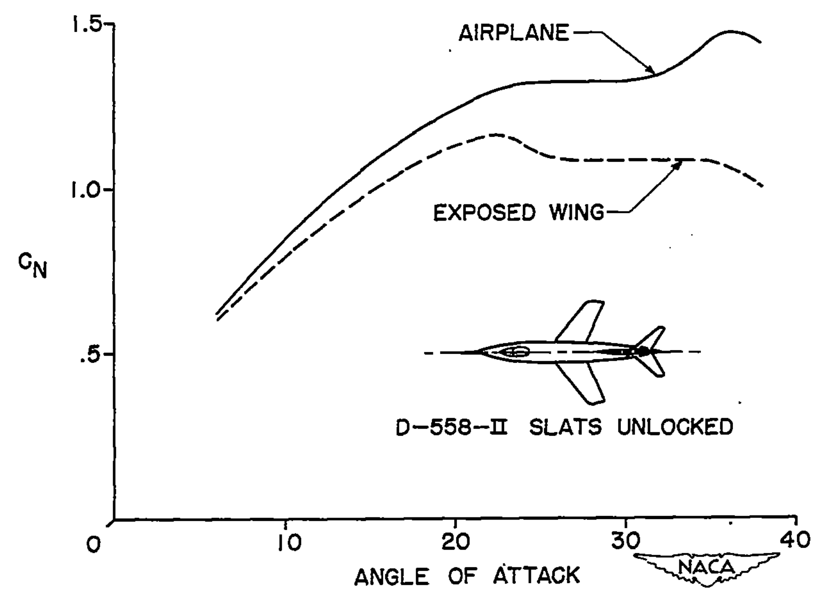

Figure 1.- Variation of normal-force coefficient of the Douglas D-558-II research airplane with angle of attack for a 1g approach stall. Flaps up; slats unlocked.

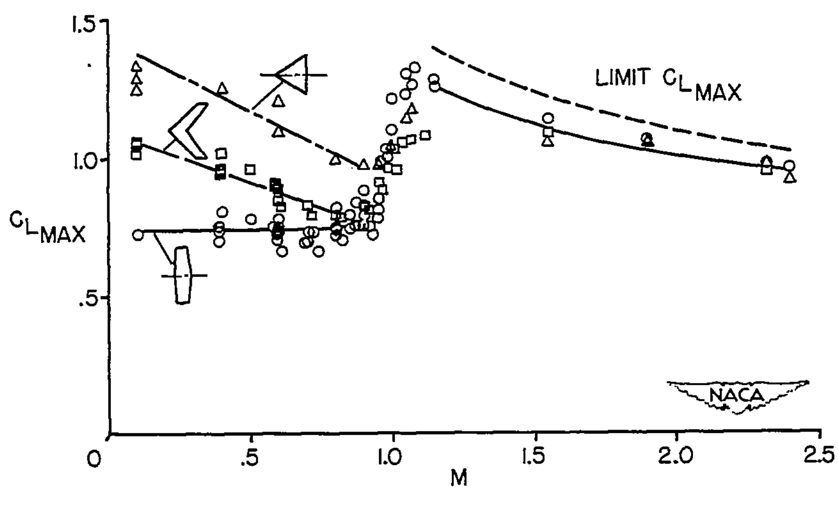

Figure 2.- Effect of wing plan form on the variation of maximum lift coefficient with Mach number.

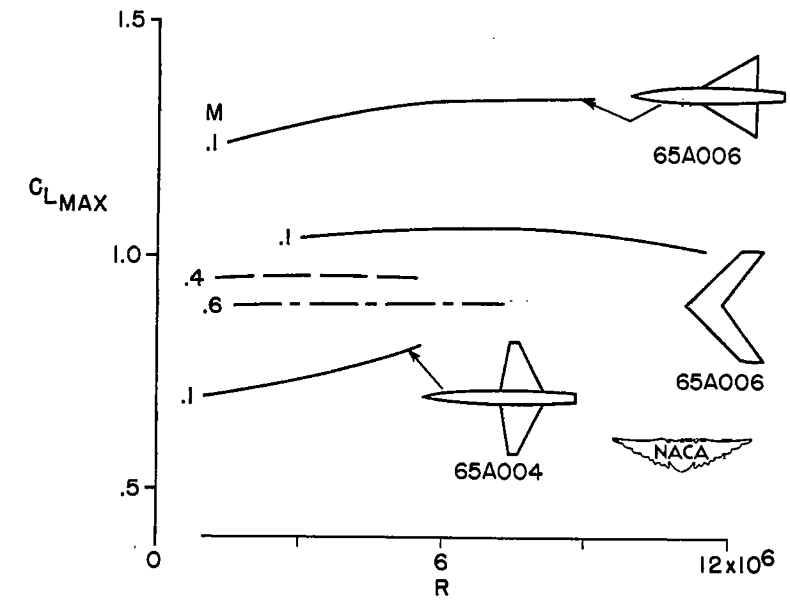

Figure 3.- Effect of Reynolds number on wing maximum lift coefficient at subsonic speeds.

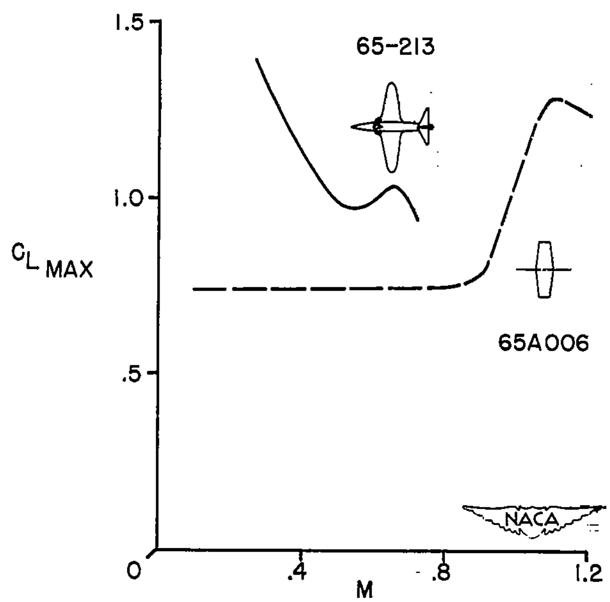

Figure 4.- Effect of thickness on the variation of maximum lift coefficient with Mach number.

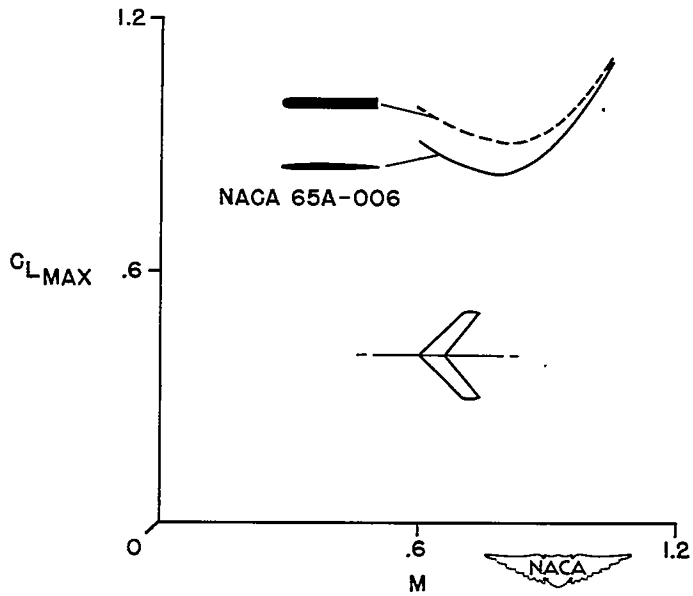

Figure 5.- Effect of airfoil section on the variation of maximum lift coefficient with Mach number.

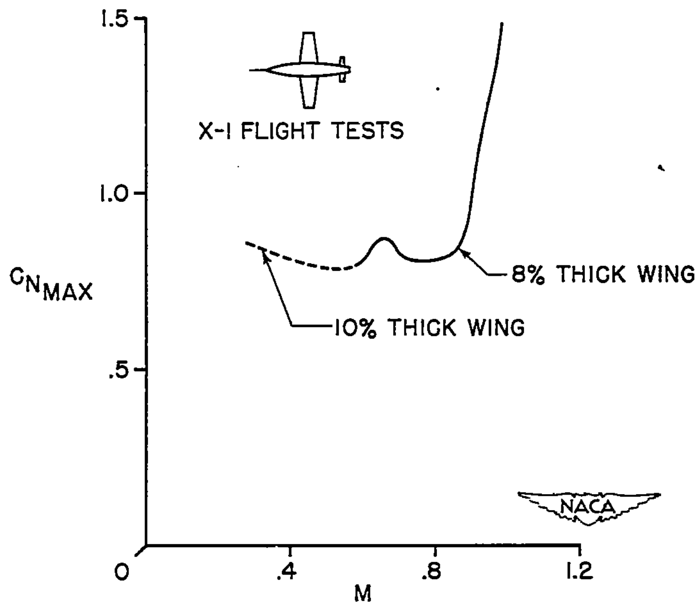

Figure 6.- Variation of maximum normal-force coefficient with Mach number for the X-1 research airplane.

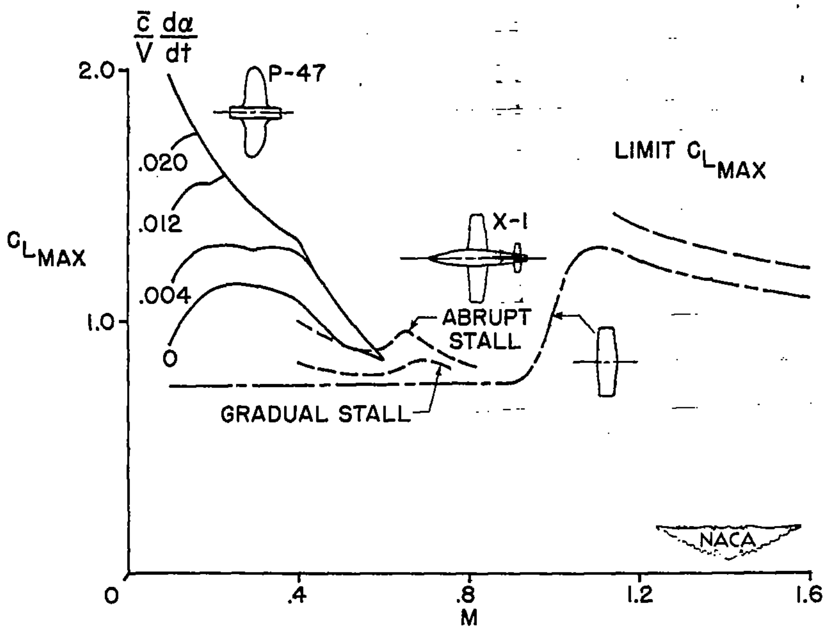

Figure 7.- Effect of rate of pitch on the variation of maximum lift coefficient with Mach number.

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