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RESEARCH MEMORANDUM

SOME NOTES ON THE AERODYNAMIC LOADS ASSOCIATED WITH EXTERNAL-STORE INSTALLATIONS

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RESEARCH MEMORANDUM

SOME NOTES ON THE AERODYNAMIC LOADS ASSOCIATED WITH EXTERNAL-STORE INSTALLATIONS

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SUMMARY

The results presented in this paper indicate that the effects of stores on wing load distribution at subsonic speeds may be predicted by available methods at the lower angles of attack where wing flow separation is negligible. At the higher angles of attack where wing flow separation exists, a store located inboard on a swept wing may act much like various devices designed to delay wing pitch-up by reducing the loss in load at the wing tip due to flow separation. Furthermore, the results indicate that the normal force and pitching moment of a store located at the wing tip can be calculated quite well by available methods. On the other hand, no theoretical procedure is available to calculate the severe lateral forces and moments encountered at zero sideslip on an inboard arrangement of stores on a swept wing.

INTRODUCTION

The continued use of external stores on airplanes has intensified the interest in general loads information in this field. Until recently, the only results available had been obtained to solve a certain specific problem and were of little use in relation to the general requirements of designers. Several external-store load programs intended to provide general design information are currently being followed by the National Advisory Committee for Aeronautics. It is the purpose of this paper to review the available results of some of these investigations, conducted for the most part at subsonic speeds, and to indicate some observations that may prove helpful in the design of future external-store installations.

SYMBOLS

C_L	lift coefficient, $\frac{\text{Lift}}{qS_W}$
C_m	static aerodynamic pitching-moment coefficient referred to 0.25c' of wing, $\frac{\text{Pitching moment}}{qS_W c'}$
C_B	bending-moment coefficient, $\frac{\text{Twice root bending moment}}{qS_W \frac{b}{2}}$
c_n	section normal-force coefficient, $\frac{\text{Normal force}}{qc}$
P	pressure coefficient, $\frac{p_l - p}{q}$
y_{cp}	lateral center of pressure referred to wing semispan, $\partial C_B/\partial C_L$
Δy_{cp}	increment in lateral center-of-pressure location due to external store, $y_{cp_{model + store}} - y_{cp_{model}}$
C_{N_S}	store normal-force coefficient, $\frac{\text{Normal force}}{qS_S}$
C_{m_S}	store pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_S l_S}$
C_{Y_S}	store side-force coefficient, $\frac{\text{Side force}}{qS_S}$
C_{n_S}	store yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS_S l_S}$
N_S	store normal force, lb
Y_S	store side force, lb
q	free-stream dynamic pressure
p	free-stream static pressure
p_l	local static pressure

M Mach number

α angle of attack of wing, deg

S_W wing area, sq ft

S_S maximum frontal area of store, sq ft

c' mean aerodynamic chord of wing, ft, $\frac{2}{S_W}\int_0^{b/2} c^2 dy$ (using theoretical tip)

$\bar{c}$ average chord of wing semispan, ft

c local wing chord, ft

b wing span, ft

y distance outboard of plane of symmetry, ft

l_S length of store

D diameter of store

t/c thickness ratio of pylon

Λ sweep of the 0.25c line

A aspect ratio of wing

DISCUSSION

Store-Induced Wing Loads

The loads associated with external-store installations can be considered in two parts. One part is concerned with the effects of the store installation on the loading of wings, and the other is concerned with the direct loads on the stores. The first part of this paper deals with store-induced wing loads.

In order to determine the store-induced wing loads, tests have been made of a 45° sweptback wing of aspect ratio 4.0 in combination with a fuselage. As shown in figure 1, the wing was equipped with pressure orifices at five stations across the span. In the analysis of the results, all five pressure stations were considered as being on the same wing panel at semispan locations of 20, 40, 60, 80, and 95 percent. Two arrangements of the external stores were investigated - an inboard arrangement and a wing-tip arrangment. In both arrangements, the stores were attached directly to the wing surface.

In this investigation the distributions of section normal forces over the wing semispan have been obtained at subsonic and low transonic speeds. First, results are presented for the inboard external-store installation. Figure 2 shows the effect of this installation on the spanwise distribution of section normal-force coefficient and on the static aerodynamic pitching-moment coefficient at a subsonic Mach number of 0.70.

The variation in the static aerodynamic pitching moment has proven to be a useful guide to changes in span loading over a sweptback wing. One of the most significant changes in span loading indicated is the loss in wing-tip load that is related to airplane pitch-up - pitch-up is characterized by a rapid positive increase in static aerodynamic pitching moment. At an angle of attack of 12°, which is well beyond the onset of pitch-up for this wing, the loss in experimental wing-tip load is apparent in the distribution of section normal forces by comparison with the span loading calculated by potential-flow methods of reference 1. Before the onset of wing pitch-up (as represented by the results at $\alpha = 4^\circ$), the load distribution calculated by potential-flow methods is in good agreement with experiment.

The static aerodynamic pitching moment also illustrates the principal effect of inboard stores on the loading of the plain wing. That effect is to delay pitch-up to higher angles of attack. In this respect an inboard external store behaves in much the same way as certain auxiliary devices designed to delay wing pitch-up. Some of these devices are discussed in references 2 and 3. The distribution of section normal-force coefficient over the wing panel at an angle of attack of 12° with the store on the wing shows increased loading at the wing tip that is represented fairly well by the calculated loading of the plain wing. At a lower angle of attack ($\alpha = 4^\circ$), the calculated loading of the plain wing is almost identical to the experimental loading of the wing-store combination.

To illustrate chordwise loading, the chordwise distribution of pressure at an angle of attack of 12° and a Mach number of 0.70 is presented in figure 3. The results show that, on the inboard side of the store, the store reduces the loads of the plain wing by promoting thickened boundary-layer conditions. The additional tip loading due to the store is seen to come from a small region of loadings similar to those that can be predicted by potential-flow methods just outboard of this store and increased normal-force loads coming from reduced separation losses outboard of this region.

The points of design interest shown by these results are that at subsonic speeds in place of more detailed loading information the static aerodynamic pitching moment can be used as a guide to indicate the limit of the angle-of-attack range over which the span load distribution of a plain wing, calculated by potential-flow methods, may be used to represent the span load distribution of a swept-wing—fuselage combination having inboard external stores. Furthermore, an inboard external store extends the range in which calculated span loadings can be used in the same way as auxiliary devices designed to delay wing pitch-up. The amount of extension, however, is likely to depend upon the store arrangement. It follows that, if the design limit of a swept-wing airplane is not attained prior to pitch-up, recourse must be taken to experimental span loadings for design purposes.

Although the information available on the effect of inboard external stores at transonic speeds is limited, results obtained on the installation just discussed at a Mach number of 0.91 (fig. 4) provide some insight into the loading conditions that may be expected in this speed range. The delay in wing pitch-up caused by the inboard external store at subsonic speeds has vanished at a Mach number of 0.91. The similarity between auxiliary devices designed to delay wing pitch-up and inboard stores is again apparent, since both lose effectiveness in delaying wing pitch-up with entry into the transonic speed range. At an angle of attack of 12°, the plain wing and the wing-store combination are experiencing wing-tip separation, as evidenced by pitch-up, and the loading characteristics are similar. The calculated distribution does not provide a reliable indication of the experimental loadings in this angle-of-attack range. However, where there is negligible wing separation prior to pitch-up, illustrated by the results at an angle of attack of 4°, the inboard store again has no major effect on the wing span loading.

The discrepancy between the calculated loading and the experimental loadings of the plain wing and the wing-store combination can be attributed to the fact that theory does not adequately estimate the lift-curve slope of the model at this Mach number.

The diminution of the span loading of the wing tip with increase in Mach number (figs. 2 and 4) is represented in the chordwise loading (figs. 3 and 5) by the reduced suction pressures on the outboard side of the store and beyond this region in the reduced section loads associated with the stalled type of pressure distributions of the chordwise loadings. Theory cannot be expected to predict stalled-type loadings such as these. The attainment of supercritical flow conditions terminated by compression shock on the wing and the wing-store combination at the wing-fuselage juncture as evidenced by the second peak in the pressure distributions is one of the reasons the lift-curve slope of the model is not adequately estimated by theory in this speed range.

The effects of tip stores are now considered. It is well-known that these store arrangements have some significant aerodynamic advantages on straight-wing airplanes that appear also to exist but to a somewhat lesser degree on wings with sweepback. The advantages come from an additional loading of the wing tip induced by the tip store that can be interpreted as an effective increase in wing aspect ratio. This effect is illustrated in reference 4. In figure 6 this additional tip loading is shown at a Mach number of 0.70 in the distribution of section normal force at an angle of attack of 4°. The calculated span load distributions for the plain wing and for the wing-store combination are included. Span loading was calculated by the method of reference 5. The calculated and experimental increments in span load due to the tip store are in good agreement. The loading over the tip store also calculated by this method is in good agreement with the measured store load. The experimental distribution over the store was obtained by distributing a measured store total normal force according to the theoretical distribution. It is of interest to note that, of the total additional loading over the wing and the tip store, about 40 percent is carried directly on the store.

Inasmuch as the additional tip loading due to the store is proportional to angle of attack, it is evidenced in the aerodynamic pitching moment by a change in stability. Beyond the effect on stability at the lower angles of attack, the tip store has no major effect on the variations in static aerodynamic pitching moment. Therefore, the distribution of section load at the higher angles of attack would be expected to be similar as they are shown to be at an angle of attack of 12°.

At supersonic speeds, information is available on the effect of stores on the lateral center of pressure. The results were obtained on a small-size semispan model with a 45° sweptback wing at Mach numbers of 1.4, 1.6, and 2.0. The results are shown in figure 7 in terms of the incremental change in location of the lateral center of pressure due to the store. The nose sections shown in this figure represent the locations of the stores in both the chordwise and spanwise directions. The lateral centers of pressure were obtained over the angle-of-attack range ($\alpha = 0^{\circ}$ to 8°) where the wing-root bending moment varied linearly with lift coefficient and can be considered to represent conditions discussed previously at subsonic speeds for the low angle of attack.

The tip-mounted store results in a measurable outboard movement in the lateral center of pressure that is equivalent to an additional tip load; however, there is little change in the lateral center of pressure for inboard stores. The dashed fairing approaching the wing tip indicates a region of uncertainty as to the change in lateral center of pressure due to stores in these locations. The cross-hatched region represents the entire change in the incremental lateral center of pressure due both to Mach number and store chordwise position. Thus, in a qualitative sense external stores show characteristics at supersonic speeds similar to those at subsonic speeds. Unpublished results also indicate that the same type of changes in lateral center of pressure due to stores was obtained on an unswept wing at supersonic speeds.

Store Loads

Several investigations, the results of which are unpublished, have been made to evaluate the second part of the loading of external-store installations, that is, direct store loading. One such investigation was made on a North American F-86A-1 airplane with 245-gallon auxiliary fuel tanks equipped with small horizontal fins. The installation on the airplane is shown in figure 8. Normal and side forces on one of the tanks were obtained by pressure measurement. The pressure orifices were located in meridian planes along the tank length.

The variations of normal and side forces on the tank with airplane lift coefficient are shown in figure 9. Keeping in mind that a full 245-gallon tank has a fuel load of about 1,500 pounds, it is apparent that the maximum normal forces attained, designated by N_S, are small in comparison to the fuel load and are in a direction to compensate for it. Higher normal forces would of course be shown at altitudes below the 30,000-foot level of these tests, but even at sea level where the forces may be as much as three times as large, they would still be considerably less than the fuel load.

Side forces, designated by Y_S, however, reach levels at the higher Mach numbers that are considerably above the normal-force loads. Such characteristics are indeed interesting since it would not be expected that loads as large as these would be encountered in flight where there was no intentional sideslip. The side forces are important because they indicate that the largest loads may occur in the plane of least structural strength of the installation. For this reason, another factor arising from performance requirements may introduce design problems in the lateral plane of pylons. For performance reasons at high speeds, it is recommended that the pylons supporting external tanks be kept thin, perhaps as much as several percent thinner than wings, and free of external bracing. Such a criterion may become difficult to follow with lateral loads of the size suggested by these and other results to be presented subsequently.

Systematic wind-tunnel investigations of direct store loads are also being made. Models on which some results have been obtained are shown in figure 10. The wing-fuselage models employed a straight and a sweptback wing. On each model, inboard and wing-tip store arrangements were investigated. One store in each arrangement was equipped with an internal strain-gage balance that measured the store forces and moments. Results of the tunnel investigations at zero yaw are shown at a subsonic Mach number of 0.50. The store force coefficients are based on the store maximum frontal area, whereas moment coefficients are based upon store maximum frontal area and length. Some of the results presented herein have been taken from results presented in reference 4.

Store yawing-moment coefficient, designated by C_{Y_S}, and store side-force coefficient, designated (C_{n_S}) are presented in figure 11. The positive directions of all store load coefficients are the same as those employed in aerodynamic practice by the National Advisory Committee for Aeronautics. These results indicate that the large lateral loading of the inboard store is primarily a result of wing sweep since both the store yawing-moment coefficients and side-force coefficients are considerably less for the inboard stores on the straight-wing model than for the swept-wing model. The side-force coefficient at an angle of attack of 10° would be equivalent on a fighter airplane at sea level in unyawed flight to a load of about 1,000 pounds. Although the data are extremely limited, there is evidence that the lateral loading of tip stores may also become large enough to be considered.

The store normal-force coefficients, presented in figure 12, indicate that the level of loading for inboard arrangements including the effect of sweeping a wing from 3.6° to 46.7° is low. The order of magnitude of the tunnel result is, in fact, about the same as that predicted by viscous theory for an isolated external store and shown by the dashed curve in the left-hand plot of this figure.

Somewhat higher normal-force coefficients are shown for the tip arrangements probably because of the pressure field around the wing tip. The rapid increase in up load with angle of attack of the tip store may not result in loads large enough to produce structural overload since the coefficients shown here suggest normal loads of the same order of magnitude as those produced by fuel loads for such a store used as a tank. The moment loads due to these normal forces may on the other hand become critical. Calculations made by the method of reference 5 for the swept configuration are shown as a dashed curve in this figure. These results indicate that the method of reference 5 estimates well the slope of the normal-force coefficients of the tip store.

The pitching-moment coefficients of the wing-tip store are shown in figure 13 in the plot on the right. The pitching-moment coefficients are presented about an axis on the tank that coincides with the approximate location of the torsional axis of airplane wings. The pitching-moment coefficients of the tip store increase rapidly with angle of attack as did the normal-force coefficients. In effect these results show that, if an airplane equipped with tip stores executes a pull-up to high angles of attack at low altitude, the store pitching load that must be absorbed by the wing panel is proportional to angle of attack and may result in significant wing torsional loads. Experience has demonstrated that, on several straight-wing airplanes in which wing failure occurred during such a maneuver, wing torsional effects coming from tip-store loadings such as these are large enough to contribute to the wing failure. Since the aerodynamic store loading is upward, these conditions are of course more critical for stores without internal load. The calculated curve, also obtained by the method of reference 5, indicates that this method again estimates, at least for this installation, the slope of the pitching-moment curve. It is not yet clear whether as good prediction of the pitching loads by this method of calculation can be expected with other geometrically different tip-store arrangements.

The pitching-moment coefficients of inboard stores shown in the plot on the left are seen to be as correspondingly low as the normal-force coefficients of this arrangement. They are less even than predicted by viscous theory (shown by the dashed curve) for an isolated external store.

Since fins are commonly used on external stores, it is of interest to examine some results (fig. 14) that show the effects of one arrangement of fins on store moment coefficients. The fins were located at 45° from the horizontal and the vertical and were of a size and shape similar to those under consideration for use on one type of external store. The fins were large enough to more than neutralize the pitching-moment coefficients of the store alone. The results show that the fins reduced the pitching-moment load but increased the yawing-moment load on the tip store, but they increased the pitching-moment load and decreased the yawing-moment load on the inboard store. The arrangement of fins tested is the type found on bombs and is not intended to represent fins selected to neutralize any particular component of store loads. Fins such as these, however, if employed on either arrangement of external stores, may be expected to increase at least one component of store load.

CONCLUDING REMARKS

In conclusion, the results presented indicate that the effects of stores on wing load distribution at subsonic speeds may be predicted by available methods at the lower angles of attack where wing flow separation is negligible. At the higher angles of attack where wing flow separation exists, a store located inboard on a swept wing may have much the same effect as various devices designed to delay wing pitch-up by reducing the loss in load at the wing tip due to flow separation. In the angle-of-attack range where pitch-up develops, the chordwise distribution of load is largely unpredictable. Furthermore, the results indicate that the normal force and pitching moment of a store located at the wing tip can be calculated quite well by available methods. On the other hand, no theoretical procedure is available to calculate the severe lateral forces and moments encountered at zero sideslip on an inboard arrangement of stores on a swept wing.

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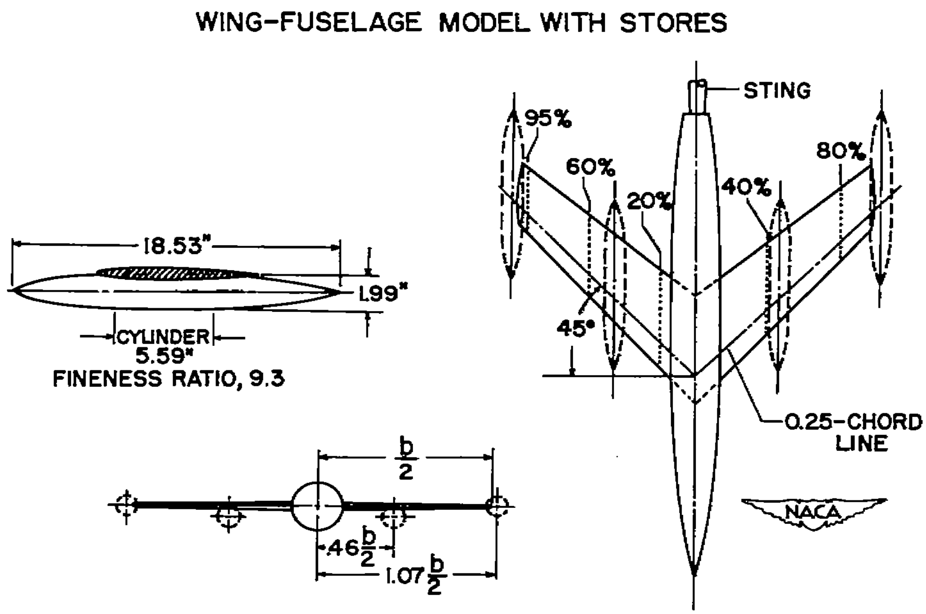

Figure 1.

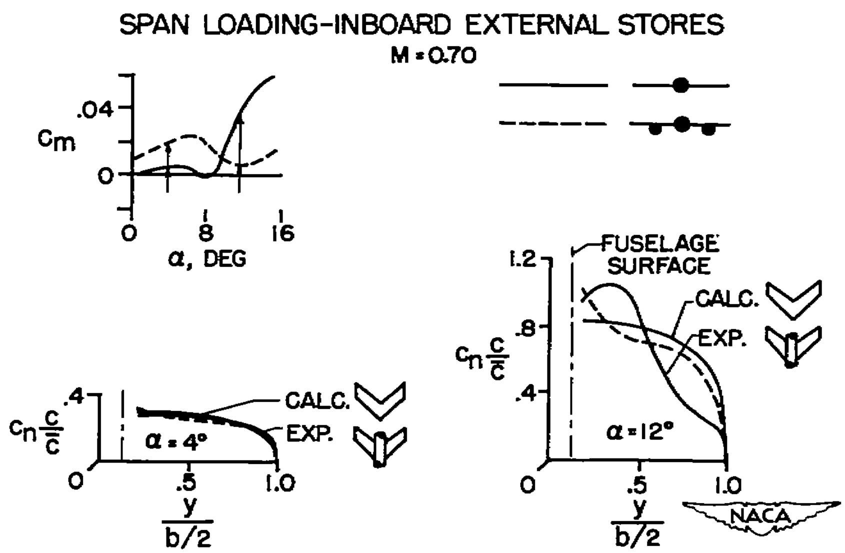

Figure 2.

PRESSURE DISTRIBUTION - INBOARD STORES

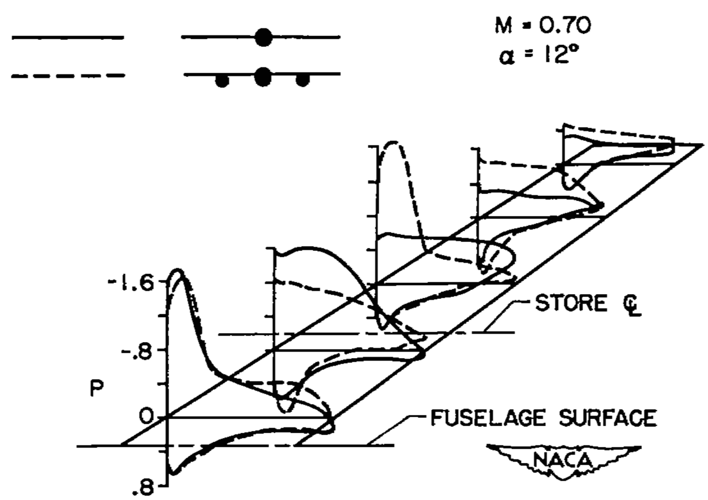

Figure 3.

SPAN LOAD - INBOARD EXTERNAL STORES

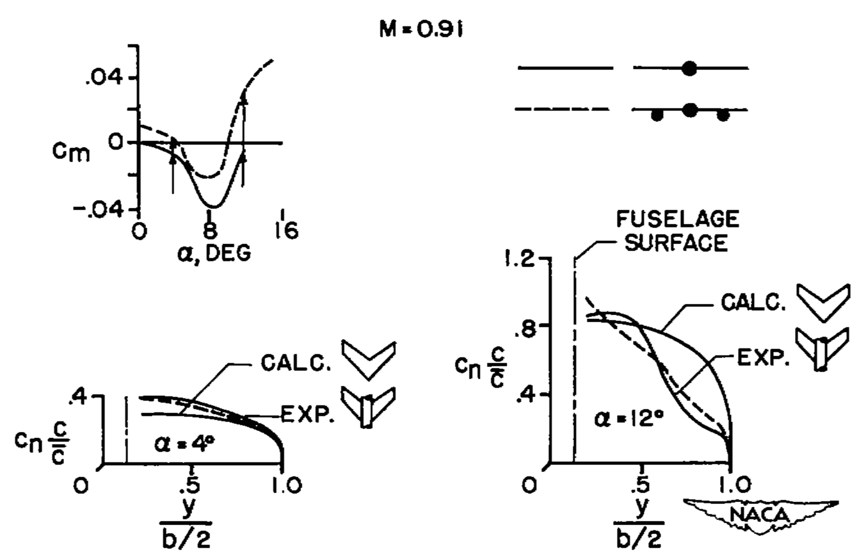

Figure 4.

PRESSURE DISTRIBUTION – INBOARD STORES

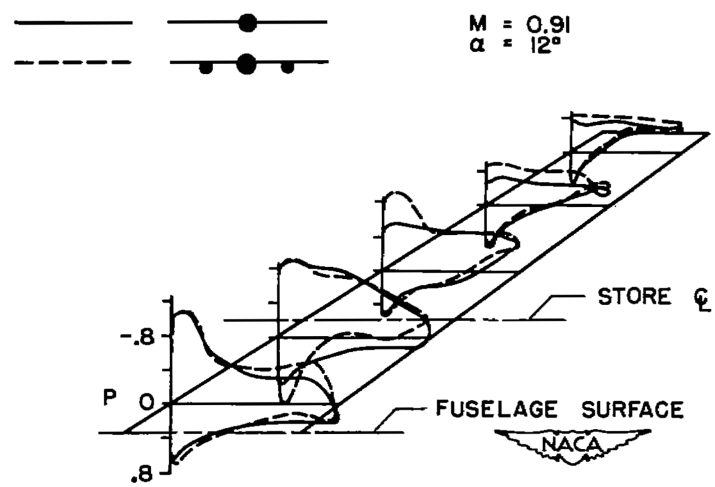

Figure 5.

SPAN LOADING–TIP EXTERNAL STORES

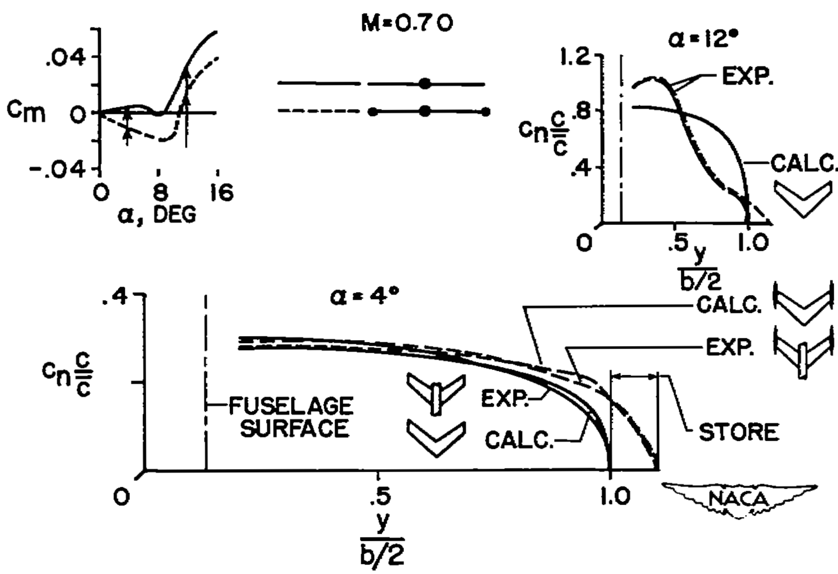

Figure 6.

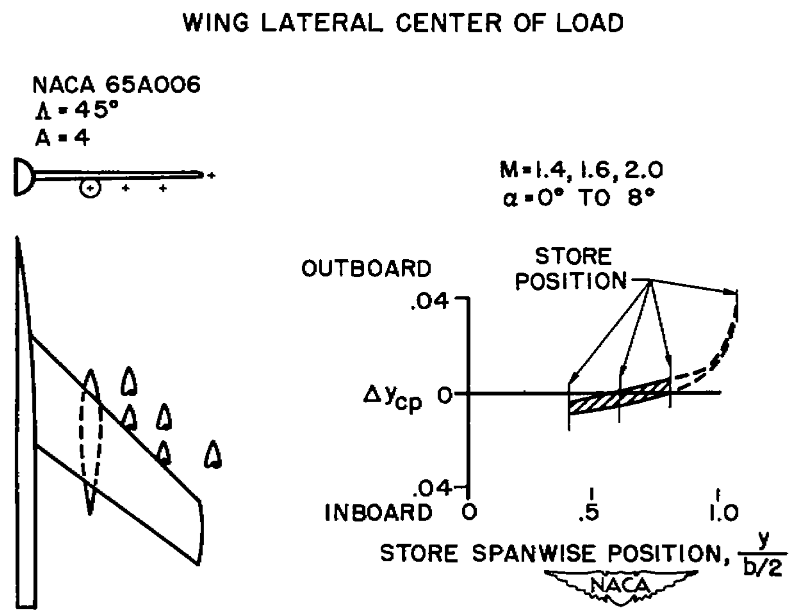

Figure 7.

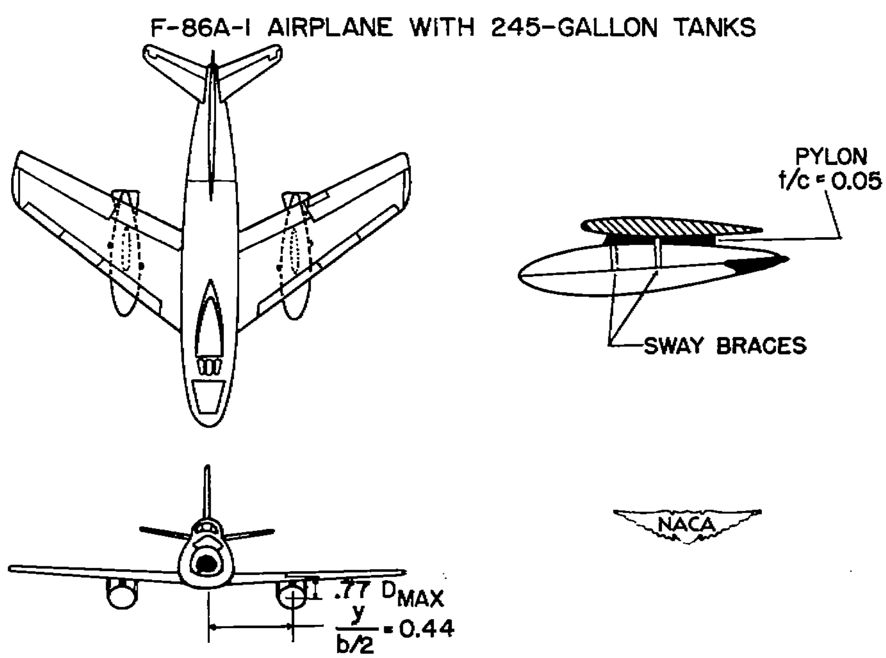

Figure 8.

FORCES ON 245-GALLON TANK

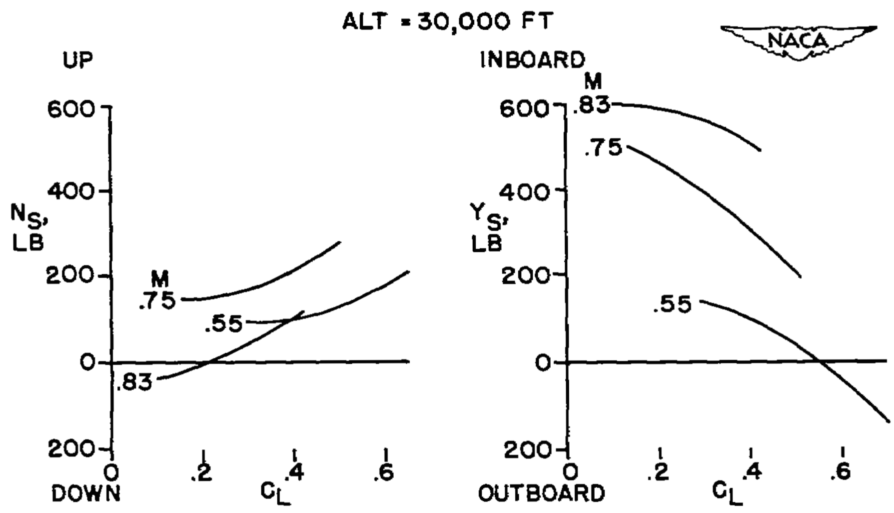

Figure 9.

WING-FUSELAGE MODELS WITH STORES

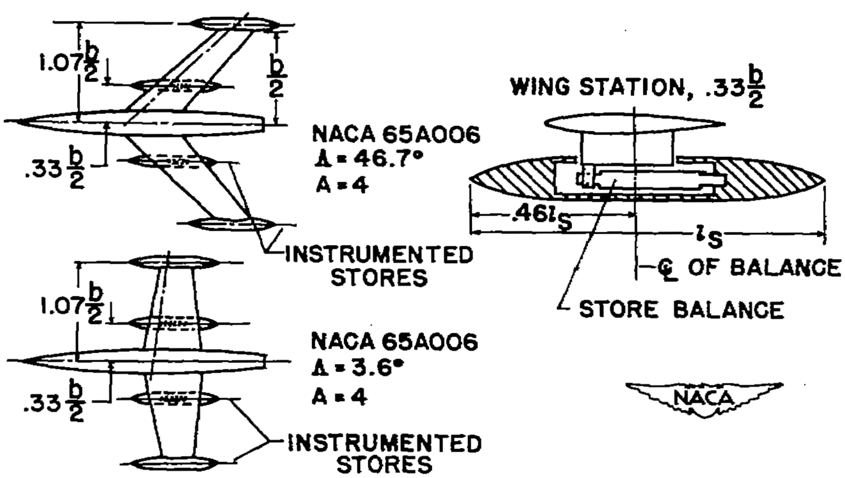

Figure 10.

LATERAL LOADS ON STORES

M = 0.50

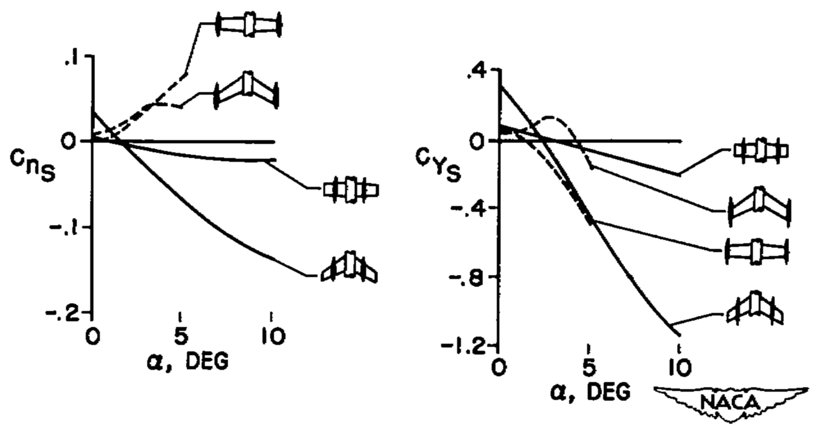

Figure 11.

NORMAL-FORCE LOADS ON STORES

M = 0.50

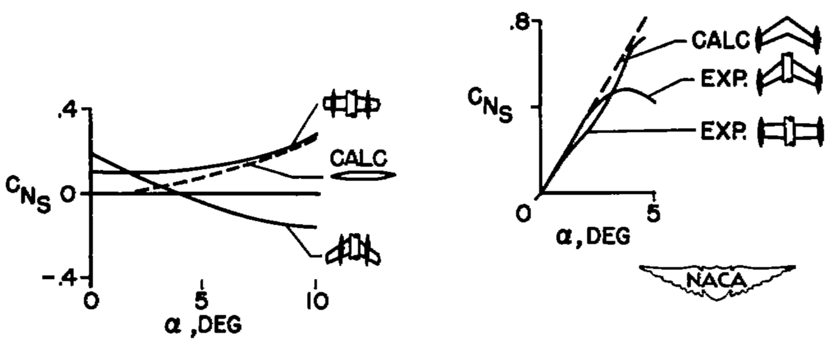

Figure 12.

PITCHING-MOMENT LOADS ON STORES

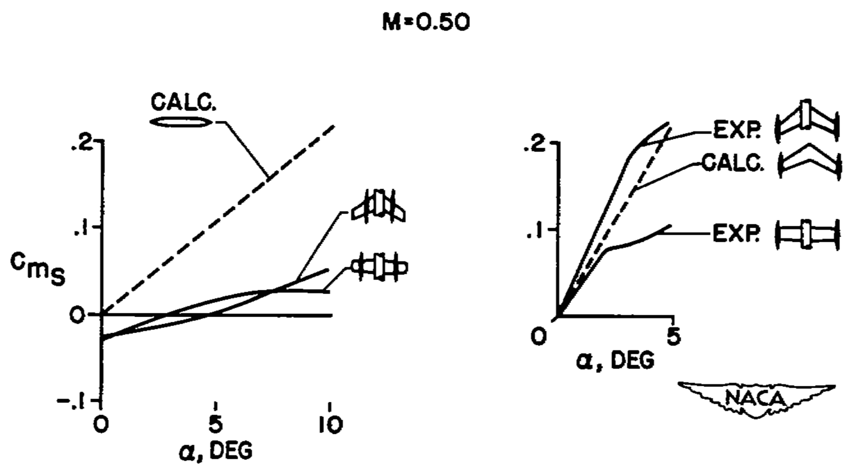

Figure 13.

MOMENT LOADS ON STORES

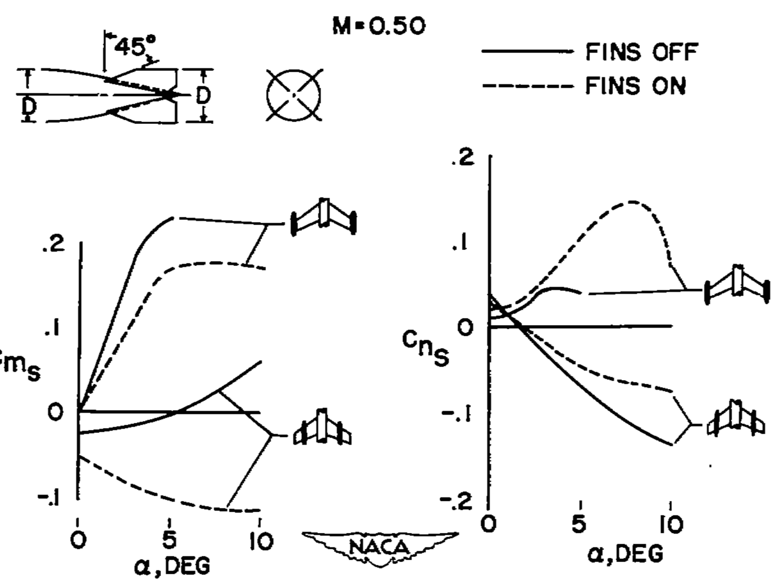

Figure 14.

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