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RESEARCH MEMORANDUM

LOADS ON EXTERNAL STORES AT TRANSONIC AND

SUPERSONIC SPEEDS

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SUMMARY

Results of recent wind-tunnel investigations of the loads on external stores at transonic and supersonic speeds have shown that the most critical store loading appears to be that due to the store side force, both because of its magnitude and because the force acts in the direction of the least structural strength of the pylon.

The magnitude of the side forces is determined principally by angle of attack, store position, and Mach number. Angle of attack and store positions are inextricably related since the rate of change of side force with angle of attack, which can be very large, is primarily a function of position. Also, at moderate angles of attack, the rate of increase of side-force coefficient with angle of attack for a given store position is essentially constant with Mach number. The effects of Mach number are shown principally in the values of the coefficient at small angles of attack. These values are strongly influenced by local flow angularities and the changes in flow behavior that occur at transonic and supersonic speeds.

INTRODUCTION

In providing for the use of external stores on high-speed aircraft the designer is faced with the problem of determining what factors exert the greatest influence on the development of critical store loading conditions and how the character of the loading conditions varies as the speed is increased from subsonic to supersonic Mach numbers.

Theoretical treatment of the problems is difficult because of the complexity of the flow field about an aircraft-store configuration. The initial approach, therefore, has of necessity been experimental. Until recently such experimental studies have been concerned either with specific design problems or with a limited range of variables such as angle of attack and Mach number.

The purpose of this paper is to show the relative importance of some of the factors which influence the development of critical loading conditions on external stores. Principally, the effects of angle of attack, Mach number, and to some extent store position for various wing plan forms will be examined in the speed range from subsonic to supersonic Mach numbers near 2.0.

The greater part of the data to be presented in this paper were obtained in the Langley 9- by 12-inch blowdown tunnel. Some results obtained in flight tests will, also, be presented.

SYMBOLS

C_Y store side-force coefficient, $\frac{\text{Store side force}}{qS_S}$

C_n store yawing-moment coefficient referred to $0.4l_S$, $\frac{\text{Store yawing moment}}{qS_S l_S}$

q free-stream dynamic pressure

S_S maximum frontal area of external store

l_S closed length of store

$\bar{c}$ mean aerodynamic chord of wing

c local wing chord

A aspect ratio of wing

$b/2$ semispan of model

λ taper ratio of wing

$\Lambda_{\frac{c}{4}}$ sweepback of wing quarter-chord line

β angle of sideslip for complete airplane measured with respect to free stream, or angle of skew of external store measured with respect to model plane of symmetry as shown in figure 5

α angle of attack measured with respect to free stream

M Mach number

RESULTS AND DISCUSSION

Figure 1 shows the geometry of the wing models and the store locations for which experimental data have been obtained at Mach numbers from 0.7 to 1.96. The Reynolds number based on store length was about 2.2×10^6. The store was tested at each of two spanwise positions on both the unswept and sweptback wings and two chordwise positions on the 60° delta wing. Only the more significant results of these tests have been selected for presentation.

The semispan wing models were cantilevered from a five-component strain-gage balance set flush with the tunnel wall. The store, which had a Douglas store shape and a fineness ratio of 8.6 based on the closed length, was cut off at 80 percent of its length to permit installation of an internal sting-supported balance. As shown by the cross-sectional views in figure 1, the pylons or struts were attached to the wings and separated from the store by an extremely small gap which is exaggerated in the figure. This gap was maintained constant while the angle of attack of the store and wing varied from -3° to 12°. Four components of the forces and moments on the store were measured simultaneously with measurements of the loads on the wing. Only the store loads, however, will be discussed in this paper.

Examination of the data indicated that the most severe problems were associated with side-force loads. Figure 2 illustrates the build-up of the side forces with angle of attack and with Mach number. The examples chosen represent practical store locations on each of two wings and illustrate the size of the forces that may very well be encountered. The side forces and yawing moments have been scaled up from the measured data to correspond to a 400-gallon store at an altitude of 40,000 feet. Loads are shown at angles of attack of 0° and 10°.

It should be pointed out that an angle of attack of 10° at $M = 2.0$ represents a $5\frac{1}{2}$g maneuver condition with a wing loading of 75 pounds per square foot. Such an acceleration is less than that which may be required of a fighter-type aircraft.

Figure 2 shows that in either example very large side forces are incurred at an angle of attack of 10° and supersonic Mach numbers. The magnitude of these forces presents a very serious problem since the direction of the force is in the direction of the least structural strength of the pylon.

The importance of yawing moments in establishing critical loads is not clear cut since the support stresses involved may be pretty much a function of the geometry of the configuration. It is worth noting, however, that for the largest yawing moments (which occurred at an angle of attack of 10° for the store in the presence of the delta wing) the center of pressure is three-tenths of the store length behind the store nose.

The normal forces, which are not shown, show only small variation with either angle of attack or Mach number and even at supersonic speeds are considerably less than the weight of the full fuel tank. It appears that the inertia forces in maneuvering flight will considerably outweigh the aerodynamic normal forces. In any event, providing structure for their support is much less difficult than in the case of the side forces.

Because of their magnitude and direction, the side forces will be treated exclusively in the balance of this paper.

Figure 3 shows the variation with angle of attack of store side-force coefficient based on store frontal area. Data are shown at Mach numbers of 0.75, 1.05, and 1.62 for each of two store locations in the presence of the unswept, sweptback, and delta wing.

This figure shows very large increases in the outward side force with increasing angle of attack for stores in the presence of all three wing plan forms. At moderate angles of attack, the curves are linear and for a given store position the slopes of the curves show remarkably small effects of Mach number even at transonic speeds. The effect of Mach number is shown principally at small angles of attack by the intercept variation. Note, for example, that, for the stores in the presence of the sweptback wing, the value of the intercept increases between Mach numbers 0.75 and 1.05 and then is negative at Mach number 1.62. Also, at small angles of attack, nonlinearities are evident in many of the curves, particularly those for the delta-wing stores. The nonlinearities and values of the coefficient at small angles of attack are strongly influenced by local flow angularities and by changes in flow behavior that occur at transonic and supersonic speeds. Details of the effect of flow angularities and the interferences of the wing flow field on store loads at subsonic speeds are given in reference 1. The nonlinear nature of the curves at low angles indicates considerable care must be exercised in using data obtained at low angles of attack to predict the side forces at higher angles of attack.

Large effects of store position on the side forces at moderate angles of attack are shown. In the case of the unswept wing, moving the store outboard greatly increases values of the coefficient at angle of attack for all Mach numbers. This is because the relieving effect of the wing tips on the pressure field under a wing in a lifting condition inclines the flow in the direction of the tips. The lateral component of the inclined flow increases in velocity as the tip is approached and, consequently, lateral forces on objects near the tips will be greater than on objects near the plane of symmetry. In fact, data presented at Mach numbers up to 0.9 in reference 2 have indicated that side forces on a store at 95 percent of the semispan may be twice as great as those indicated here.

Moving the store outboard on the sweptback wing shows the same general trends as for the unswept wing although the effects of spanwise position are somewhat obscured by the change in chordwise position relative to the wing itself.

Chordwise effects can be quite large as is shown for the delta wing. For the stores in the forward position but located some distance below the wing without pylons or supporting structure, the side forces are considerably less than those shown in figure 3. These data which are not shown indicate that there are powerful effects of blocking the laterally inclined flow between the store and wing surface just back of the wing leading edge.

It is interesting to note (see fig. 3) that although moving the store inboard reduces the rate of buildup of side force with angle of attack, the installation drag of the store is increased. Reference 3 has shown that the most favorable drag characteristics at supersonic speeds were obtained with the store located near the wing tip. However, of the two store positions shown for the 60° delta wing, the store at the rearward position showed the smallest installation drag (ref. 4) and also, as figure 3 shows, the smallest side-force loads at angle of attack.

More extensive treatment of the effects of store position on store loads at low angles of attack and supersonic speeds is given in reference 5.

The data presented so far have shown important effects of angle of attack, store position, and Mach number on store side forces. Details of the store installation and supports, however, are also important.

The store installations considered so far have been for stores located immediately adjacent to the wing lower surface. Figure 4 shows data for three configurations: a short pylon, a long pylon, and a condition with no pylon. Side-force and yawing-moment coefficients (based on the store frontal area and store closed length) for the store in the presence of the sweptback wing are plotted against angle of attack for three Mach numbers: 0.75, 1.41, and 1.96. For the store adjacent to both the short pylon and the long pylon, very little difference in the curves was found except at Mach numbers near 1.4. Similarly, in reference 2, at Mach numbers up to 0.9, increases in pylon length for stores as much as 1.6 diameters below the wing had only minor effects on the side-force variation with angle of attack. Figure 4 shows that removing the pylon, however, greatly reduced the rate of increase of side-force coefficient with angle of attack throughout the entire Mach number range. Similar effects of extending the pylon length and of removing it altogether have been found for the store at 0.80b/2 on the unswept wing. It appears that the pylon has a large aerodynamic effect on the store side forces and it is probable that large loads are carried on the pylon itself. The reasons for such large effects of the pylon are only partially understood and further investigation is necessary to clarify the problem. However, these data indicate the possibilities of substantial reductions in store side force through redesign or relocation of the pylon.

One way of reducing the side-force loads on a store for a given angle of attack would be to skew the store relative to the wing plane of symmetry. The results of this approach are shown in figure 5. Here side-force coefficient is plotted against angle of attack for three Mach numbers for the store in the presence of the sweptback wing. Data are shown for 0° and 5° angle of skew (as is defined in the upper left-hand corner of fig. 5). As might be expected, skewing the store 5°, nose inboard, resulted in a displacement of the curves at all Mach numbers but had no appreciable effect on the rate of increase of side-force coefficient with angle of attack.

It may be noted that between Mach numbers of 1.41 and 1.96 considerable displacement of the curves is shown for both the skewed and unskewed store. This large change with Mach number is attributable largely to the effects of the shock wave from the nose of the fuselage (which was considerably foreshortened in this particular model). In fact, this displacement was reduced 50 percent by extending the fuselage nose forward by an amount equal to one-half the store length. Incidentally, this variation has been confirmed by repeat tests. Although in some cases such variation may cause some difficulty, it still appears that side forces at a given angle of attack may be reduced over a large range of Mach numbers by skewing the store.

So far, only the effects on side forces of angle changes in the pitching plane have been considered. The more direct effects of sideslip angle when the complete aircraft as well as the store is yawed are also of interest. Figure 6 shows some information on these effects that were obtained in flight tests of an F-86 airplane. The store, which had a fineness ratio of 5, is shown in the upper part of this figure. The coefficients were obtained by integration of the pressure distributions on both store and pylon and are based on the store frontal area. The data shown for zero sideslip angle are given in reference 6 whereas the other results are unpublished.

Side-force coefficient is plotted against angle of attack on the left-hand plot of figure 6 and against sideslip angle on the right-hand plot for a Mach number of approximately 0.6. It can be seen that the rate changes due to angle of attack and angle of sideslip are about the same at 10° angle of attack and 4° angle of sideslip, respectively.

It is well to remember that the increase in side force with angle of attack becomes larger as the store is moved outboard. The increase with sideslip angle, however, may become larger as the store is moved inboard since the fuselage interference can considerably increase the loading due to sideslip angle.

It is worth mentioning that in these flight tests the effects of yawing, pitching, and rolling velocities on the aerodynamic store loads were determined. These effects, however, were small relative to the effects of the changes shown for angles of attack and sideslip.

The side forces on the pylon at both angle of attack and sideslip are much smaller than for the store. However, considering the size of the pylon relative to the store, they indicate that the forces on a larger pylon may be quite substantial.

CONCLUDING REMARKS

The results that have been presented have indicated the following conclusions:

The most critical loading on external stores at transonic and supersonic speeds appears to be that due to the store side force, both because of its magnitude and because the force acts in the direction of the least structural strength of the pylon.

The magnitude of the side forces is determined principally by angle of attack, store position, and Mach number. Angle of attack and store positions are inextricably related since the rate of change of side force with angle of attack, which can be very large, is primarily a function of position. Also, at moderate angles of attack, the rate of increase of side-force coefficient with angle of attack for a given store position is essentially constant with Mach number. The effects of Mach number are shown principally in the values of the coefficient at small angles of attack. These values are strongly influenced by local flow angularities and the changes in flow behavior that occur at transonic and supersonic speeds.

Langley Aeronautical Laboratory,
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Langley Field, Va., April 26, 1955.

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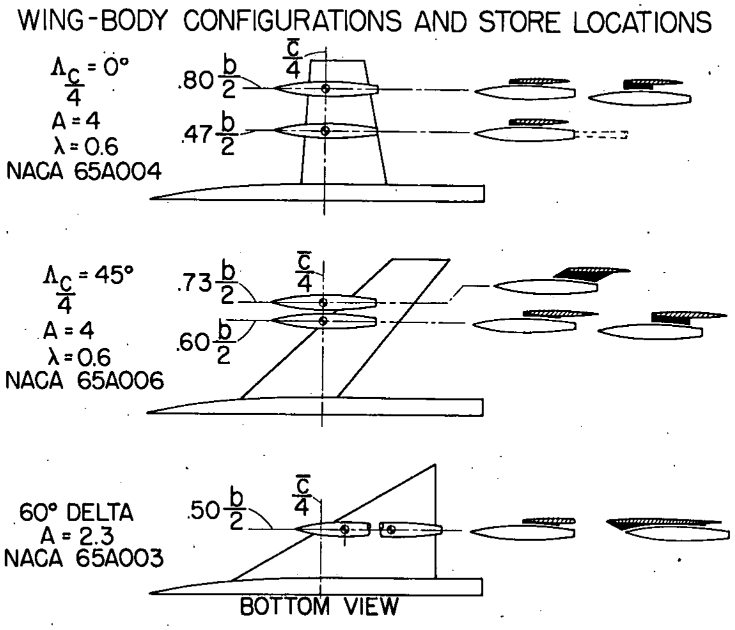

Figure 1

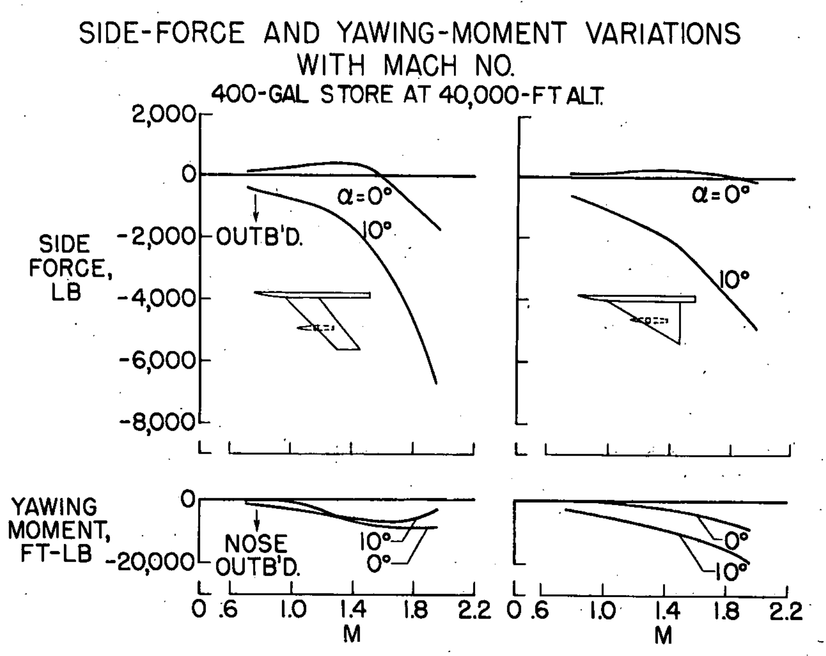

Figure 2

SIDE-FORCE VARIATION WITH ANGLE OF ATTACK

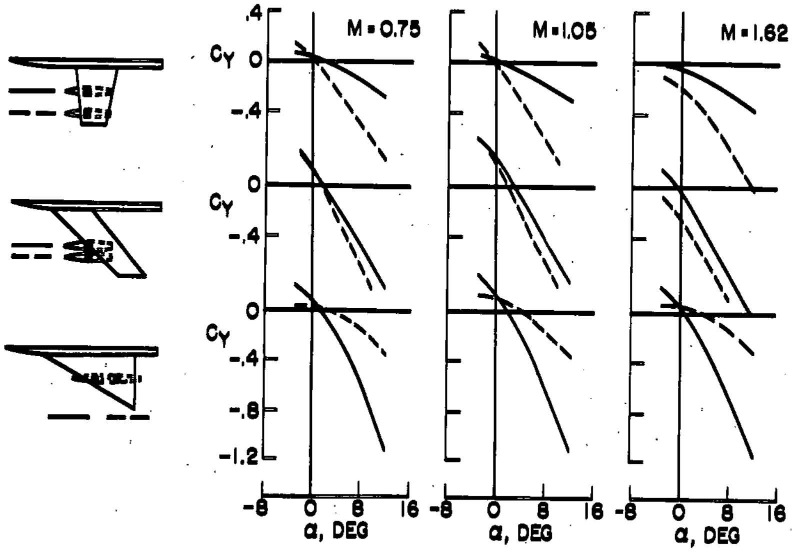

Figure 3

EFFECT OF STORE VERTICAL POSITION AND SUPPORT PYLON

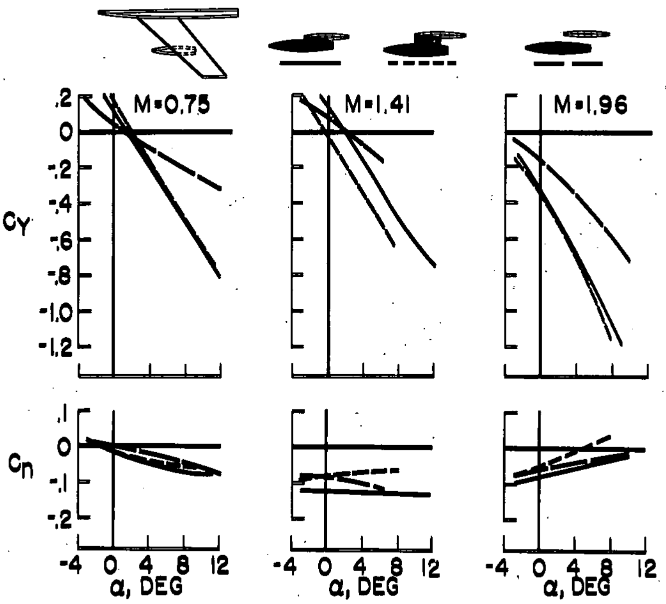

Figure 4

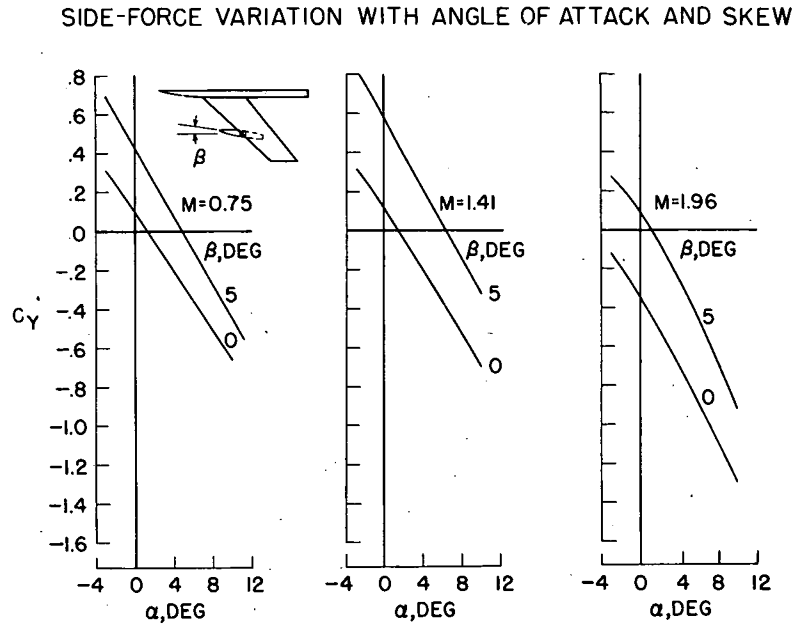

Figure 5

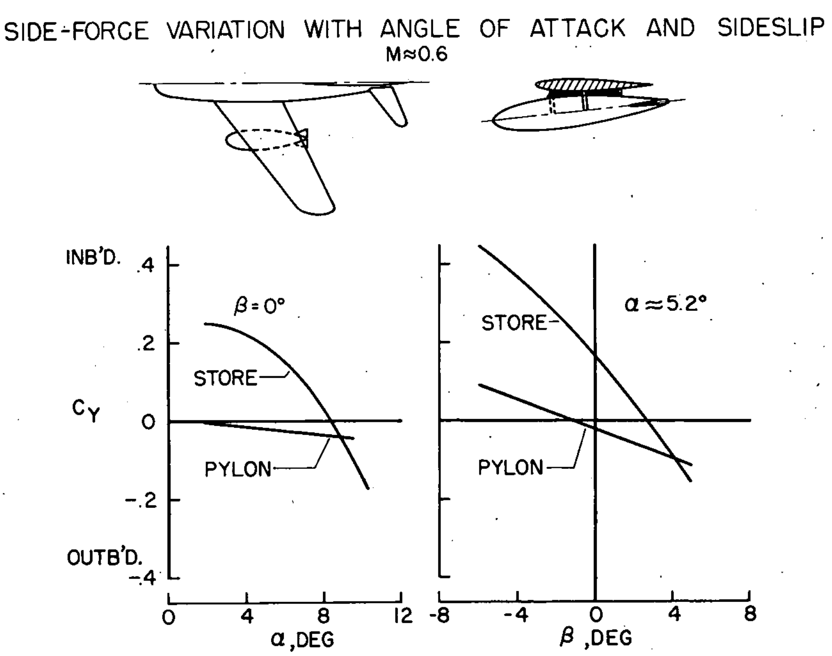

Figure 6