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CHARACTERISTICS OF A CONFIGURATION WITH A LARGE ANGLE OF SWEEPBACK

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A brief discussion is given of some recent experimental results obtained on a supersonic transport-type airplane for a large range of Mach numbers. The theoretical arguments which led to the configuration of this airplane were brought out at the NACA Conference on Supersonic Aerodynamics at the Langley Laboratory, June 19-20, 1947; hence, it will not be necessary to dwell on them herein. Briefly, our calculations showed that a reasonably good lift-drag ratio and, hence, reasonably good fuel economy, could be maintained up to a Mach number of 1.5. The configuration required would incorporate a long slender body and wings having a large angle of sweepback together with the highest practicable aspect ratio.

Figure 1 is a photograph of the model, designed to incorporate these features, tested in the Ames 1- by 3-foot supersonic tunnel and the Ames 1- by $3\frac{1}{2}$-foot tunnel. A maximum lift-drag ratio of better than 10 to 1 was expected with this configuration. The first experiments in the Ames 1- by 3-foot supersonic tunnel showed lower values but in these experiments there were indications of laminar separation over an appreciable portion of the wing surface at zero lift, a condition attributed to the low Reynolds number of the test and an effect of the sweepback. Since these first tests, lift-drag ratios as high as 9 to 1 at the low Reynolds numbers have been obtained by the use of some modifications of the original design. Instead of a flat symmetrical wing the revised model had a cambered, twisted wing designed to support a nearly uniform lift distribution at the cruising lift coefficient. Both the original and the revised model showed highest lift-drag ratio with the leading edge of the wing at 67° sweepback.

Figure 2 shows lift-drag ratio L/D plotted against lift coefficient C_L for the revised model in the Ames 1- by 3-foot supersonic tunnel. It will be noted that the characteristics are varying fairly rapidly with Reynolds number at the scale of these tests. At both Reynolds numbers, surface flow studies show regions of laminar separation on the wing at zero angle of attack. However, some recent experiments on a larger wing in this tunnel show that the laminar separation phenomenon disappears at higher Reynolds numbers; hence, it is believed that the calculated values can be reached or exceeded at full scale.

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In addition to tests of the revised model in the Ames 1- by 3-foot supersonic tunnel we have continued a variety of experiments on the original model. The object of the experiments is to define the behavior of this airplane over as wide a range of Mach numbers and Reynolds numbers as possible. This program is quite new and some of the preliminary results shown herein may be subject to later correction.

The most interesting result is the variation of drag coefficient C_D with Mach number M obtained in the Ames 1- by $3\frac{1}{2}$-foot tunnel and shown in figure 3. In these tests no drag rise occurred throughout the range of Mach numbers up to 1.5. Actually, of course, the supersonic drag is expected to be somewhat higher than the drag at subsonic speeds as indicated by the dashed-line curve, but the difference is small and in these tests might have been masked by Reynolds number effects. Although no claim is made for great accuracy of measurement in these tests, the value at $M = 1.5$ is in agreement with that obtained in the Ames 1- by 3-foot supersonic tunnel on the same model.

Although the minimum drag coefficient showed no appreciable change with Mach number, the lift-drag ratios obtained at supersonic speed were less than the subsonic values. Figure 4 shows the variation of maximum lift-drag ratio throughout the Mach number range as obtained from the Ames 1- by $3\frac{1}{2}$-foot tunnel. One fact brought out in these tests is that at low Reynolds numbers the lift-drag ratio values at subsonic speeds fall considerably below the usual estimates. At all speeds the rate of increase of drag with lift coefficient was greater than that indicated by the induced drag theory - a characteristic of separated flow. Evidently the laminar separation phenomenon noted earlier is not an effect of supersonic speed but is to be associated with the Reynolds number and the sweepback. Tests of the wing alone in the Ames 12-foot low-turbulence pressure tunnel at a higher Reynolds number showed values from 16 to 1 to 18 to 1, in the subsonic range.

The stability and control characteristics of this model are of great interest. One important question is to find how far the aerodynamic center travels within the range of flight Mach numbers. Unfortunately, data from different sources are not in very good agreement on this point as figure 5 indicates. This diagram shows the fore and aft location of the neutral-stability point superimposed on a plan view of the airplane drawn to the same scale and plotted against Mach number. The two test points at the ends of the curves are calculated values for the wing alone. The wing-flow tests

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showed a pronounced backward shift of the aerodynamic center, or, in other words an increase in stability, near a Mach number of 1; whereas the Ames 1- by $3\frac{1}{2}$-foot-tunnel tests indicated a gradual variation. Neither the Ames 1- by $3\frac{1}{2}$-foot tunnel nor the wing-flow tests indicated any rapid variation of lift in this region and their lift curves are in good agreement throughout. The reasons for the disagreement in pitching moment are not yet understood.

It seems to be a generally applicable rule that the wing forms designed for highest efficiency at supersonic speed show the poorest lifting qualities in the landing condition. High efficiency at supersonic speed is the result of achieving insofar as possible a two-dimensional flow over the oblique wing. In a perfect two-dimensional flow the stalling lift coefficient is reduced by the cosine-squared of the sweep angle. With 60° sweep this means that the wing sections will stall at one-fourth their normal lift coefficient.

Figure 6 is taken from data obtained on a large model in the Ames 40- by 80-foot tunnel and illustrates this stalling behavior. A peculiarity of the behavior of these wings is that the initial flow separation is not accompanied by a loss in lift - in the present case the lift kept increasing up to nearly 45° angle of attack. This increasing lift can hardly be utilized in practice, however, because of the high drag and the erratic center-of-pressure travel associated with the separated flow. It will be noted that in the full-scale tests the drag curve follows the normal induced drag law up to a lift coefficient C_L of about 0.3. Beyond 0.3 the resultant force begins to fall back toward the normal to the chord, indicating a loss in the suction force at the leading edge as a result of separation. At this point, $C_L = 0.3$, also the pitching-moment coefficient C_M begins to depart from the values calculated for a potential flow. Other characteristics of the wing show similar nonlinear behavior beginning at this point, which corresponds approximately to the section $c_{l_{max}} \cos^2\Lambda$.

Because of the high sinking speed, or the large amount of power required for level flight, and because of the nonlinear stability characteristics, the airplane could probably not be flown safely above this initial stalling lift coefficient. The obvious remedy for this situation is of course to straighten out the wings for landing. However, the low useable lift coefficient and higher landing speed of the sweptback wing are not believed to present

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any unsurpassable difficulty. Through the use of Handley Page slots or nose flaps the landing lift coefficient can probably be increased to 0.5 or 0.6. Higher lift coefficients than this do not result in any decrease of the power or thrust required to maintain a given sinking speed unless the aspect ratio is increased. Conventional airplanes have already exceeded the speed at which landings can be made safely without power. In the present case a wing loading of 40 pounds would result in a landing speed of 165 miles per hour and a relatively small amount of thrust would be required to maintain a sinking speed below 20 feet per second.

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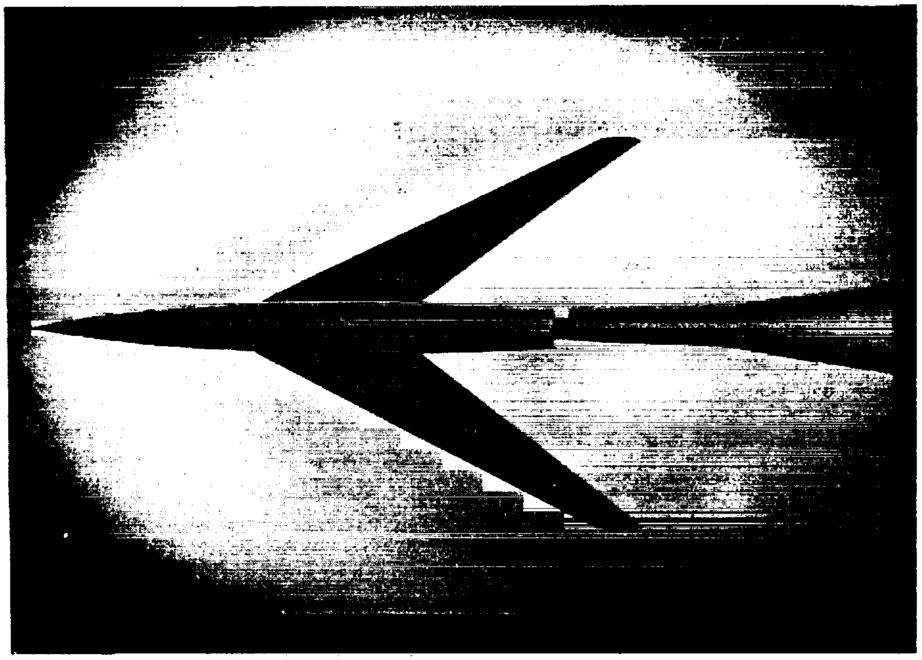

Figure 1.- Original model tested in Ames 1- by 3-foot supersonic tunnel and Ames 1- by $3\frac{1}{2}$-foot tunnel.

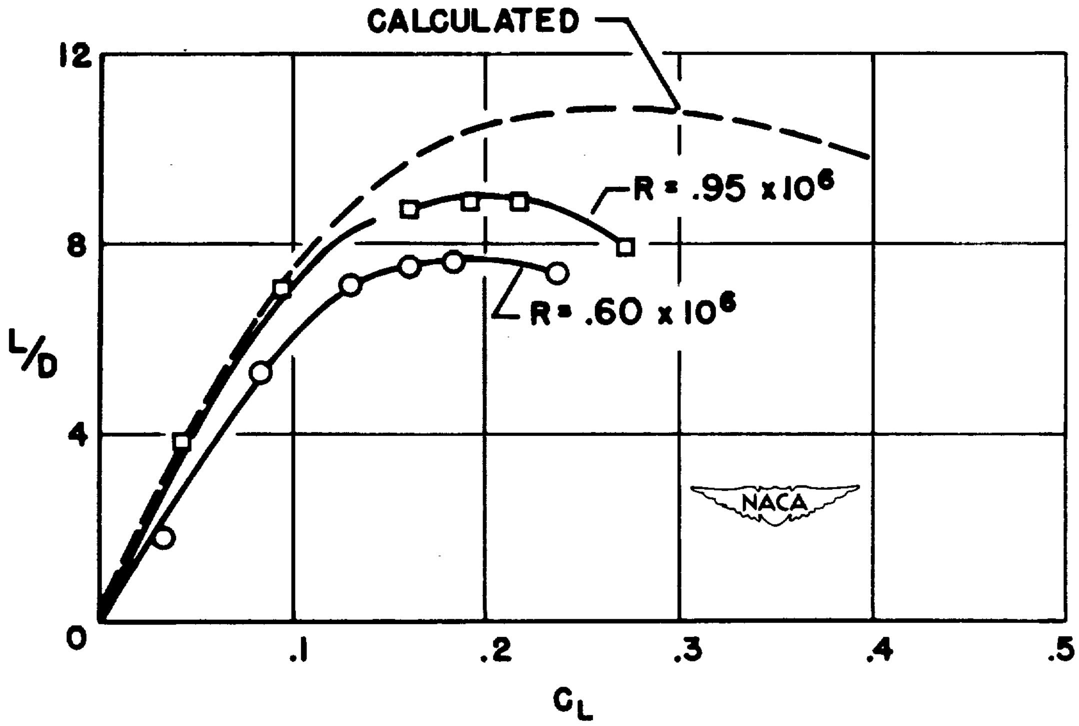

Figure 2.- Lift-drag ratio plotted against C_L for revised model in Ames 1- by 3-foot supersonic tunnel.

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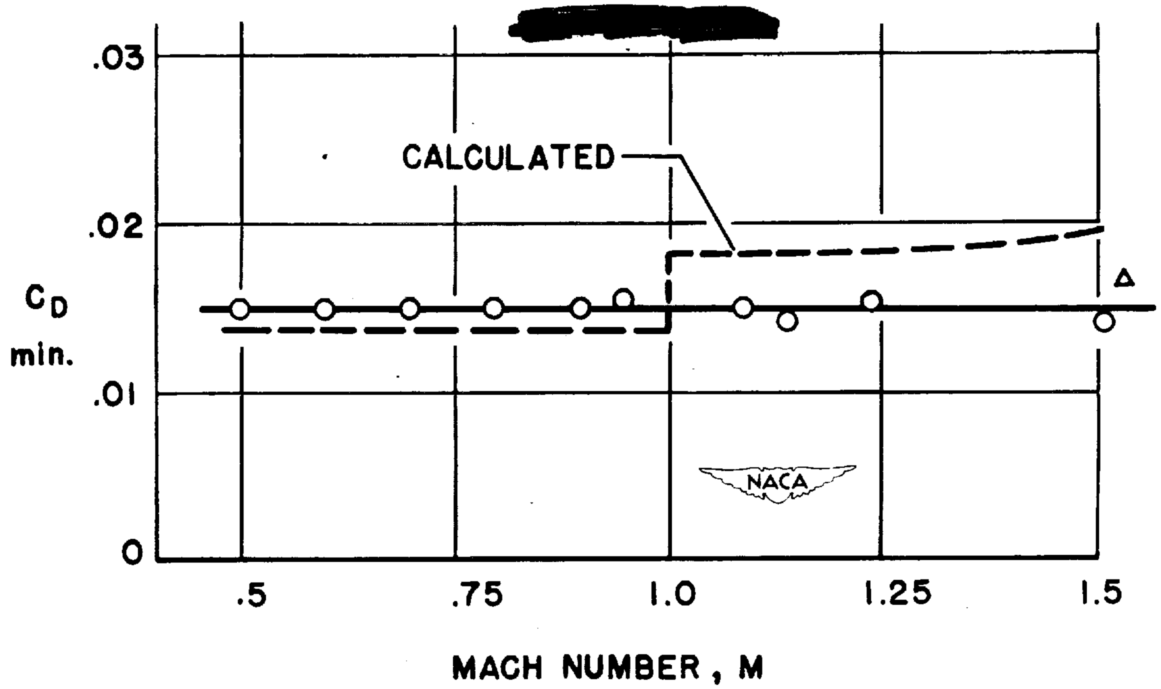

Figure 3.- Variation of drag coefficient with Mach number for original model.

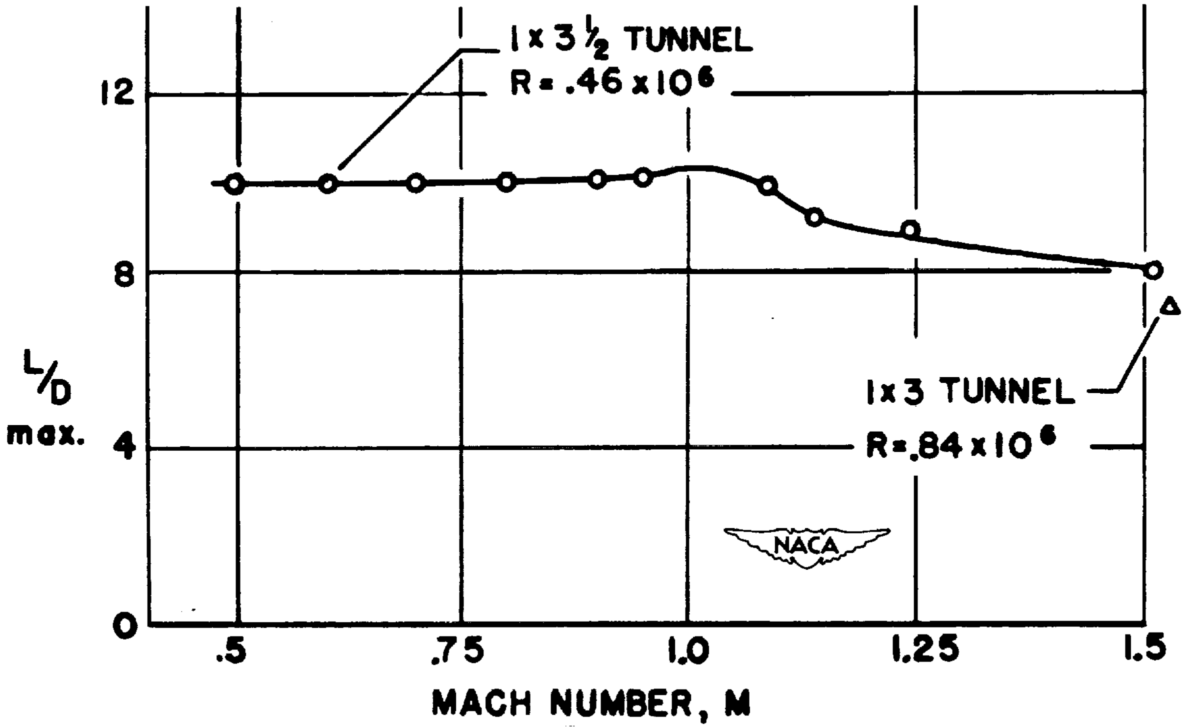

Figure 4.- Maximum lift-drag ratios plotted against Mach number for original model.

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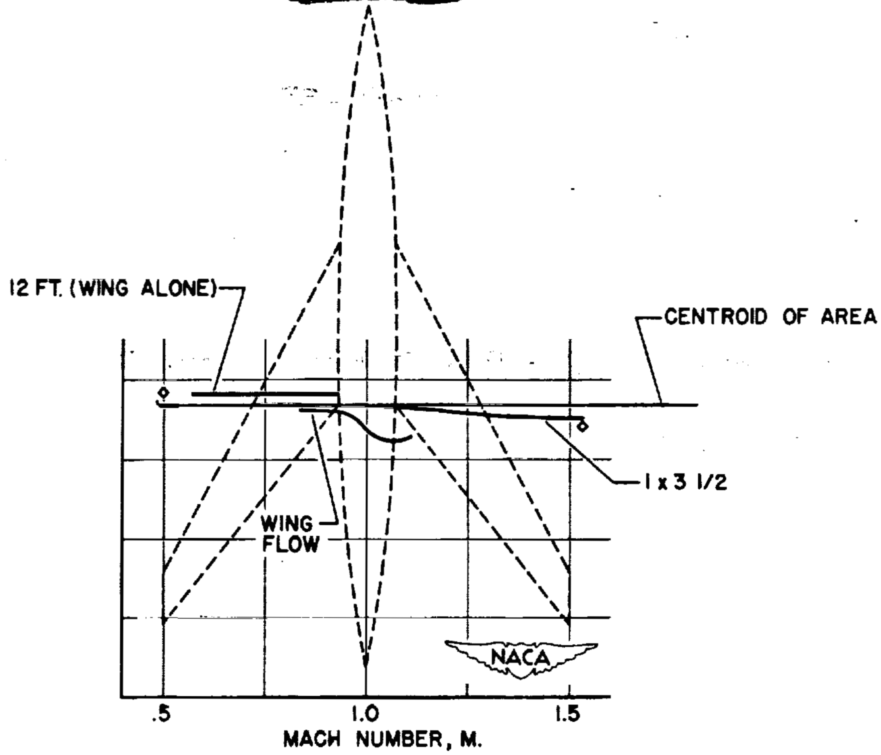

Figure 5.- Positions of aerodynamic center at various Mach numbers.

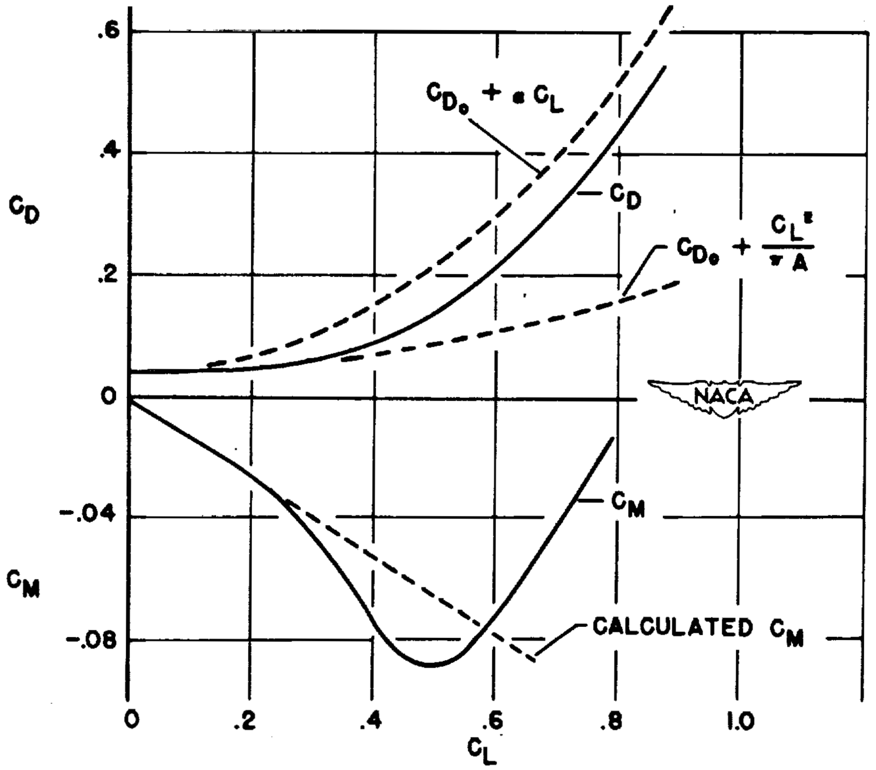

Figure 6.- Variation of drag and pitching-moment coefficients with lift coefficient from tests in Ames 40- by 80-foot tunnel.

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