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MEMORANDUM

SEVERAL METHODS FOR REDUCING THE DRAG OF TRANSPORT CONFIGURATIONS AT HIGH SUBSONIC SPEEDS

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Langley Field, Va.

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SEVERAL METHODS FOR REDUCING THE DRAG OF TRANSPORT CONFIGURATIONS AT HIGH SUBSONIC SPEEDS

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SUMMARY

Results of investigations of several promising methods for alleviating the drag rise of transport configurations at high subsonic speeds are reviewed briefly. The methods include a wing leading-edge extension, a fuselage addition, and additions on the wing. Also, results are presented for a complete, improved transport configuration which incorporates the fuselage and wing additions and show that the improved configuration could have considerably higher cruise speeds than do current designs.

INTRODUCTION

The cruise speeds of the current subsonic jet transports are limited by the severe drag rise of these airplanes as they approach the speed of sound. Numerous design variations for delaying and reducing this drag-rise have been investigated in past years. Also, a number of new variations have been studied relatively recently. To provide an indication of possible future improvements of the performance of subsonic transports, results for some of the more promising of these recent modifications are described in the present paper. The variations discussed include some which might be incorporated in existing transport configurations without excessive redesign or modification and others of more complex nature which could probably be incorporated only in new transport designs.

DRAG-RISE PHENOMENA

An indication of the magnitude of the increase in drag at high subsonic speeds is illustrated by the wind-tunnel results presented in figure 1. Presented in this figure is the variation of drag coefficient C_D with Mach number M for a configuration similar to the current jet transports. The wing has 35° of sweep and an aspect ratio of 7. The results are presented for a lift coefficient C_L of 0.3, which is near the values for cruise of the current jet transports. As may be seen, the drag coefficient starts to rise at Mach numbers somewhat above 0.80. At a Mach number of 0.92, the drag coefficient is twice that at the lower speeds. For most of the current jet transports, the maximum Mach numbers are limited to approximately 0.88, while the speeds for reasonably efficient cruise are somewhat less than this value.

At the lift coefficients normally utilized for jet transports, the drag rise results primarily from separation of the boundary layer on the upper surface of the wing induced by the presence of a shock wave associated with the development of a local region of supersonic flow above the wing. The boundary-layer separation phenomenon is illustrated in figure 2. Shown in this figure are flow patterns in a thin film of oil on the upper surface of the wing of the configuration shown in the previous figure for a Mach number of 0.88 at a lift coefficient of 0.4. The film of oil is made visible through illumination by ultraviolet light. The flow of oil conforms with the local flow in the boundary layer and provides an indication of the nature of that flow. (See ref. 1.) The sharp change of the oil thickness along the midchord of the sections indicates the initiation of boundary-layer separation. The outward flow of oil on the rearward portion of the wing indicates a boundary-layer flow that is typical of separation on a sweptback wing.

METHODS OF IMPROVEMENT

To provide improvements in the drag at high subsonic speeds, the shock-induced boundary-layer separation on the wing must be reduced. The more significant means for accomplishing this action are as follows:

- Direct boundary-layer control
  - Fences
  - Vortex generators
  - Suction or blowing

- Reduction of shock strength
  - Wing modifications
    - Additional sweep
    - Reduced thickness ratio
    - Redistribution of camber
    - Leading- or trailing-edge extensions
  - Fuselage changes
    - Streamline contouring
    - Area-rule shaping
    - Concentrated additions
  - Additions on wing

The methods may be divided into two broad groups: First, those which provide a direct action on the boundary layer and, second, those which reduce the strength of the shock wave, with a resulting alleviation of separation. The methods of the first group usually provide only relatively small reductions of shock-induced separation. Therefore, the discussion presented herein will be limited to methods for reducing the strength of the shock wave. Of the various methods listed, results will be presented for the wing extensions, fuselage additions, and additions on the wing.

Wing Modifications

The most powerful means of reducing the shock strength is wing sweep. (See ref. 2.) However, for the wings used for subsonic transports, large amounts of sweep normally result in very severe pitch-up. Thus, the sweep angles used for the current transports have been limited to moderate values. The shock strength may also be reduced by reducing the thickness ratio of the wing (ref. 3) and modifying the camber distribution (ref. 4). Each of these wing changes normally would require a complete redesign of the wing. For existing wing designs, improvements in these wing parameters may be obtained effectively by adding leading-edge and trailing-edge extensions to the basic wing structures. Results obtained for such a leading-edge extension on a wing with 40° of sweep are presented in figure 3. The extension was 20 percent of the chord at the wing-fuselage juncture and tapered to zero at the 50-percent-semispan station. It may be seen that the extension provides a significant delay of the drag rise at a lift coefficient of 0.3. However, such a modification also results in an adverse effect on the pitch-up similar to that obtained for a moderate increase in wing sweepback.

Fuselage Changes

Among the changes of fuselage shape to reduce the shock strength are those which provide a fuselage contour which is alined with the streamlines of the flow over a sweptback wing (ref. 5) and those which improve the longitudinal area distribution for the airplane on the basis of the area rule (ref. 6). For configurations similar to subsonic transports, these fuselage contours provide moderate delays in the drag rise (refs. 3 and 7); however, these shapes have not as yet been utilized in transport designs, since the improvements have not justified the structural complexity involved. More recently, a fuselage addition for reducing the shock strength which does not involve such severe problems of application has been investigated. (See ref. 8.) This addition, which is concentrated on the forward portion of the top of the fuselage (fig. 4), provides a desired fuselage camber as well as improving the area distribution. The basic configuration is the same as that shown in figure 1. The fuselage addition results in a delay in drag rise approximately the same as that provided by the more extensive streamline contouring or normal area-rule shaping.

Additions on Wing

Changes described in the previous section generally provide a significant reduction of separation on the inboard sections of a wing but result in little reduction of separation on the outer regions of the high-aspect-ratio wings normally utilized for subsonic transports. In order to reduce the separation on these regions, special bodies added to the wing, as shown in figure 5, have been proposed. (See ref. 9.) These bodies might be added to an existing configuration or incorporated in a new design. The bodies are entirely above the wing as shown in the cross section in figure 5 and extend from near the leading edge of the wing to beyond the trailing edge. The noses of the bodies decelerate the local supersonic flow ahead of the shock wave standing above the wing and thus reduce the strength of this wave. Results of an investigation of the effect of the bodies on the drag coefficient for the wing-fuselage combination of the configuration shown in figure 1 are shown in figure 5. The additions provide a considerable reduction of the drag at high subsonic speeds at a lift coefficient of 0.3. The reduction of the boundary-layer separation associated with this reduction of drag is illustrated by comparison of the surface oil flow for the configuration with the bodies (fig. 6) with that for the configuration without the added bodies (fig. 2). With the bodies added, the sharp change of oil thickness and the strong outflow of oil associated with boundary-layer separation on the basic wing are essentially eliminated.

The bodies added to the wing (fig. 5) also provide marked alleviation of the pitch-up for swept wings throughout the Mach number range. This effect is illustrated in figure 7, which presents the variation of pitching-moment coefficient C_m with lift coefficient C_L at a Mach number of 0.88 for the configuration just discussed with and without the added bodies. The curve for the configuration without the added bodies has a severe break in the slope near a lift coefficient of 0.3. Such a break would usually result in pitch-up for an actual airplane. With the bodies added, this adverse break is eliminated.

IMPROVED CONFIGURATION

In order to demonstrate the improvements in drag at high subsonic speeds that might be obtained for a new transport design incorporating several of the devices just described, a configuration representative of such a design has been investigated recently. The test configuration is shown in figure 8. An addition has been attached to the top, forward portion of the fuselage. Six bodies have been added to the wing. The four inner bodies have been made sufficiently large to enclose engines. The air inlets for engines placed in these bodies would be near the leading edge of the lower surface of the wing. However, no inlets are incorporated in the model investigated. Placement of the engines in these fairings, of course, eliminates the drag of the engine installation in the normal underslung location. This drag may be relatively large at the higher subsonic speeds.

The sweep of the improved configuration of figure 8 has been made 45°. The significant alleviation of the pitch-up of sweptback wings provided by the added bodies considerably relaxes the limitation on wing sweep previously imposed by these adverse changes. With the use of these bodies, sweeps considerably greater than the 30° or 35° used for current transports should be practical. The aspect ratio of the configuration is 7, which is approximately the value for most current transports. The thickness of the wing varies from 11.5 percent of the chord at the root to approximately 7.5 percent of the chord at the 50-percent-semispan station with a thickness of 7.5 percent of the chord from that station to the tip. The wing is cambered to obtain a lift distribution which should provide good high-speed characteristics at a lift coefficient of 0.3.

In figure 9, the variation of drag coefficient with Mach number at a lift coefficient of 0.3 for this improved configuration is compared with that for the representative current configuration of figure 1. At high subsonic speeds, the drag characteristics for the improved configurations are markedly superior to those for the current design. These improvements in drag should result in considerably higher cruise and maximum speeds. With the same relative thrust of the current transports, the improved configuration could fly at or very near the speed of sound. The stability characteristics throughout the speed range and the maximum lift at low speeds for the improved configuration are satisfactory. However, although such a configuration offers possibilities for markedly improving aerodynamic characteristics, the design of an actual transport airplane based on such a configuration would, of course, require consideration of a number of other important factors.

CONCLUSIONS

Results have been presented which indicate that a wing leading-edge extension, a localized addition on the fuselage, and additions on the wing can provide significant reductions of the drag rise at high subsonic speeds for configurations similar to current subsonic jet transports. Such additions possibly could be incorporated into current transports, without excessive redesign, to provide some increases of the cruise speeds for these configurations. Utilization of the fuselage and wing additions in new, improved designs should result in subsonic transports with considerably higher cruise and maximum speeds.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 6, 1958.

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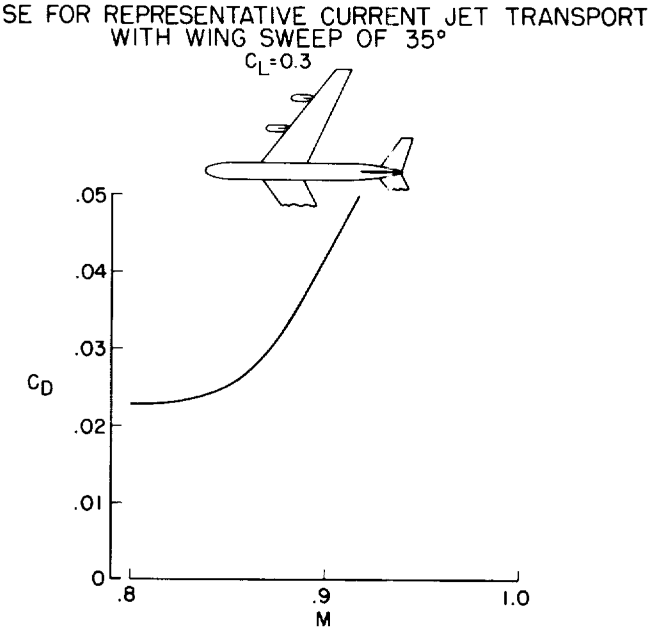


Figure 1

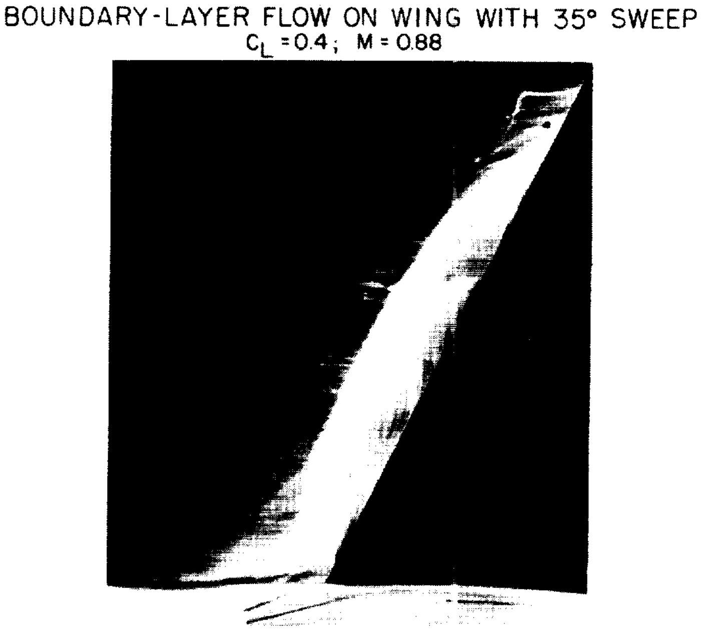
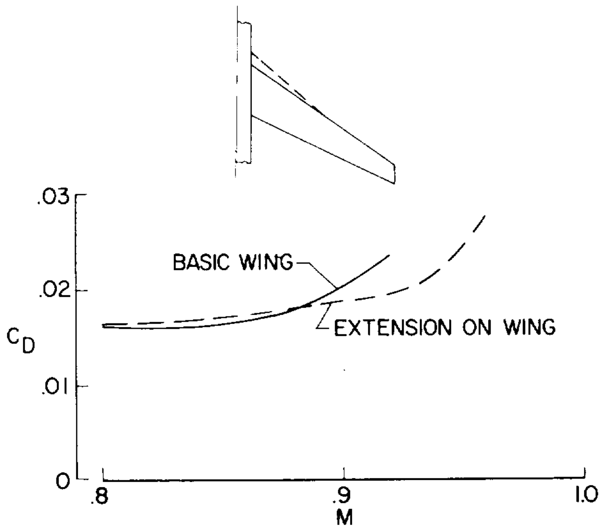
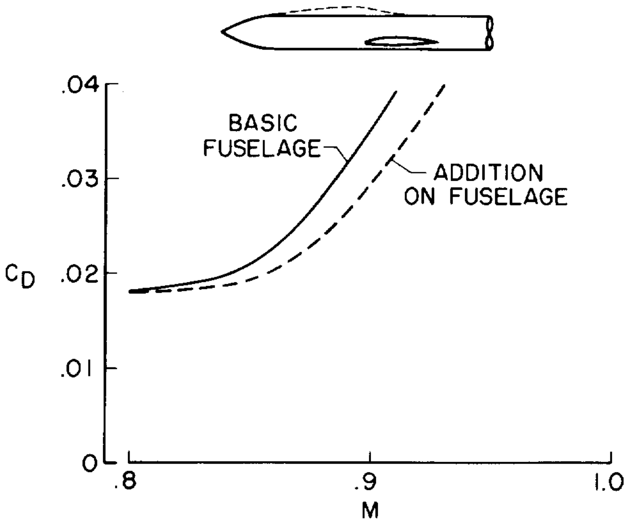


Figure 2 L-58-165



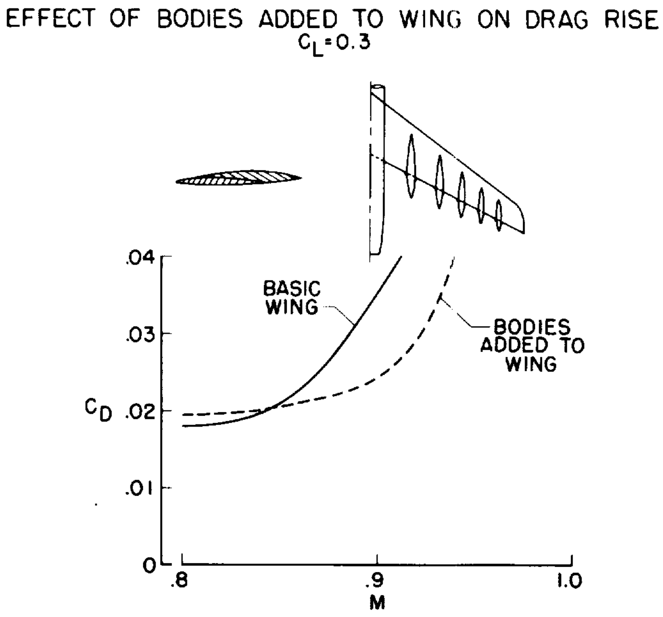
EFFECT OF WING LEADING-EDGE EXTENSION ON DRAG RISE
$C_L = 0.3$

Figure 3



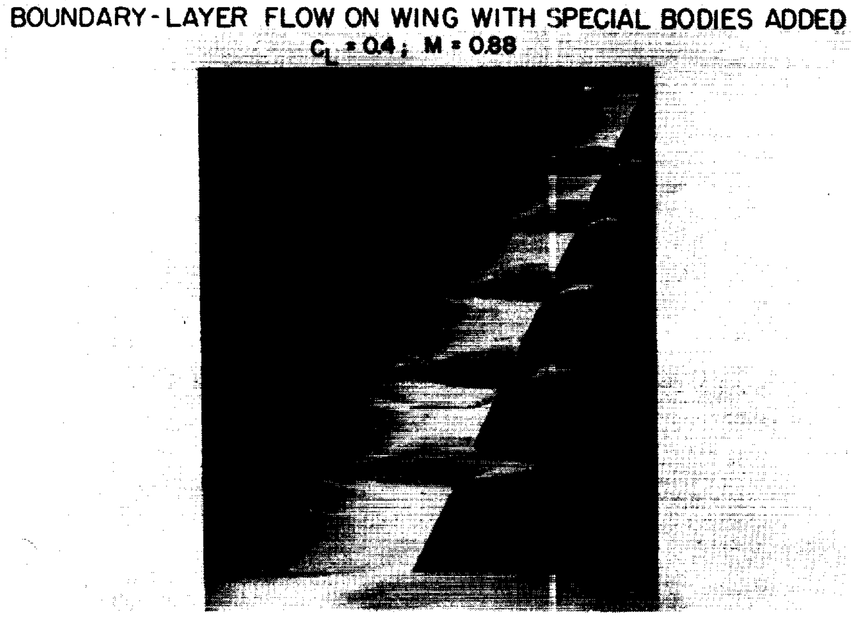
EFFECT OF FUSELAGE ADDITION ON DRAG RISE
$C_L = 0.3$

Figure 4



EFFECT OF BODIES ADDED TO WING ON DRAG RISE
$C_L = 0.3$

Figure 5



BOUNDARY-LAYER FLOW ON WING WITH SPECIAL BODIES ADDED
$C_L = 0.4$; $M = 0.88$

Figure 6

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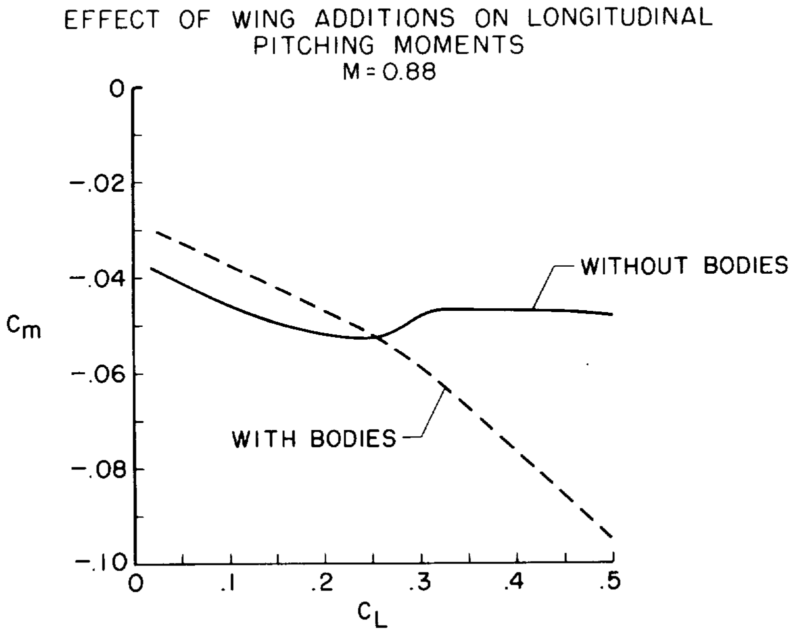

Figure 7

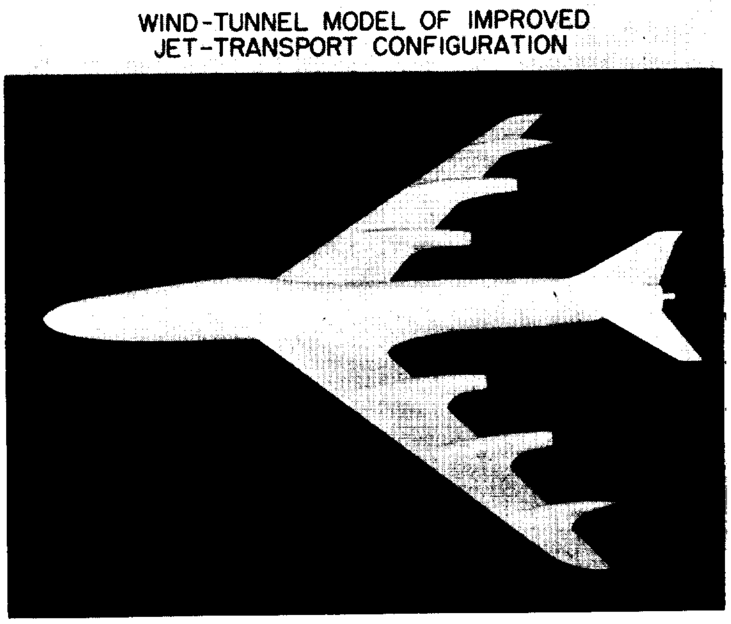

Figure 8

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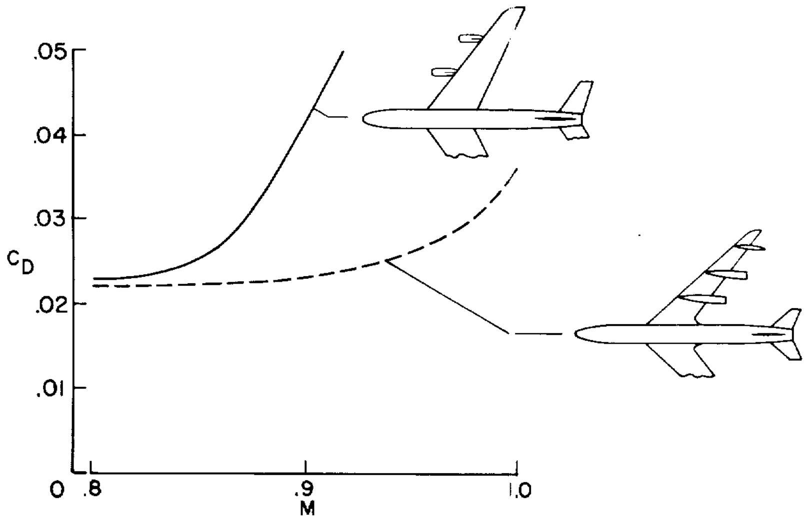

COMPARISON OF DRAG RISE FOR CURRENT AND IMPROVED JET-TRANSPORT CONFIGURATIONS

$C_L = 0.3$

Figure 9

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