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NATURAL LAMINAR FLOW NACELLE FOR TRANSPORT AIRCRAFT

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[redacted] PURPOSE OF TEST

Conceptually, a nacelle designed to have laminar flow over a significant portion of its length should provide a substantial reduction in the installed drag of the engine/nacelle/pylon of transport airplanes. While many factors may make the attainment of laminar flow on nacelles difficult, the magnitude of the reduction in installed drag and the corresponding increase in airplane performance makes research in this area of interest. Therefore, the Propulsion Aerodynamics Branch at the NASA Langley Research Center has undertaken, in cooperation with the General Electric Company, a research program to study the potential of laminar flow nacelles for reducing installed engine/nacelle drag.

The purpose of this research program was twofold: (1) to experimentally verify a method for designing laminar flow nacelles and (2) to determine the effects of installation on the extent of laminar flow on the nacelle and on the nacelle pressure distributions. The procedures used to accomplish these objectives were:

1). Analytical design a nacelle that had a pressure distribution favorable for the maintenance of laminar flow.

2). Verify this nacelle design experimentally by measuring the pressure distributions on an uninstalled flow-through-nacelle model and through flow visualization techniques determine the location of transition.

3). Following successful completion of steps 1 and 2, analytically design a nacelle and pylon installed on a high wing transport configuration. The design criteria was that the installed nacelle have essentially the same pressure distribution as the uninstalled nacelle.

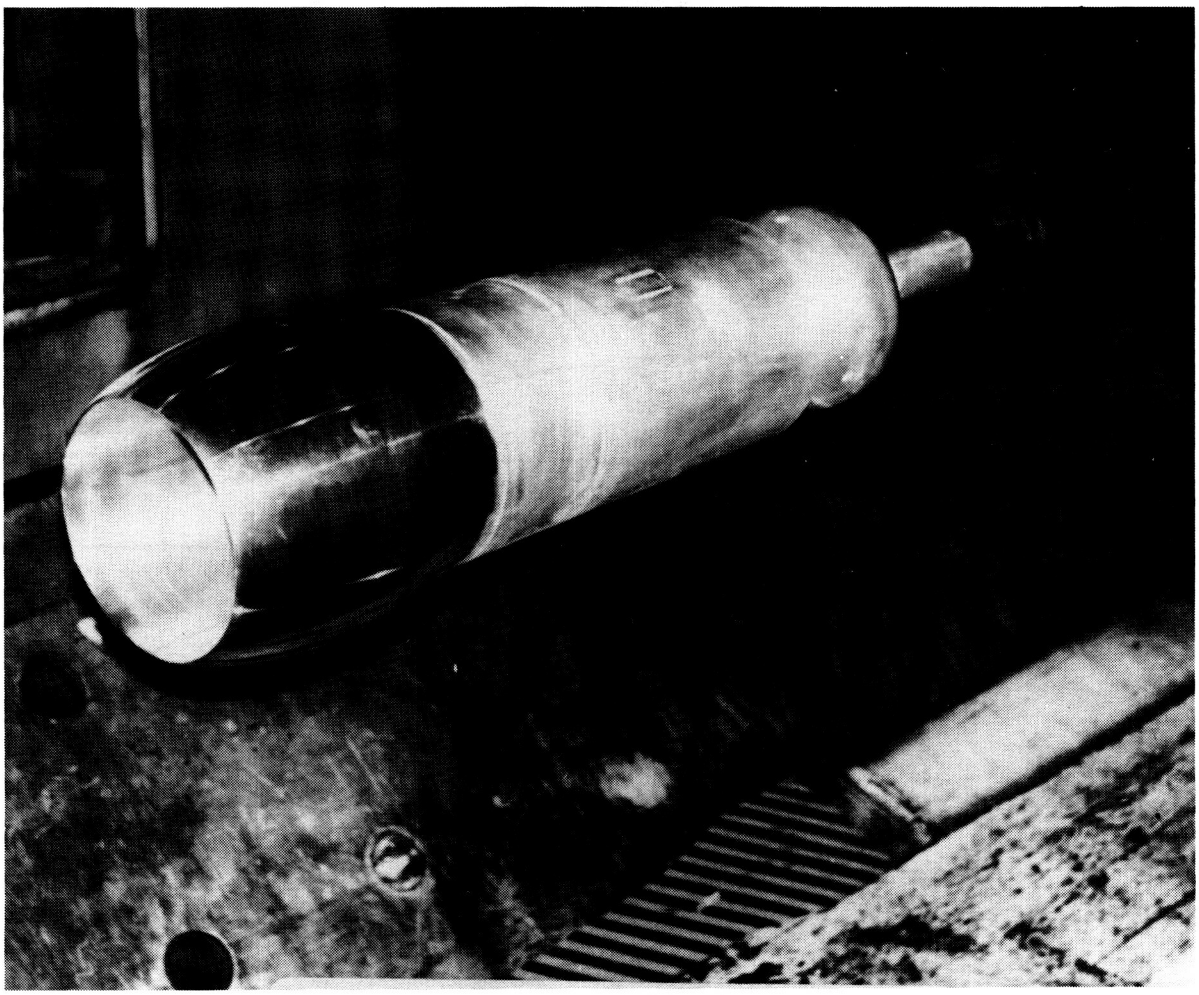
4). Determine experimentally whether the installation of the nacelle on the high wing transport produced the predicted pressure distributions and also determine if the installation causes premature transition.

The analytical designs were developed by the General Electric Company. The experimental investigations were conducted in the Langley 16-Foot Transonic Tunnel. The tests were made at a freestream Mach number of 0.80 and a unit Reynolds number of approximately 4 million per foot. At a freestream Mach number of 0.8, boundary layer transition occurs in this facility on a 10 deg. polished cone at a Reynolds number of 5.4 million. The angle-of-attack was varied from -2.5 deg. to 4 deg.

In order to assess the integration effects on the laminar flow nacelle design, the effects of fixed and free transition, nacelle longitudinal position, and pylon contouring were investigated using a high wing transport model. The results indicated that nacelle/pylon/wing integration did not affect the laminar flow on the nacelle. The increment in installed drag between free and fixed transition for the nacelle on a symmetric pylon was essentially the difference between the calculated turbulent and laminar skin friction drag for the nacelle. Locating the nacelle in a forward position relative to the wing reduced the compressibility effect on the wing lower surface thereby reducing the installed drag. Contouring the pylon resulted in a further reduction in the installed drag.

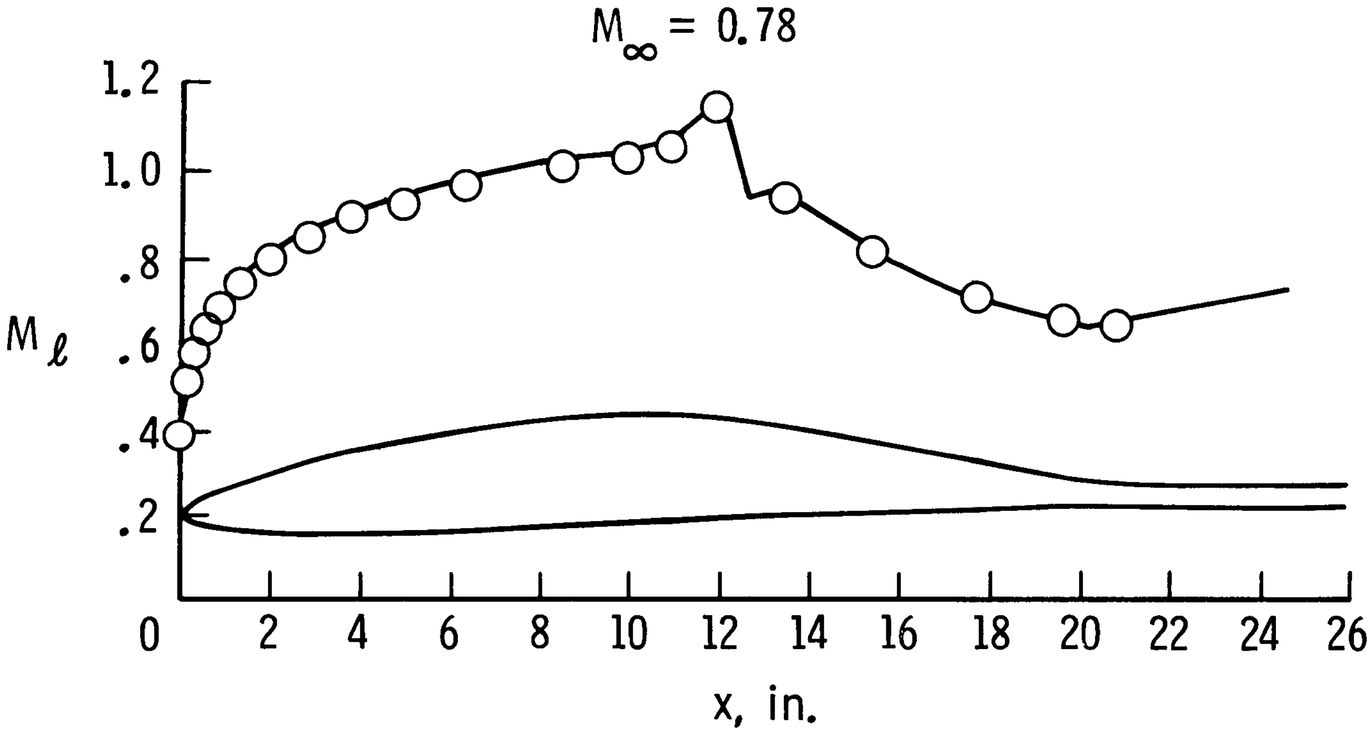
ISOLATED NACELLE IN THE 16-FOOT TRANSONIC TUNNEL

The isolated nacelle was designed by General Electric to have a favorable pressure distribution over 70 percent of its length. The nacelle shown was the largest possible model based on the restraints of the existing inlet test rig of the 16-Foot Transonic Tunnel. The nacelle had a maximum diameter of 21 inches with a throat diameter of 15.6 inches and was approximately 22 inches in length. The nacelle was designed to have a maximum length of favorable pressure gradient at a Mach number of 0.78 and design cruise mass flow ratio of 0.88. To help maintain laminar flow, the surface was highly polished.



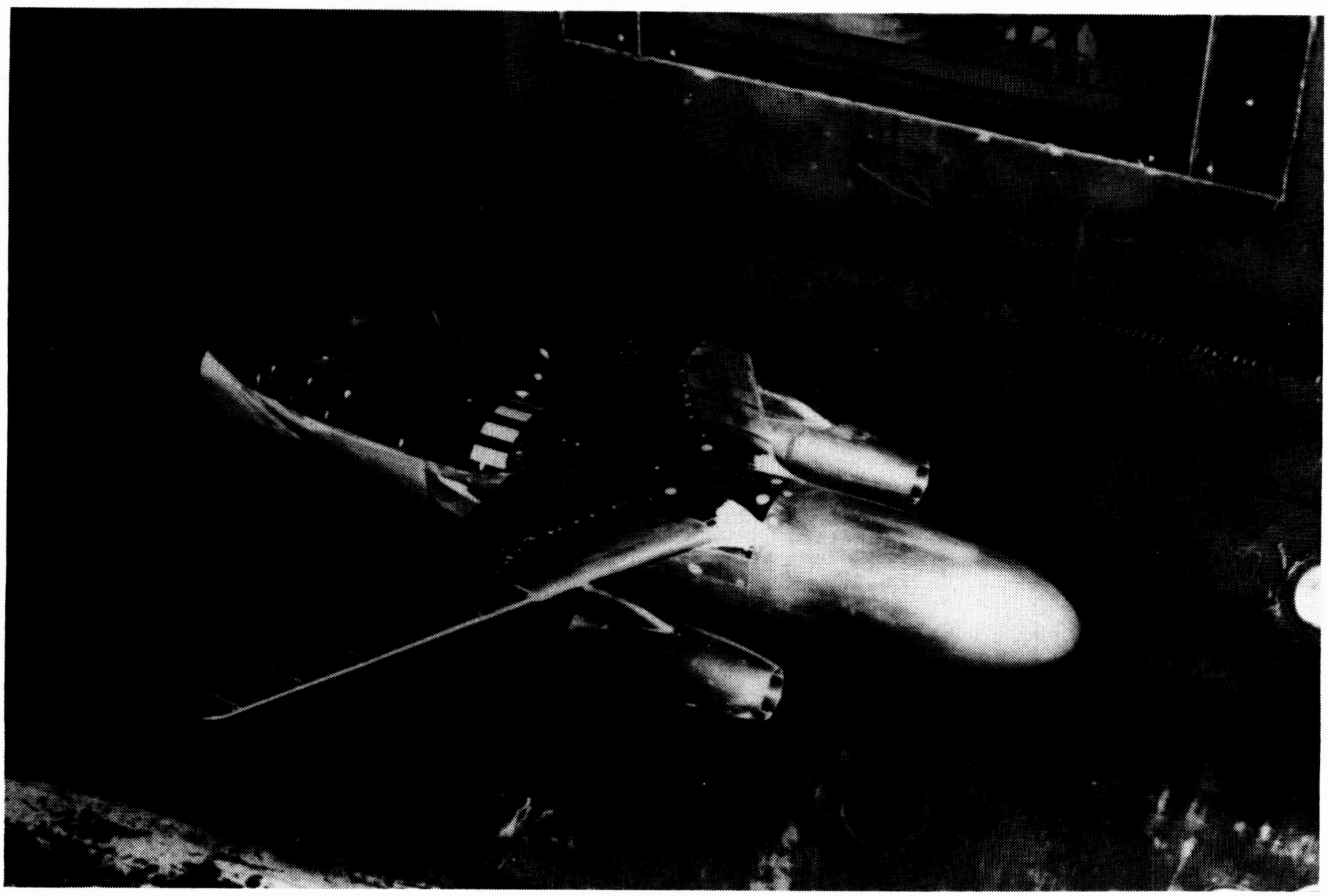
COMPARISON OF MEASURED AND PREDICTED MACH NUMBER DISTRIBUTION

The theoretical Mach number distribution (solid line) was predicted by the GE Streamtube Curvature Method which solves the Euler equations. Considerable contour tailoring near the velocity peak was required to produce an adverse pressure gradient that would initiate transition and yet not separate the flow. Wind tunnel results show excellent agreement with pre-test calculations.



PHOTOGRAPH OF MODEL WITH NACELLES INSTALLED

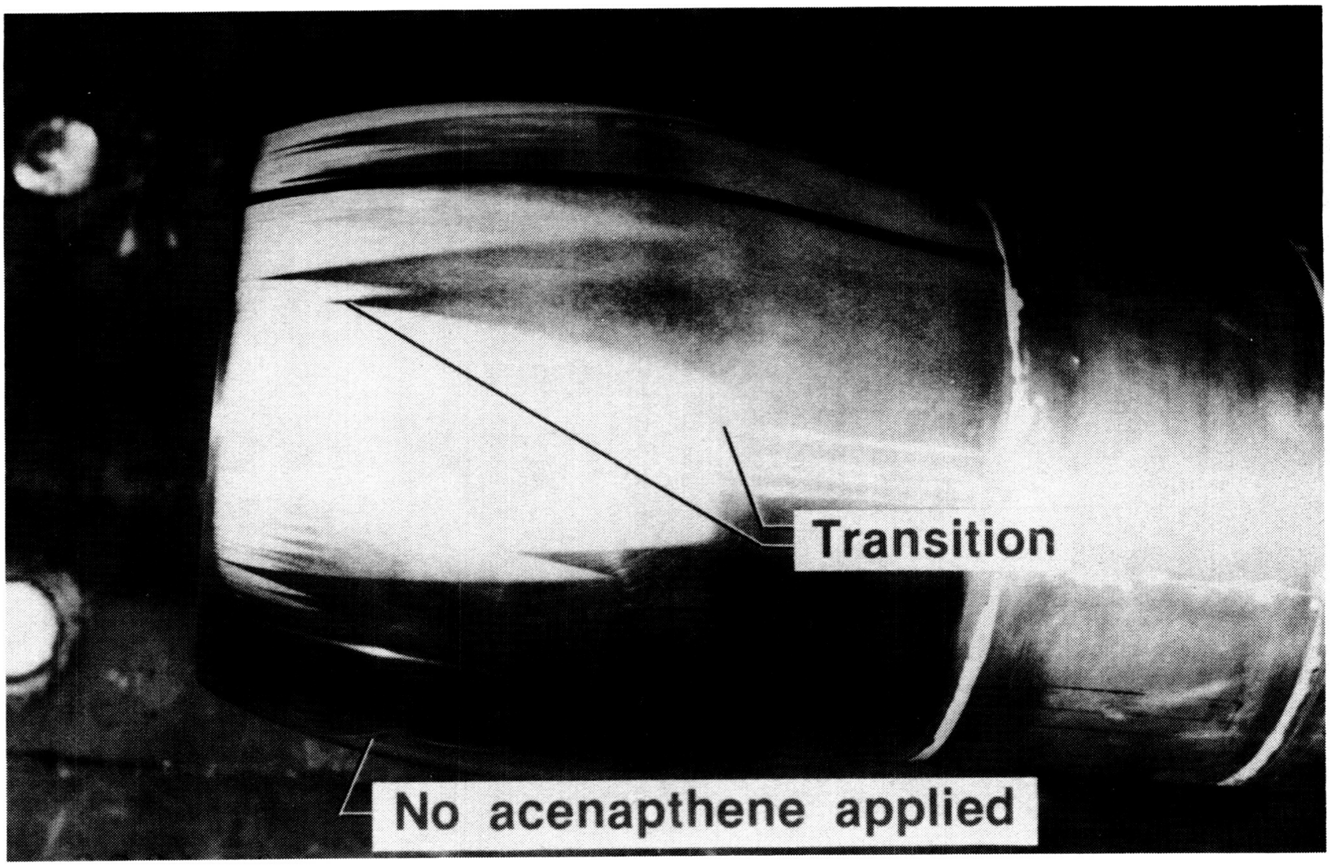
The model used in this investigation was a 1/24 scale transport model with a supercritical wing designed for a Mach number of 0.8. The high wing transport was considered desirable since it would provide more fuselage outwash than a typical low wing aircraft and therefore represent a more severe test case. The flow-through laminar flow nacelle was designed using a low order panel method in conjunction with a specific compressibility correction technique to solve for the basic installed flow field. The desired nacelle shape was analytically modeled into the wing-body flow field, and the resulting nacelle's pressure gradient was checked for separation as well as for peak surface Mach number. If either the pressure gradient or peak Mach number proved unsatisfactory, the nacelle contour was modified and the entire process repeated until a satisfactory shape was obtained. The final nacelle shape had a favorable pressure gradient over 60 percent of its length. The surfaces of these nacelles were highly polished.



ISOLATED NACELLE FLOW VISUALIZATION RESULTS

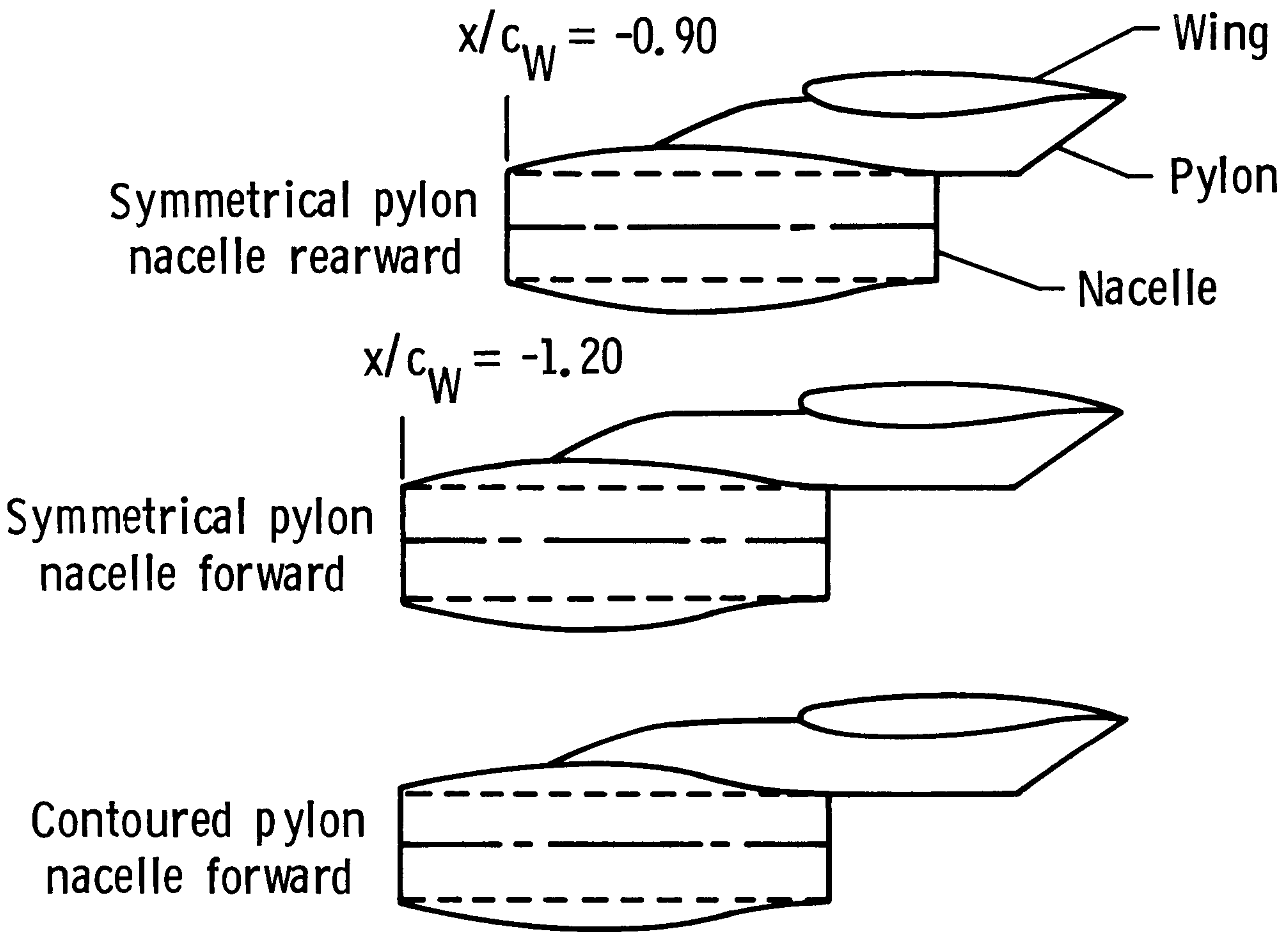
Acenaphthene was utilized for flow visualization to assess where transition from laminar to turbulent flow occurred. Acenaphthene is a sublimating chemical with a sublimation rate that is proportional to heat transfer rate (faster in turbulent flow). It is a distinct white after it is sprayed on the model and the fully laminar flow region appears a bright white after the wind tunnel run. Some portions of the nacelle produced laminar flow all the way back to the desired transition location, while other portions developed "turbulent wedges" prior to the design transition location. The sources of these premature transitions were attributable to two factors:

1. Surface roughness occurring as a result of non-uniform particle deposits of acenephthene.
2. Leading edge surface contamination due to wind tunnel particles impingement and subsequent nicks and dents.



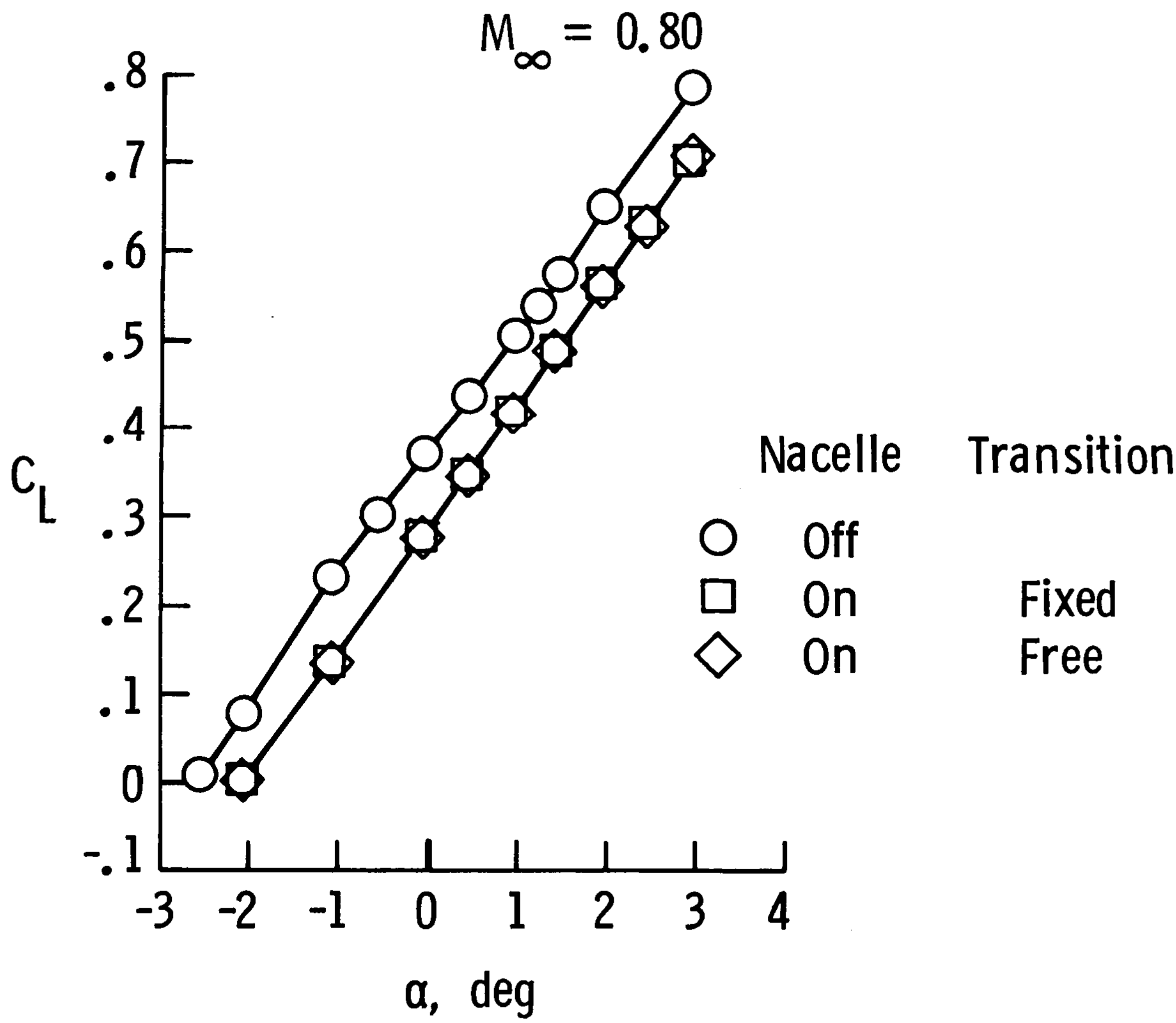
TEST MATRIX

In order to fully assess the integration effect on a nacelle designed to achieve laminar flow, the effects of fixed and free transition, nacelle longitudinal position, and pylon contouring were investigated. The nacelle was tested in a rearward and forward position on a symmetrical pylon and in a forward position on a contoured pylon.



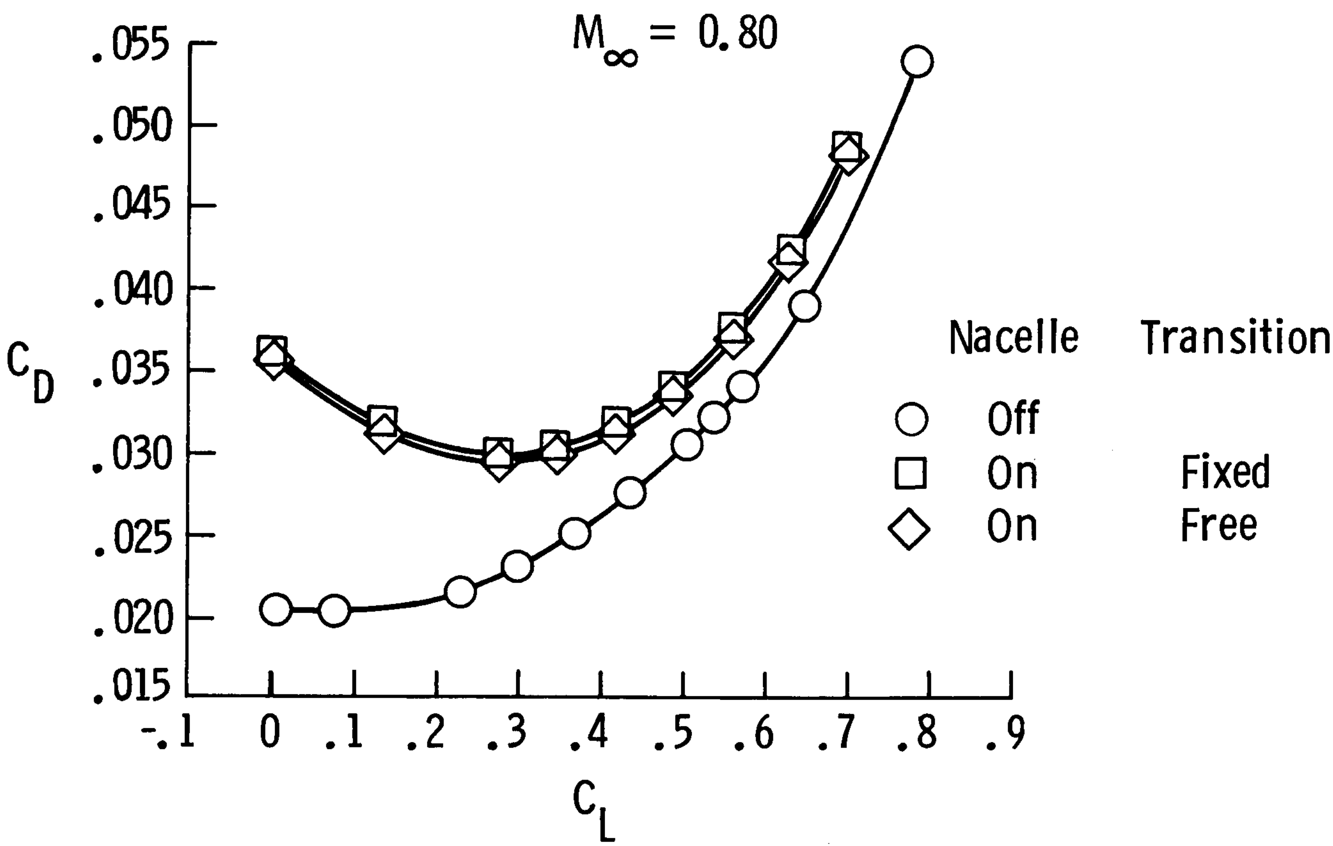
EFFECT OF NACELLE AND NACELLE TRANSITION ON LIFT

The addition of the nacelle/pylon to the wing-body configuration reduced the lift as would be expected. The addition of grit on the nacelle to trip the flow from a 60 percent laminar flow condition to a fully turbulent condition along the entire length of the nacelle, had no effect on the lift characteristics.



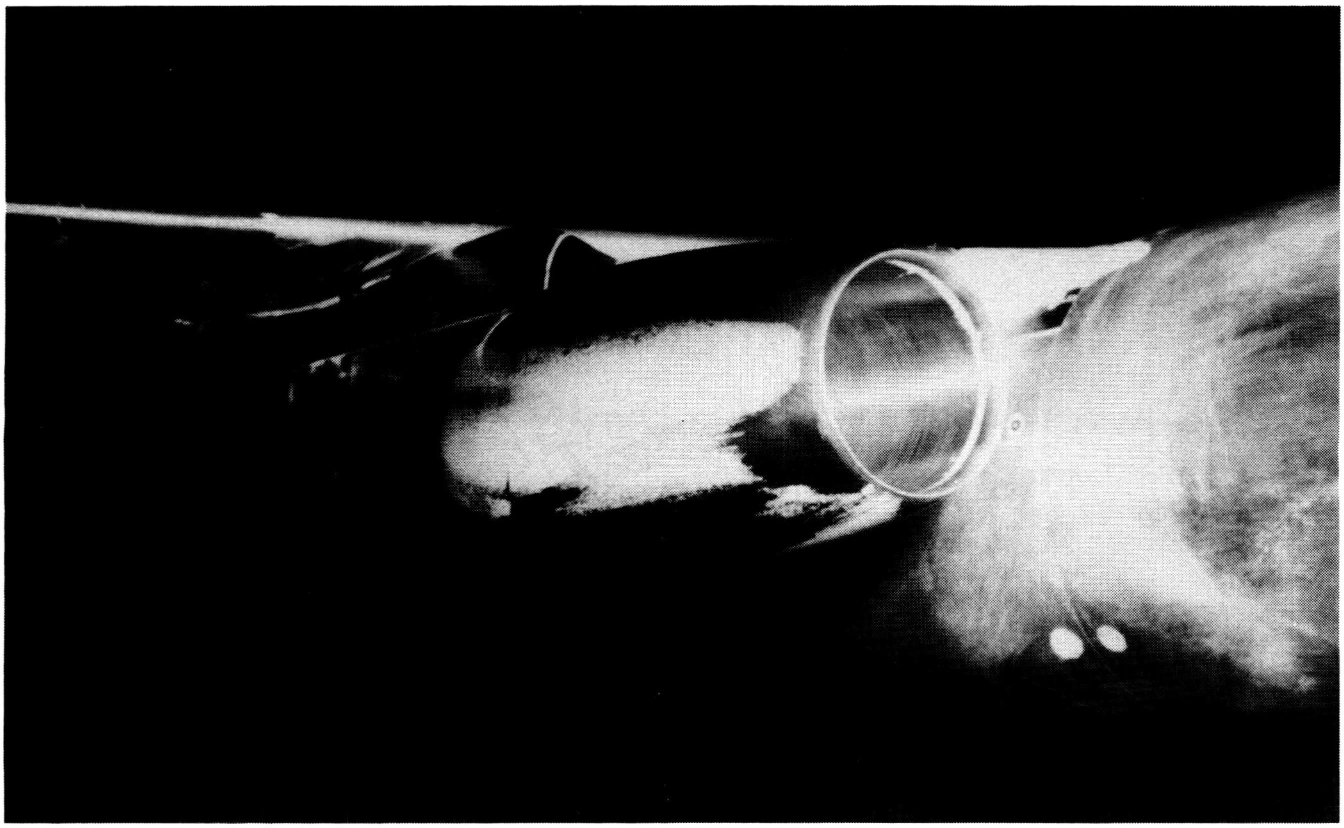
EFFECT OF NACELLE AND NACELLE TRANSITION ON DRAG

The addition of the nacelle/pylon to the wing-body configuration resulted in an increase in drag. The removal of the transition grit from the nacelle resulted in a decrease in total airplane drag (approximately 9 counts at the cruise C_L of 0.45). The increment in the flat plate friction drag for these nacelles and pylons with fixed and free transition on the nacelle indicated that the drag reduction for two nacelles of this size with 60 percent laminar flow are approximately 9 counts. This would indicate that integration effects do not significantly alter the extent of the nacelle laminar flow achieved.



INSTALLED NACELLE FLOW VISUALIZATION RESULTS

Acenaphthene was again used for the flow visualization. As noted for the isolated nacelle, there are portions of "turbulent wedges;" however, the extent of laminar flow can be clearly seen. The laminar flow on the installed nacelles is approximately 60 percent of the nacelle length.



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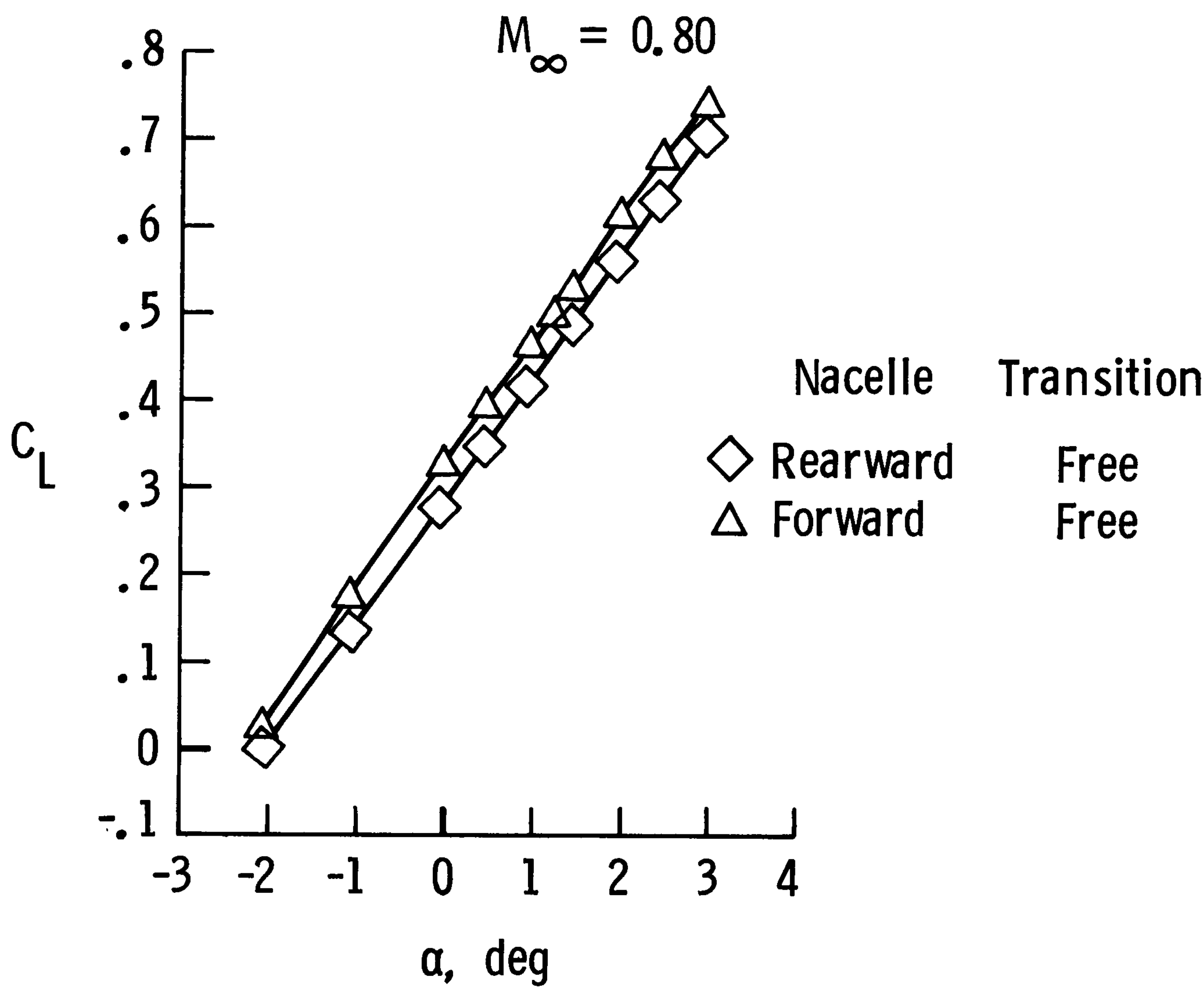
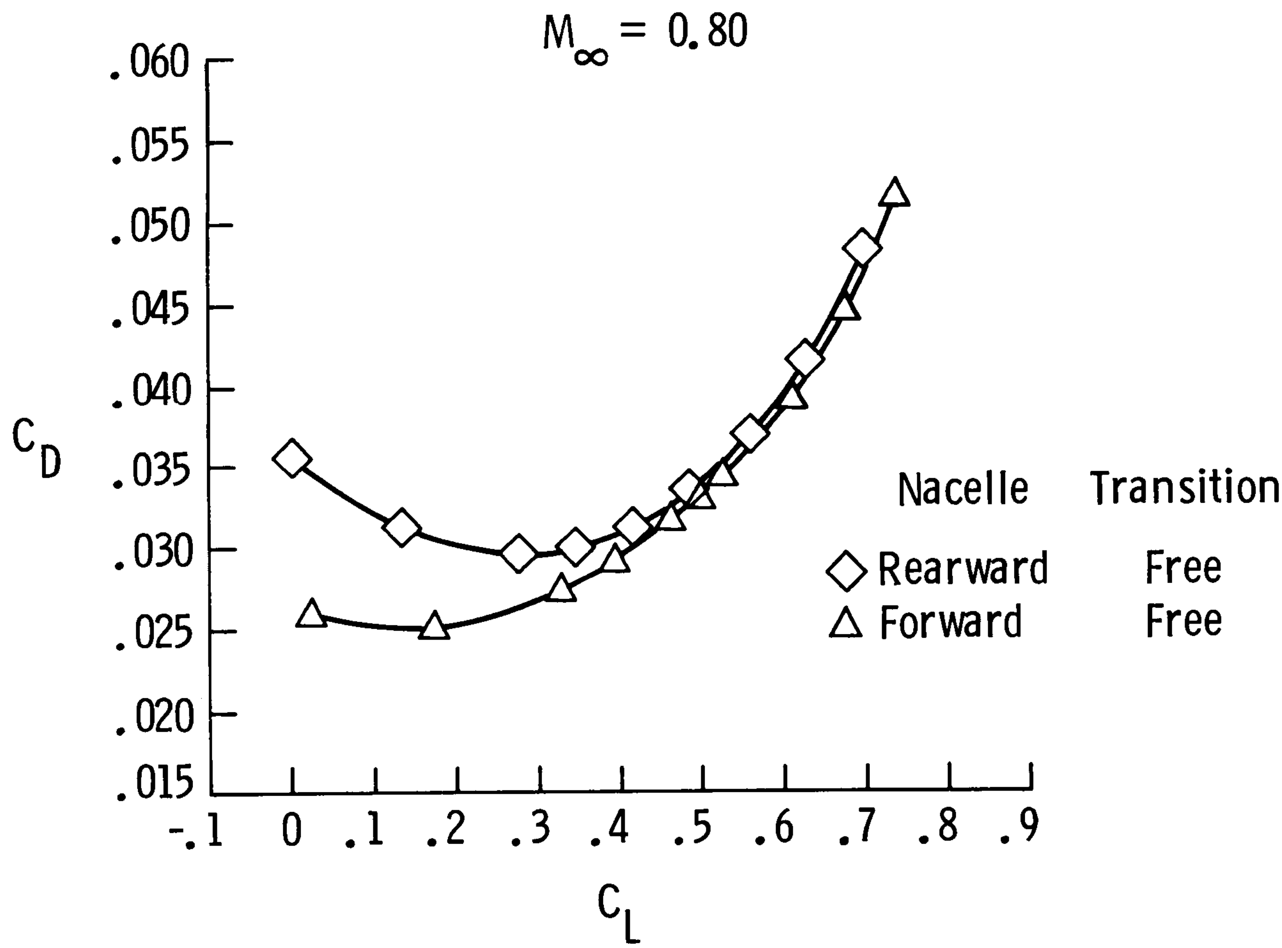
EFFECT OF NACELLE POSITION ON LIFT

An additional study was conducted in an attempt to reduce the installed drag of the wing-body-nacelle-pylon configuration by proper nacelle positioning. Moving the nacelle forward reduced the compressibility effect on the wing lower surface, thereby resulting in a lower installed lift loss.



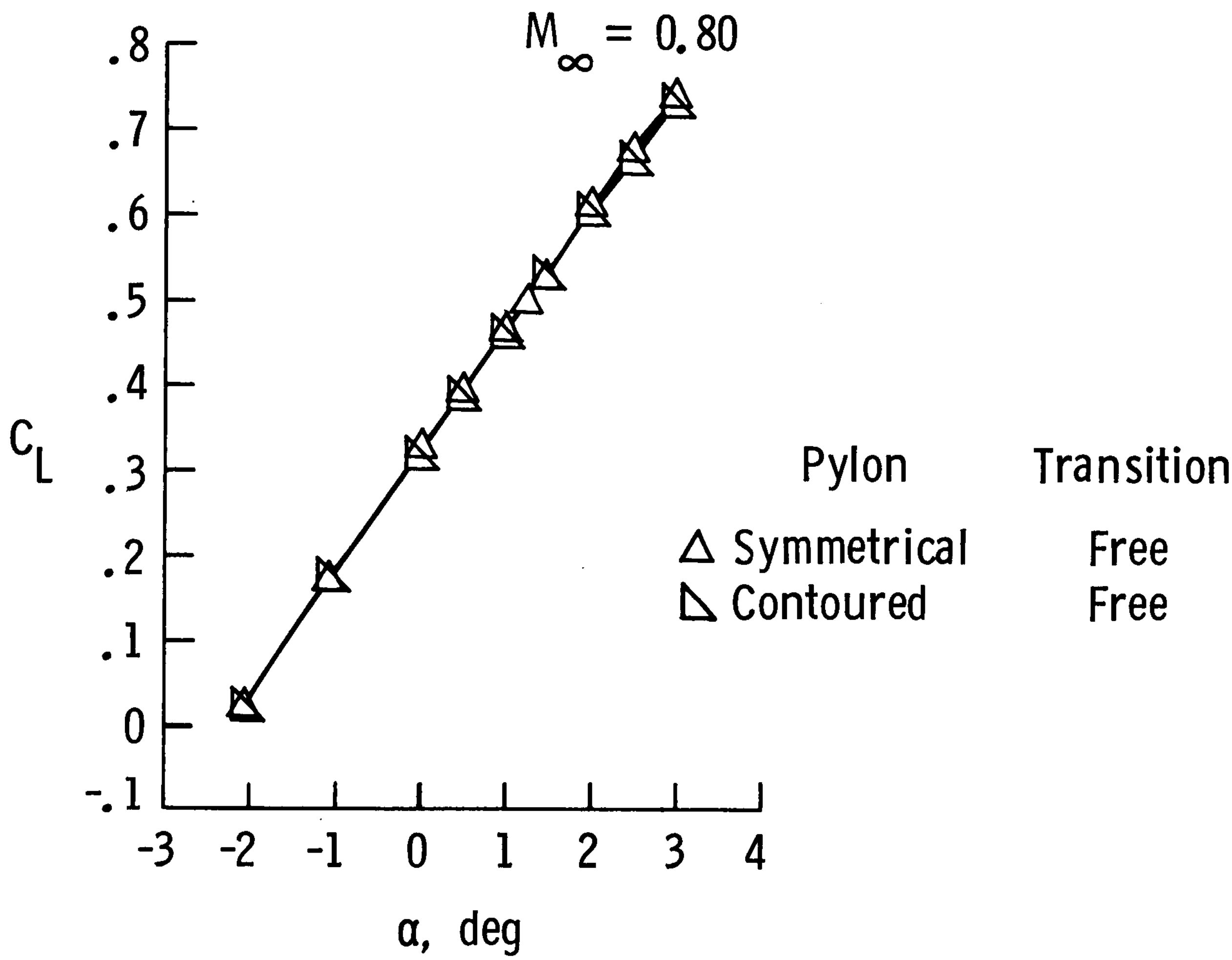
EFFECT OF NACELLE POSITION ON DRAG

Moving the nacelle to a forward position reduces the compressibility and nacelle interference effects on the wing lower surface. This results in a drag reduction of approximately 10 counts at the cruise lift of 0.45.



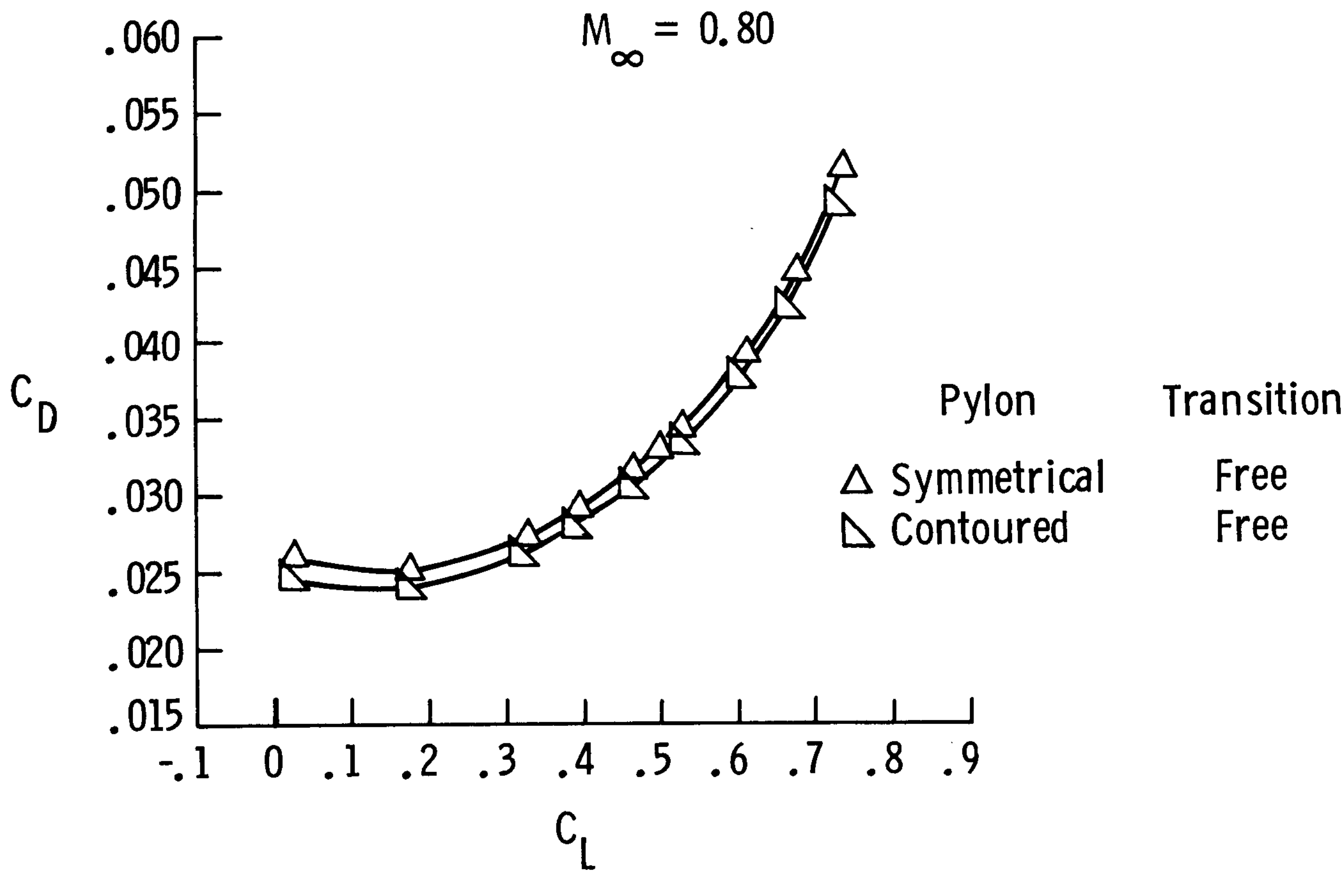
EFFECT OF PYLON CONTOUR ON LIFT

A study was also conducted to determine the reduction in installed drag that might be obtained by contouring the pylon to conform with the local streamlines. The contoured pylon had very little effect on the lift coefficient.



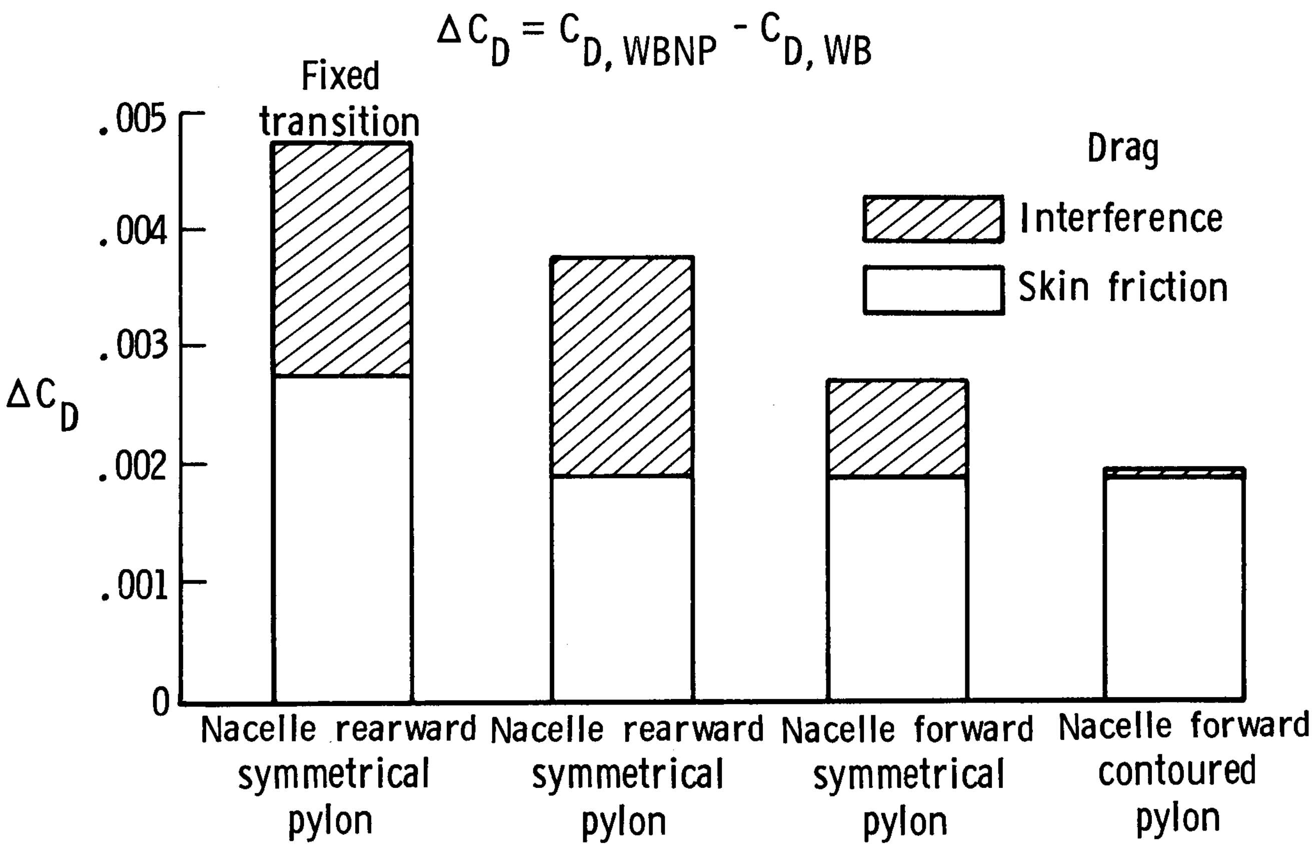
EFFECT OF PYLON CONTOUR ON DRAG

Since flow accelerations caused by pylons are a major contributor to high velocity peaks on the wing lower surface, the pylons were contoured in an attempt to reduce these high velocities. Contouring the pylon resulted in a decrease in drag of approximately 7.5 counts.



INSTALLED DRAG FOR M = 0.80 AND C_L = 0.45

The incremental drag results obtained from this investigation (wing-body-nacelle/pylon - wing-body) is presented, including the calculated flat plate skin friction drag, for each nacelle/pylon configuration. The difference in installed drag for the nacelles in the rearward position, transition fixed and free, is comparable to the difference in the calculated skin friction drag. An additional reduction in installed drag was obtained by locating the nacelle in the forward position. Pylon contouring further reduced the interference drag (including wave and form drag) to a value just above skin friction.



SUMMARY

The results of the isolated nacelle test illustrated that laminar flow could be maintained over the desired length.

Installing the nacelles on wing/pylon did not alter the extent of laminar flow occurring on the nacelle.

The results illustrated that a significant drag reduction was achieved with this laminar flow design.

Further drag reduction could be obtained with proper nacelle location and pylon contouring.