NATURAL LAMINAR FLOW FLIGHT EXPERIMENT

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ABSTRACT

Significant improvements in cruise efficiency of transport aircraft can be obtained if the flow over the wings is laminar. Active laminar flow control can prevent turbulent flow over most of the wing, but such systems add weight, cost, and complicate maintenance.

A possible alternative to active laminar flow control is natural laminar flow (NLF). Natural laminar flow utilizes an airfoil shape which encourages laminar flow to extend further over the airfoil than conventional shapes. The airfoil shape must maintain a favorable pressure gradient over most of the chord. While the advantages of laminar flow for significantly improving aerodynamic efficiency are well known, the problem of maintaining natural laminar flow has not previously been addressed at the higher Reynolds numbers and Mach numbers associated with commercial aircraft operations.

As a part of the NASA Aircraft Energy Efficiency Program, a joint Dryden Flight Research Center/Langley Research Center research effort has been conducted to investigate the feasibility of maintaining natural laminar flow on lifting surfaces. A supercritical airfoil section has been designed with favorable pressure gradients on both the upper and lower surfaces. Wind-tunnel tests in support of this experiment were conducted in the Langley Research Center 8-Foot Transonic Pressure Tunnel.

The outer wing panels of the F-111 TACT airplane were modified to incorporate partial span test "gloves" having the natural laminar flow profile. Instrumentation was installed to provide surface pressure data as well as to determine transition location and boundary-layer characteristics.

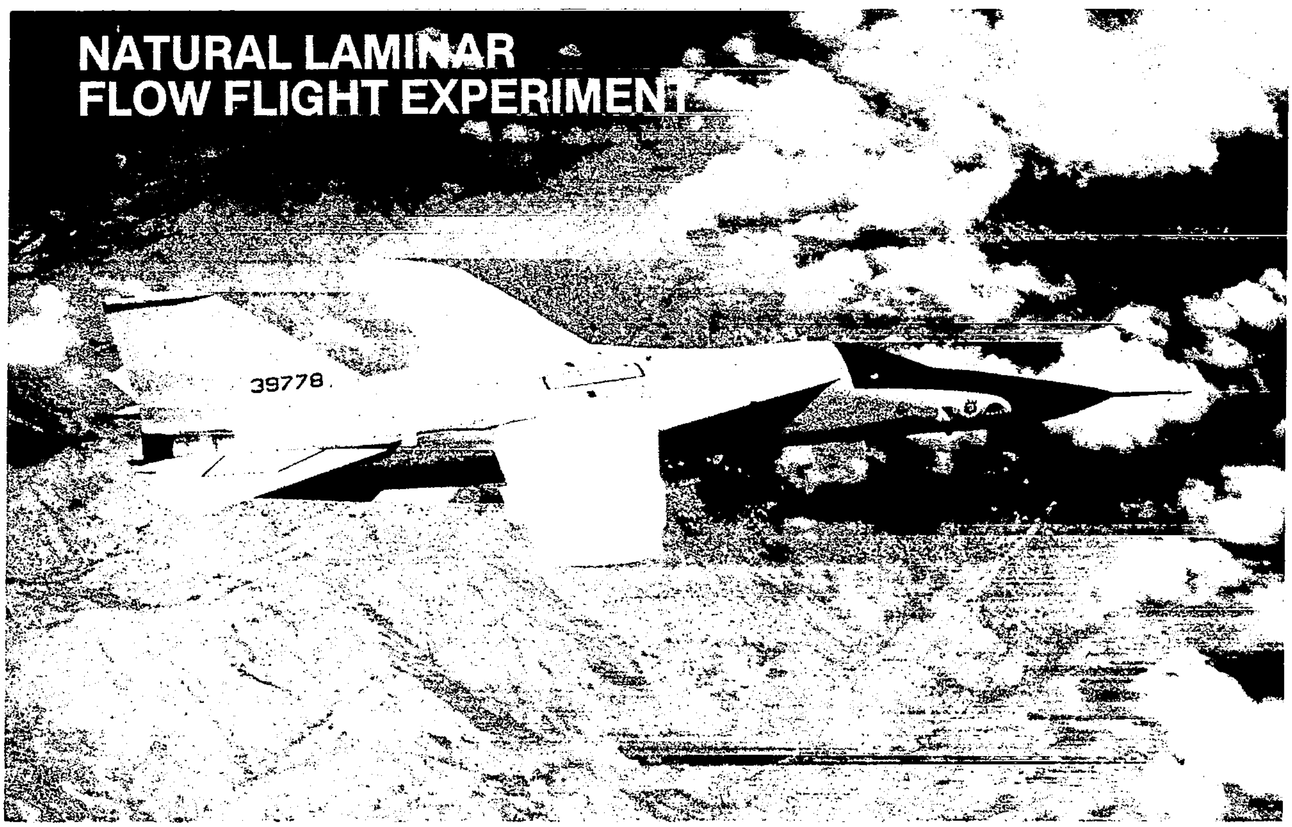
The flight experiment encompassed 19 flights. These flights were conducted with and without transition fixed at several locations for wing leading-edge sweep angles which varied from 10° to 26° at Mach numbers from 0.80 to 0.85 and altitudes of 7620 meters (25,000 feet) and 9144 meters (30,000 feet). Data analysis is underway. Preliminary results indicate that a large portion of the test chord experienced laminar flow. A quantitative measure of transition location cannot be provided at this time.

TEST BED AIRPLANE

The F-111 TACT airplane was used as the test bed for the natural laminar flow (NLF) experiment. Both wings were fitted with built-up partial span gloves having the NLF supercritical airfoil shape.

The F-111 TACT baseline wing also had a supercritical profile and variable sweep. In addition to the partial span gloves it was necessary to add fairing material inboard of the gloves to reduce the effects of shocks, characteristic of the carrier vehicle, which would otherwise have interfered with the experiment.

Test chord Reynolds numbers of 28 million were obtained with this experiment over a Mach number range from 0.80 to 0.85 and wing leading-edge sweep angles from 10° to 26°.



NLF CONCEPT

The NLF concept utilizes an airfoil shape that maintains the necessary favorable pressure gradient over a large percentage of the test chord. This concept is an alternative to active laminar flow control systems which would be more expensive, heavier, and would require more maintenance. It should be mentioned, however, that the NLF airfoil concept may also be used to enhance the performance of an active laminar flow control system.

Airfoils designed to encourage natural laminar flow have been flown on aircraft before—sailplanes and World War II and various post-war military aircraft. However, the present experiment addresses a significantly higher cruise Mach number than earlier efforts. In addition, earlier studies did not experience the problem of leading-edge crossflow effects on transition to the extent that the present study did.

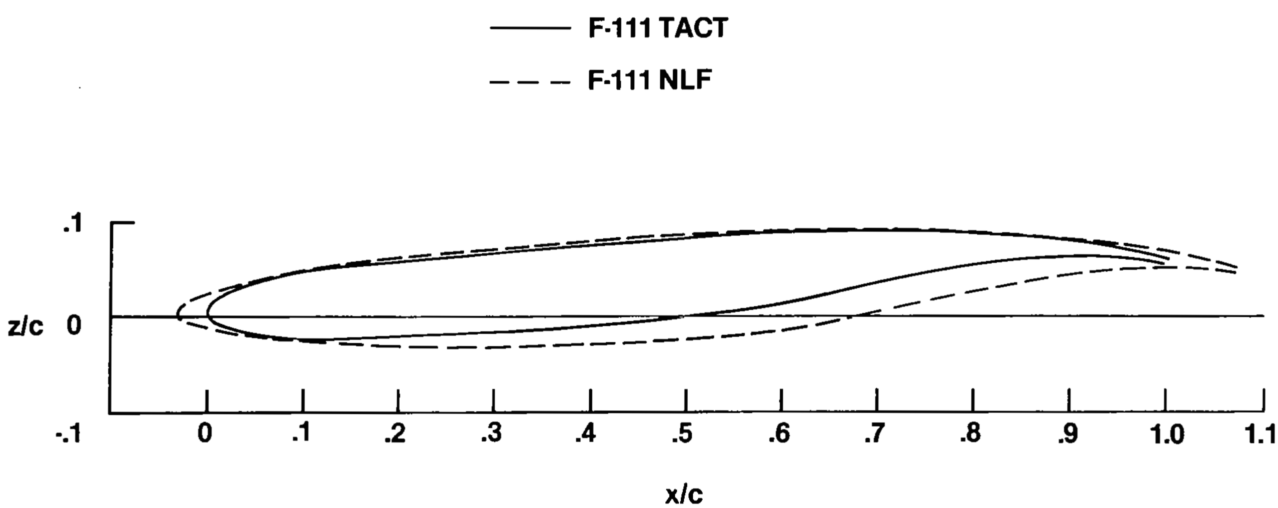
NATURAL LAMINAR FLOW

- **AVOIDS COMPLICATED SYSTEMS BY DESIGNING FOR FAVORABLE PRESSURE GRADIENTS**
  - **REDUCED WEIGHT**
  - **REDUCED MAINTENANCE**
  - **REDUCED COMPLEXITY**
- **BUT**
  - **RESTRICTED TO MODERATE WING SWEEP ANGLES**

NLF AIRFOIL

The NLF airfoil of the present experiment was initially a theoretical, two-dimensional shape designed for the required favorable pressure gradients. The theoretical shape was then fitted around the outer wing panels of a 1/24-scale model of the F-111 TACT carrier vehicle. In order to fit the test airfoil to the carrier vehicle wing, it was necessary to slightly thicken the trailing-edge region from the "ideal" shape.

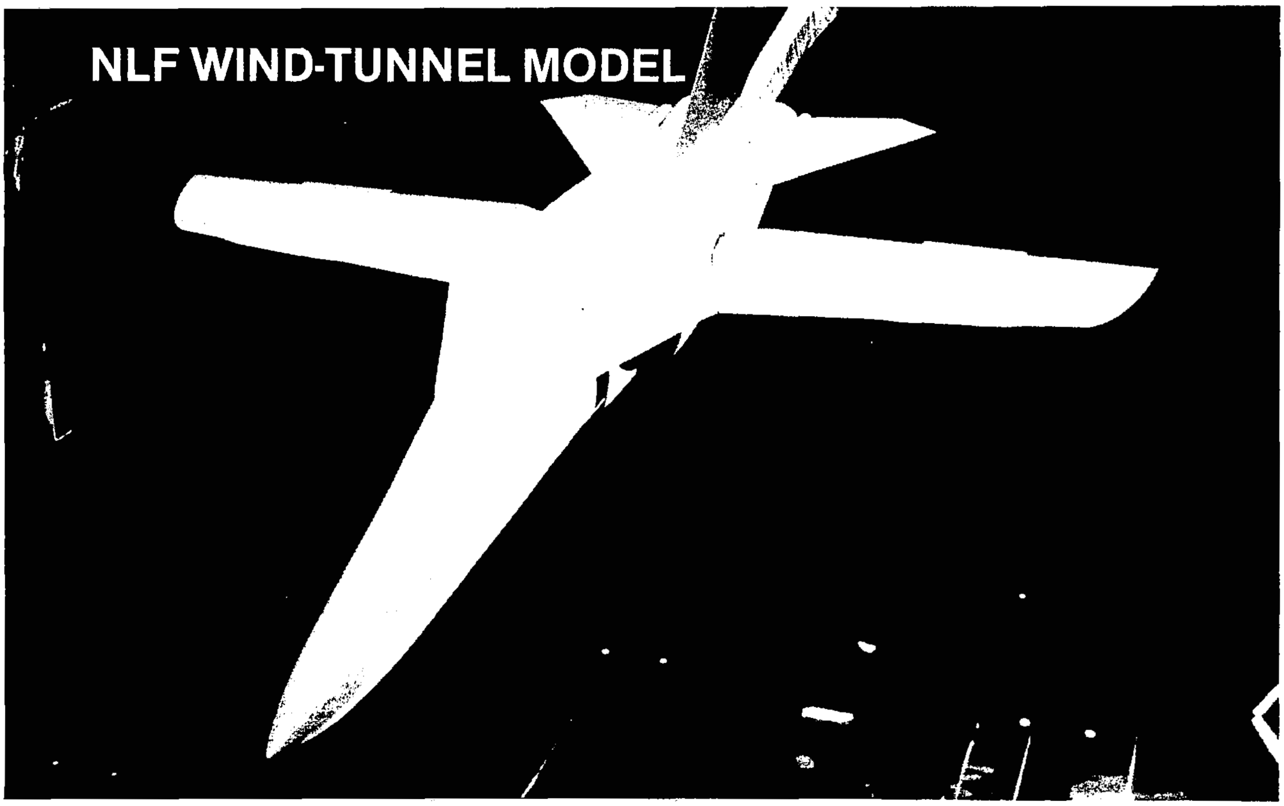
NATURAL LAMINAR FLOW AIRFOIL



NLF WIND-TUNNEL MODEL

The wind-tunnel tests were conducted to assess the stability and control characteristics of the modified configuration, establish the pressure gradients, and develop the interface (fairing) between the F-111 TACT airplane and the test glove. (The fairings were necessary for maintaining the quasi-two-dimensional flow characteristics required for the NLF experiment.)

These refinements, achieved during the 1/24-scale model tests, provided favorable pressure gradients over 65 and 50 percent of the model test chord for the upper and lower surface, respectively.

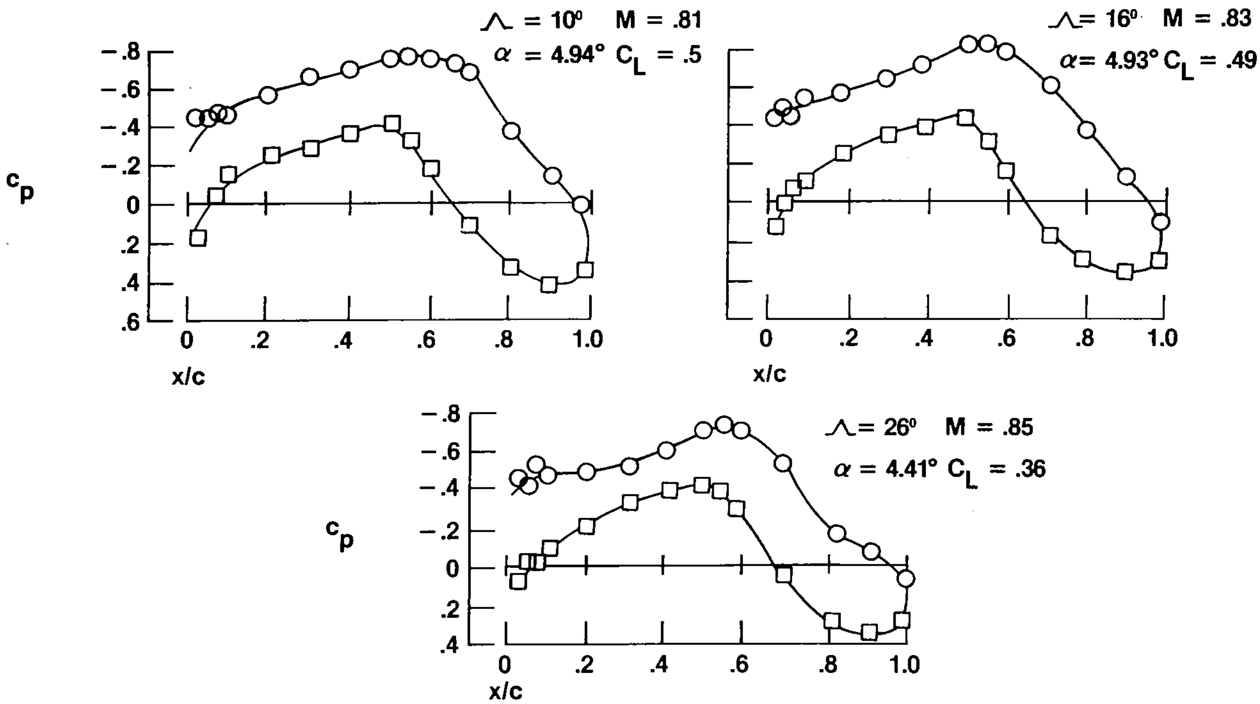


WIND-TUNNEL TEST RESULTS

The wind-tunnel model tests provided data for leading-edge sweep angles of 10°, 16°, and 26°, Mach numbers from 0.6 to 0.85 (with limited data at M = 0.3), and unit Reynolds numbers from 8.2 million to 16.4 million per meter (2.5 million to 5.0 million per foot). Force, pressure distribution, and flow visualization data were obtained.

These tests, conducted in the Langley 8-Foot Transonic Pressure Tunnel, resulted in acceptable stability and control characteristics and verified that the flow over the test glove region was free of undesirable three-dimensional effects or shocks emanating from the carrier vehicle environment. Favorable pressure gradients could be maintained over a large portion of the test chord at the higher Mach numbers ($M > 0.8$) for all sweep angles, angles of attack, and Reynolds numbers for which data were obtained.

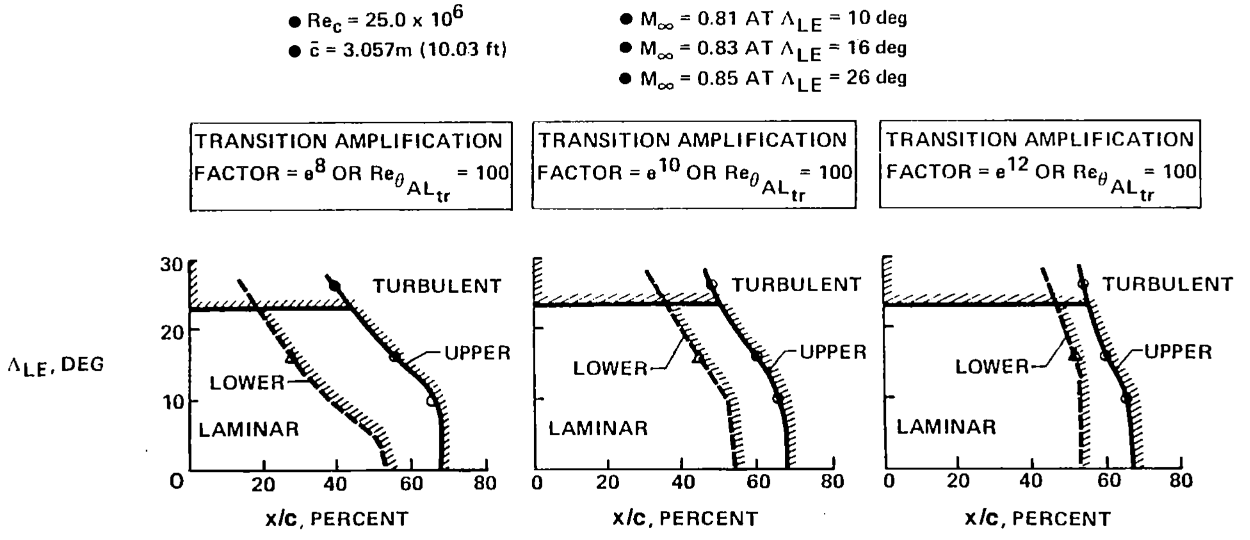
WIND TUNNEL PRESSURE DISTRIBUTIONS



SUPPORTIVE THEORETICAL STUDY

In the fall of 1979, the Boeing Aerospace Company calculated transition location for three design conditions: leading-edge sweep angles of 10°, 16°, and 26° and Mach numbers of 0.81, 0.83, and 0.85, respectively. The compressible flow analysis incorporated the effects of the Tollmien-Schlichting disturbance amplification, cross-flow disturbance amplification, and leading-edge attachment line contamination on the predicted transition location at a chord Reynolds number of 25 million. The results indicated that laminar flow can be maintained over a large extent of the chord.

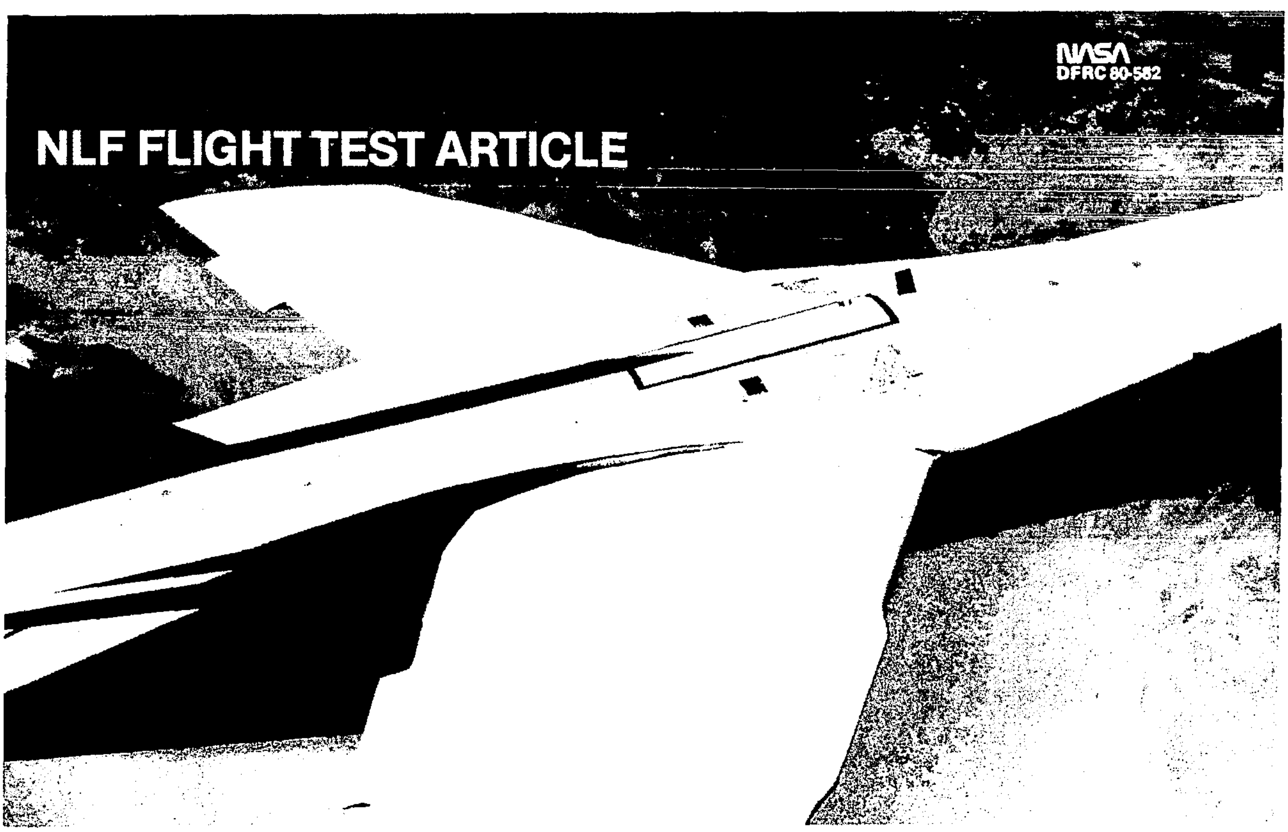
PREDICTED LOCATION OF FULLY TURBULENT FLOW
COMPRESSIBLE STABILITY



FLIGHT TEST ARTICLE

The NLF "gloves" were fabricated on the flight vehicle using fiber glass, high density foam, microballoons, and body putty. The use of these materials aided in achieving the aerodynamically smooth surface desired for this experiment. As with the wind-tunnel model, both the left and right wings were fitted with the NLF airfoil, but only the right test section was instrumented.

The instrumentation included 15 flush surface pressure orifices, a boundary-layer rake, and transition strips on both the upper and lower surfaces. The boundary-layer rake was located at 90 percent of the chord on both surfaces. The transition strips were strategically placed at several different spanwise chord locations—one location per flight.



FLIGHT PRESSURE DISTRIBUTIONS

In-flight pressure distribution data were obtained over a matrix of Mach numbers and angles of attack in an attempt to define the flight conditions for the optimum extent of favorable pressure gradient.

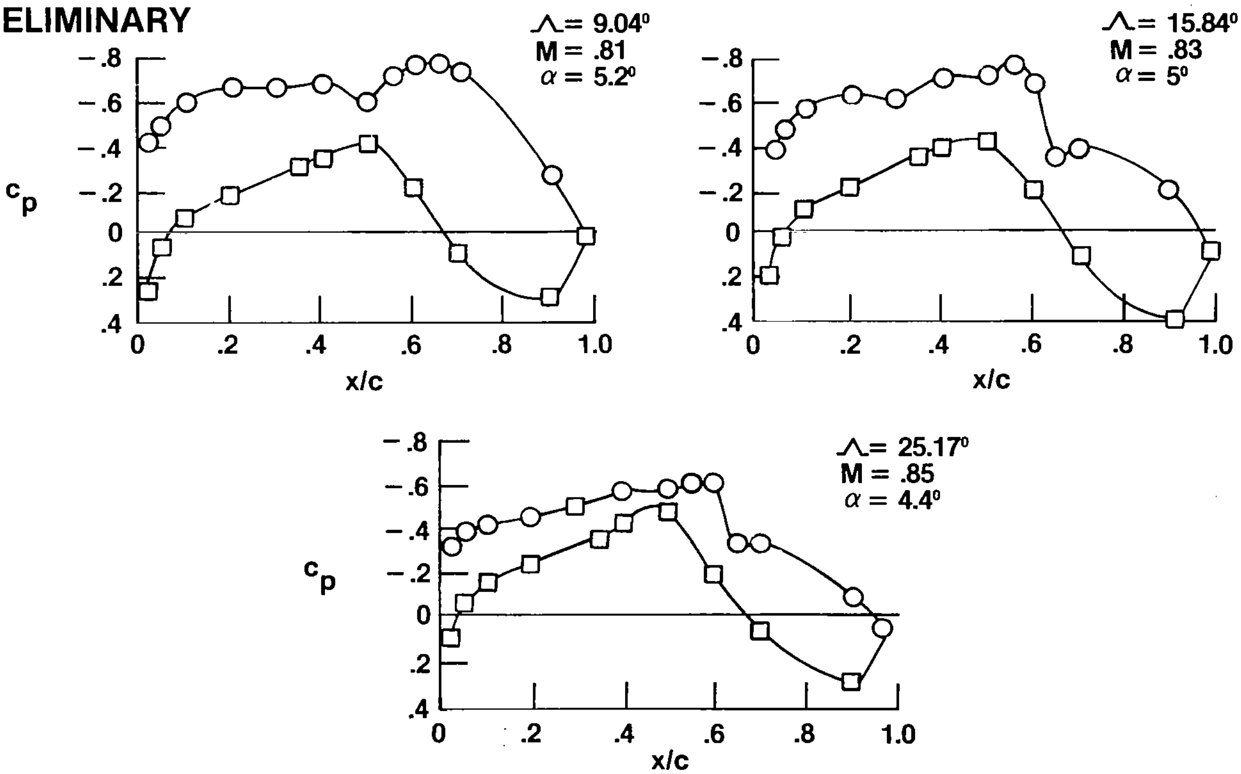
Preliminary data consistently demonstrated a significant extent of favorable pressure gradient for the same range of wing sweep angles tested in the wind tunnel.

The actual extent of laminar flow attained in flight will be determined through the study of boundary-layer profile data obtained from the upper and lower surface rakes. Fixed transition was used on some of the flights to aid in the interpretation of the boundary-layer data obtained from flights with free transition.

Preliminary analysis showed that laminar flow was maintained over a large part of the test section, but a quantitative measure of transition location could not be proclaimed at this stage of the analysis.

NLF FLIGHT PRESSURE DISTRIBUTIONS

PRELIMINARY



POTENTIAL FOLLOW-ON EFFORT

The current NLF experiment was hampered by not being conducted on a dedicated flight vehicle. A joint U.S. Air Force/NASA program (AFTI/F-111) forced termination of the NLF experiment before other factors could be assessed.

The present NLF experiment was conducted to determine the feasibility of the natural laminar flow concept for supercritical flow conditions.

Follow-on work should assess how practical the concept will be for real world operating conditions. The susceptibility of the concept to fabrication tolerances, operational blemishes, contamination, and moisture should be determined. An assessment should also be made of the requirement for leading-edge protection and maintenance. Any follow-on work deserves a dedicated test bed facility.

RECOMMENDATIONS

STUDY NATURAL LAMINAR FLOW PHENOMENA ON A DEDICATED BED FACILITY TO

- **DETERMINE SENSITIVITY OF TRANSITION TO**
  - **SURFACE MATERIAL, MOISTURE, CONTAMINATION, ETC.**
  - **SURFACE DETERIORIATION FROM OPERATIONAL BLEMISHES**
  - **SURFACE FABRICATION TOLERANCES**
- **DETERMINE REQUIREMENTS FOR**
  - **SURFACE MAINTENANCE**
  - **LEADING-EDGE PROTECTION**