D25

N88-14951

DESIGN AND EXPERIMENTAL EVALUATION OF A SWEPT SUPERCRITICAL LAMINAR FLOW CONTROL (LFC) AIRFOIL

525-05

117249

10P.

W. D. Harvey, C. D. Harris, C. W. Brooks,
P. G. Clukey, and J. P. Stack
NASA Langley Research Center
Hampton, VA

[redacted]

ABSTRACT

A large chord swept supercritical laminar flow control (LFC) airfoil has been designed, constructed, and tested in the NASA Langley/8-ft. Transonic Pressure Tunnel (TPT). The LFC airfoil experiment was established to provide basic information concerning the design and compatibility of high-performance supercritical airfoils with suction boundary layer control achieved through discrete fine slots or porous surface concepts. It was aimed at validating prediction techniques and establishing a technology base for future transport designs and drag reduction. Good agreement was obtained between measured and theoretically designed shockless pressure distributions. Suction laminarization was maintained over an extensive supercritical zone up to high Reynolds numbers before transition gradually moved forward. Full-chord laminar flow was maintained on the upper and lower surfaces at $M_\infty = 0.82$ up to $R_c \leq 12 \times 10^6$. When accounting for both the suction and wake drag, the total drag could be reduced by at least one-half of that for an equivalent turbulent airfoil. Specific objectives for the LFC experiment are given in figure 1.

LFC EXPERIMENT OBJECTIVE

Conduct basic aerodynamic and fluid dynamics research program on a high-performance, swept supercritical, LFC airfoil to determine:

- Ability to laminarize over extensive supercritical region
- Ability of stability theories to predict transition and suction laminarization requirements
- Relative merit of slotted and perforated suction surfaces for LFC and HLFC
- Effects of surface conditions and boundary layer influences on laminarization

Figure 1

TEST SETUP FOR LFC EXPERIMENT IN THE 8-FT. TPT

A schematic of the overall LFC experiment in the Langley 8-ft. tunnel is shown in figure 2 along with tunnel modifications. The major component was a large chord, 23° swept supercritical LFC airfoil of aspect ratio near one which spanned the full tunnel height. Laminar flow control by boundary layer removal was achieved by suction through closely spaced fine slots extending spanwise on the airfoil surface. After passing through the slots, the air passed through metering holes located in plenums beneath each slot and was collected by spanwise ducts with nozzles located at the ends. From the duct/nozzles, the air passed through airflow system evacuation lines, through airflow control boxes which controlled the amount of suction to each individual duct nozzle, and through sonic nozzles to a 10,000 ft^3/min compressor which supplied the suction. All four walls of the tunnel were contoured in order to produce a transonic wind tunnel flow which simulated unbounded free air flow about an infinite yawed wing at model design conditions. The contoured liner was shaped to conform to computed streamlines around the wing and corrected for growth of the wall boundary layer. The success of the LFC experiment depended to a large extent on the environmental disturbance levels in the test section. Isolation of the test section from downstream disturbances was achieved by an adjustable two wall-choke (sonic throat). Reduction of upstream disturbances such as pressure and vorticity fluctuations was achieved by the installation of a honeycomb and five screens in the settling chamber.

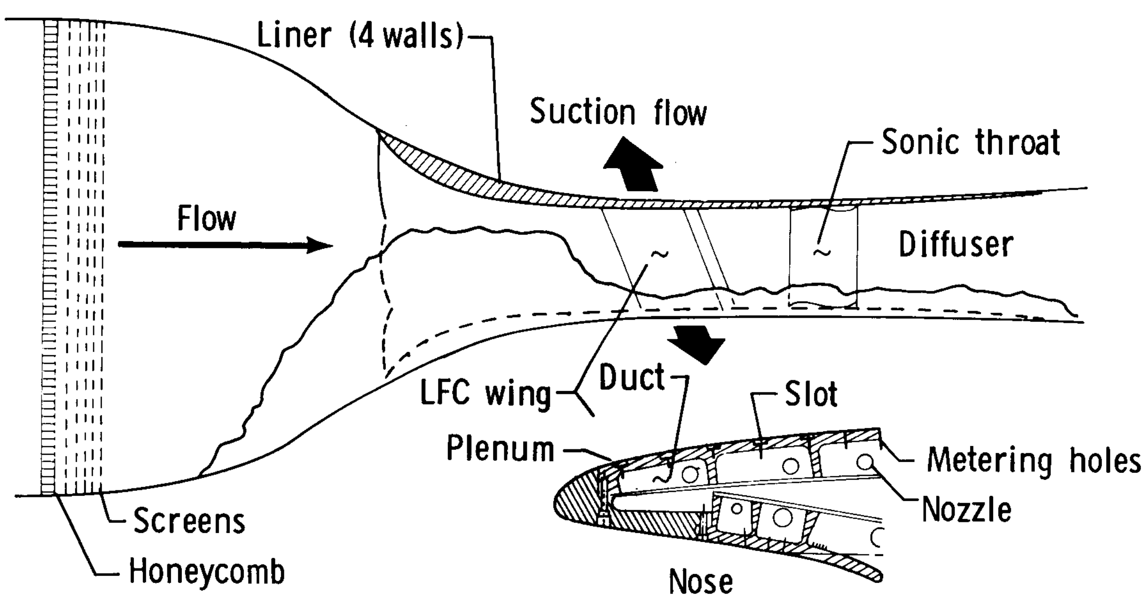

Figure 2

PHOTOGRAPH OF MODEL INSTALLED IN TUNNEL - UPSTREAM VIEW

Figure 3 is an upstream view of the finished liner and wing trailing edge as seen from the test section diffuser entrance where the liner faired into the original tunnel lines. The LFC model extended from floor to ceiling and blended with the liner. The offset of the wing mean plane from the tunnel centerline may be seen as well as the development of the liner floor and ceiling step which resulted from the differential spanwise flow displacement in the tunnel channels "above" and "below" the wing surfaces. The dark vertical area on the left of the photograph and downstream of model trailing edge is the edge of the test section access door. The dark rectangular area ahead of the model is the tunnel contraction throat region.

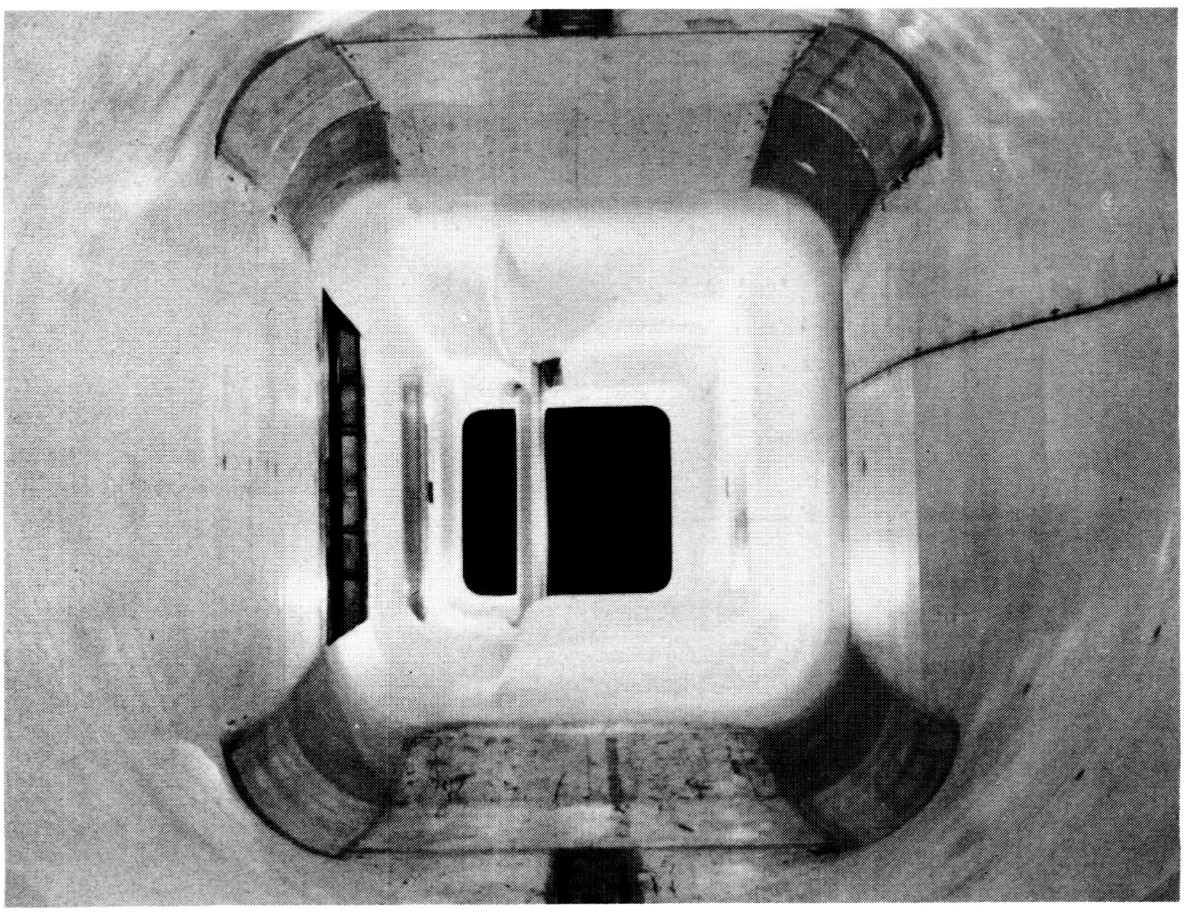

Figure 3

PHOTOGRAPH OF MODEL INSTALLED IN TUNNEL - DOWNSTREAM VIEW

Figure 4 is a downstream view of the upper surface of the model taken from immediately upstream of the model. This figure illustrates the smooth streamline contour of the liner and how it blended with the model. The dark areas at the top and bottom liner model juncture regions are suction panels in the "collar" around the ends of the model to control the growth of the boundary layer in these regions. The dark area on the left vertical wall and downstream of the model is one of the flexible two-wall chokes (sonic throat). The choke plate on the opposite wall is hidden behind the model. The dark area immediately in back of the model is the tunnel test section access door followed by the downstream high speed diffuser.

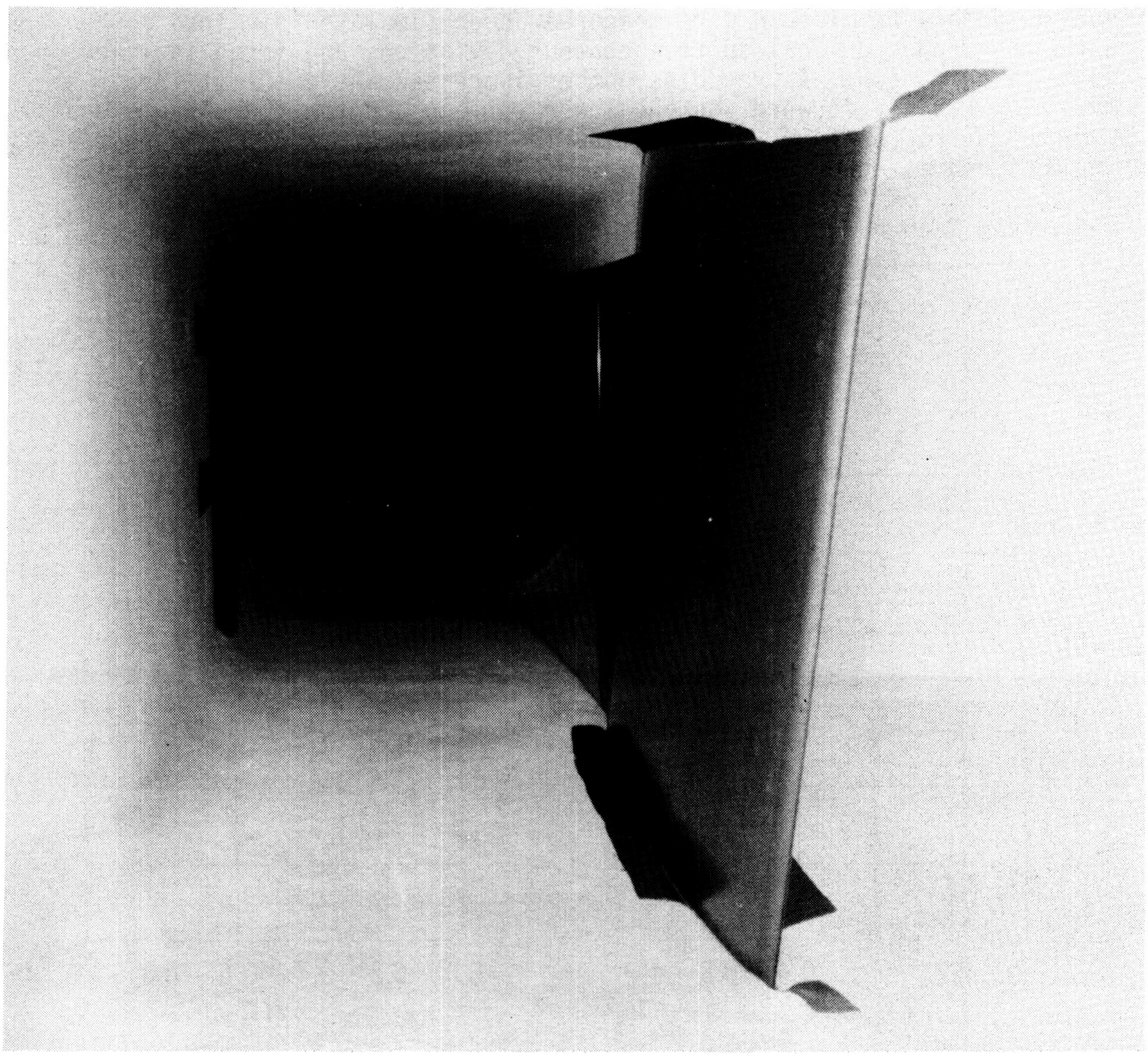

Figure 4

MEASURED AND DESIGN PRESSURE DISTRIBUTIONS

Measured and design chordwise pressure distributions on the upper and lower surfaces of the LFC model are shown in figure 5 for two chord Reynolds numbers at the design Mach number of 0.82. In general, these representative results indicate measured pressure distributions very close to design. Shockfree flow is shown for 10-million Reynolds number and essentially shockfree flow for 20-million. The slightly overall higher velocities on the upper surface and the chordwise deviation from the design pressure distribution were attributed to classical problems associated with wind tunnel testing, wall interference and model deformation under design air loads. The velocity field between the upper surface and tunnel wall (supersonic bubble zone) was slightly higher than predicted due to the liner contour and inability to completely account for boundary layer displacement effects in the design analysis. Coordinate deviations from design over the LFC model forward upper surface at midspan were measured under simulated air load to be about 0.003-inches and produced local surface contour deviations and irregularities in the pressure distribution. As Reynolds number increased above 10-million, transition moved rapidly forward on the lower surface and the flow became unable to sustain the adverse pressure gradient leading into the trailing-edge cusp and separation occurred at about 80-percent chord. This separated flow changed the local effective area distribution of the test section resulting in a slightly higher freestream Mach number and increased upper surface shock strength at 20-million Reynolds number.

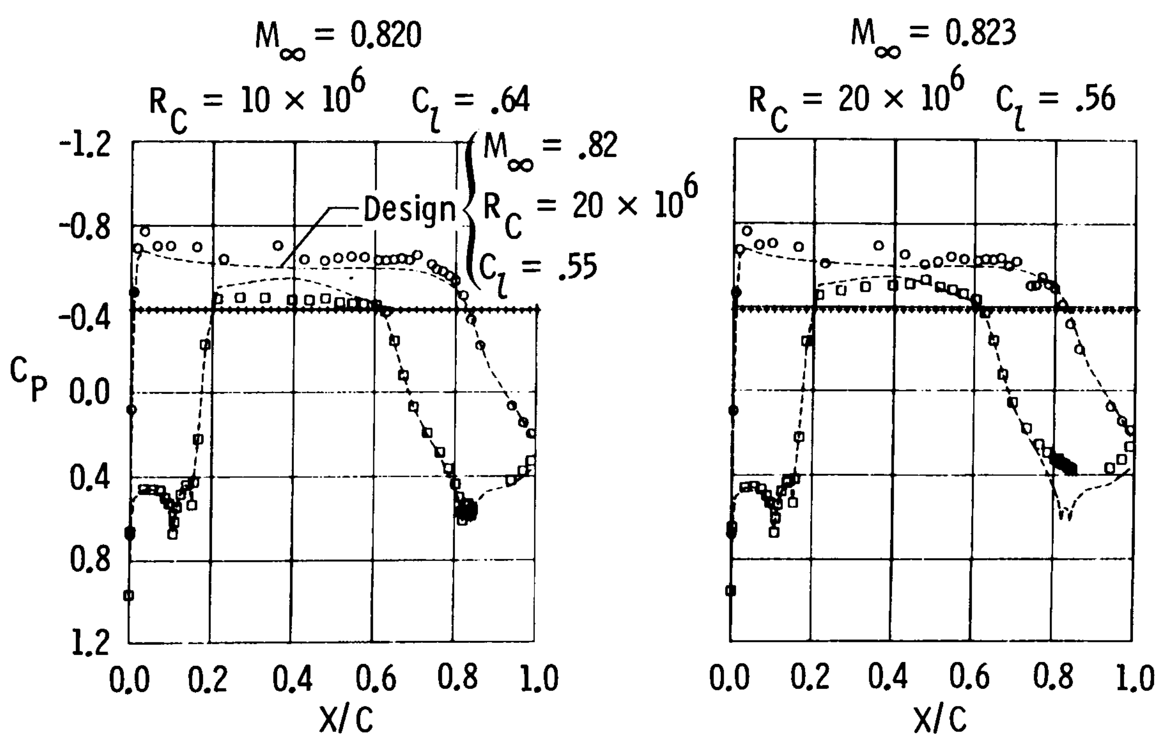

Figure 5

MEASURED AND THEORETICAL SUCTION DISTRIBUTIONS

The measured chordwise suction coefficient (C_Q) distribution required to maintain full chord laminar flow over both surfaces at the design Mach number of 0.82 and 10-million chord Reynolds number is shown in figure 6 compared to the theoretical suction distribution. The required suction level was higher than the theory over most of the upper and lower surfaces. About two-thirds of the predicted or measured total suction contribution for both surfaces is necessary for control of the lower surface geometry alone. The higher suction requirements were due to the overvelocities and the surface pressure irregularities, as well as higher suction control required to overcome the cross flow instabilities associated with the steep pressure gradients on the upper and lower surfaces and the minimization of centrifugal Taylor-Görtler type boundary layer instabilities and interactions in the concave regions of the lower surface. The overall higher suction levels are also influenced by tunnel disturbance levels which are inherently higher than free-air turbulence levels expected in flight.

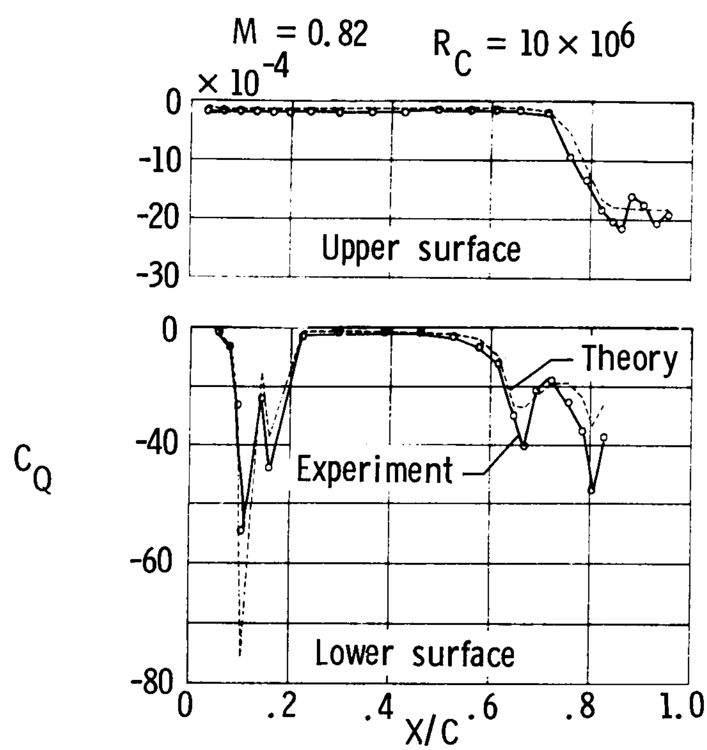

Figure 6

SUMMARY OF TRANSITION VARIATION WITH REYNOLDS NUMBER

The data presented in figure 7 show the chordwise extent of laminar flow achieved on the upper surface for several Mach numbers up to the design Mach number of 0.82, as determined by a grid of flush mounted surface thin film gages. At R_c = 10-million, full chord laminar flow could be maintained over the upper and lower surfaces for all Mach numbers. As Reynolds number was increased for constant Mach number, transition moved gradually forward on the upper surface. The Reynolds number at which this forward movement began was dependent on Mach number and occurred at progressively lower Reynolds numbers as Mach number increased. For the design Mach number of 0.82, the forward movement began between 11- and 12-million and reached about 65-percent chord at R_c = 20-million. Transition on the lower surface moved more rapidly than on the upper surface and occurred near the leading edge for M = 0.82 and R_c = 20-million. It was concluded that suction laminarization over a large supercritical zone is feasible to high chord Reynolds numbers even under non-ideal surface conditions on a swept LFC airfoil at high lift.

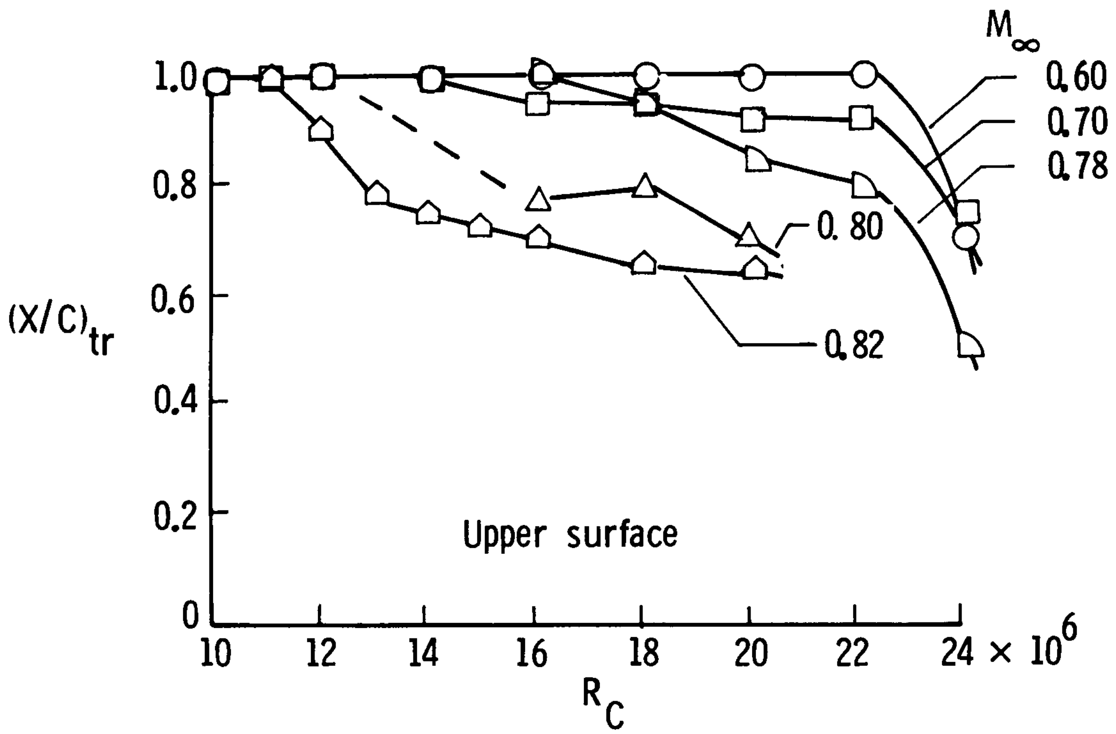

Figure 7

SUMMARY OF DRAG WITH M_∞

The total drag at M_∞ = 0.40 and 0.82 and R_c = 10 million with full chord laminar flow is seen in figure 8 to be equal to about 31 counts (c_d = 0.0031). This represents an approximate 60-percent drag reduction as compared to an equivalent conventional turbulent airfoil drag level of about 80 counts. Total drag is the sum of measured wake drag from a wake rake at midspan and the suction drag penalty required to maintain full chord laminar flow. The suction required to maintain full chord laminar flow was somewhat higher than anticipated and the contribution to the total suction drag was approximately 40-percent from the upper surface and 60-percent from the lower surface. The increase in wake drag for Mach numbers just below the design Mach number of 0.82 was associated with the formation of a weak shock wave near the leading edge as the supersonic bubble began to develop. As the bubble developed (0.78 < M_∞ < 0.80) full chord laminar flow was still present but periodic turbulent bursts occurring over the upper surface caused an increase in the wake drag. As the Mach number increased to 0.82, the supersonic zone spread rearward to approximately the 80-percent chord, the turbulent bursts over the upper surface disappeared, and the wake drag returned to near its subsonic level.

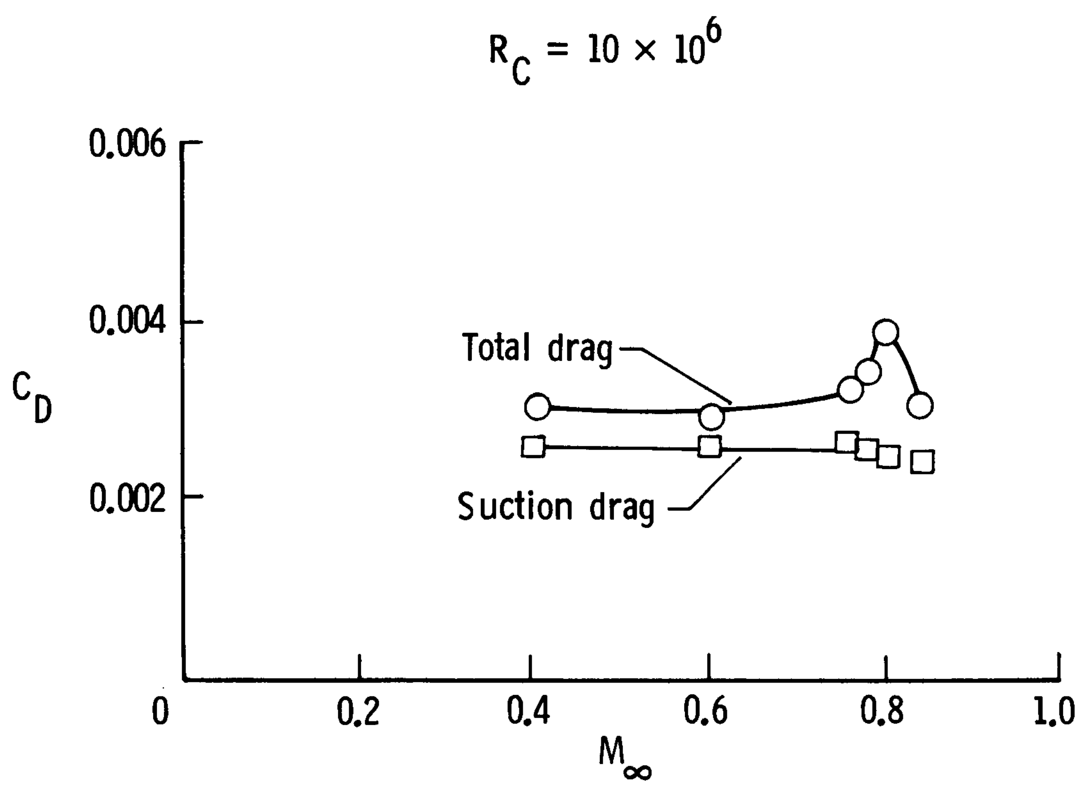

Figure 8

MEASURED DRAG ON AIRFOILS WITH/WITHOUT SUCTION CONTROL

A summary of the measured drag on airfoils with and without suction control, developed by the Airfoil Aerodynamics Branch of the Transonic Aerodynamics Division over the past several years, is shown in figure 9. The most recent design concepts with Natural Laminar Flow (NLF) or Laminar Flow Control (LFC) are identified as NLF(1)-0414F, HSNLF(1)-0213, and SCLFC(1)-0513F. Performance evaluation of all the concepts shown was conducted in NASA Langley facilities that have been rehabilitated or modified for improved flow quality and low drag testing except the 6- × 28-inch Transonic Tunnel (TT) which has not been modified. The total drag of the swept supercritical LFC airfoil with suction slots includes the suction drag penalty required to maintain full chord laminar flow. The solid symbols represent drag levels obtained with the maximum extent of laminar flow at the design lift coefficient and Reynolds number. The open symbols indicate drag levels obtained with the same airfoils with fully turbulent, attached flow tripped at the leading edge. In general, the results indicate about 60% drag reduction achieved with laminar flow over the speed range, with or without suction control or sweep, when compared with a turbulent drag level of about 80 counts. Of further major importance is the fact that both the NLF(1)-0414F and HSNLF(1)-0213 airfoils showed no degradation of lift performance or pitching moment characteristics when fully turbulent.

Data	Facility	Airfoil	Λ	$(L/D)_{max}$
○	LTPT	Long endur	0°	218
□	LTPT	NLF(1)-0414F	0°	160
▽	LTPT	NLF(1)-0215F	0°	175
△	LTPT 6 × 28 TT	HSNLF(1)-0213	0°	53
◿	8-ft TPT	SCLFC(1)-0513F	23°	183
◇	8-ft TPT	SC Turb	0°	75

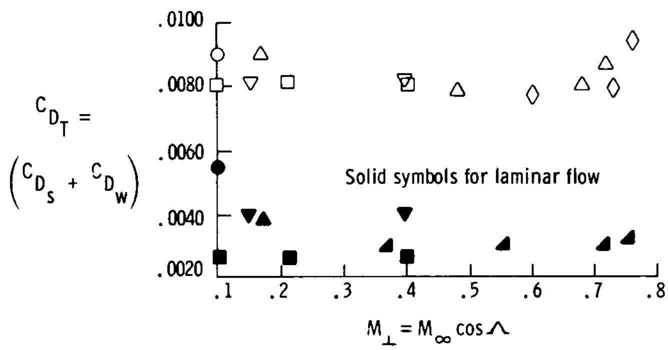

Figure 9