N90-12559

PART II: AERODYNAMIC PREDICTIONS

O. J. Rose
PRC Kentron, Inc.
Hampton, Virginia

D. S. Miller
NASA Langley Research Center
Hampton, Virginia

[redacted]

INTRODUCTION

Current boundary-layer transition analysis methods require boundary-layer profiles generated from a code which requires as input the surface pressures and velocities taken from an inviscid flow code or from experimental data (ref. 1). The purpose of this study was to examine a specific nonlinear flow code (NCOREL) as a candidate for supplying the necessary inviscid flow information (refs. 2, 3).

The approach was to compare calculated pressures with the surface pressures measured in flight on the wing of an F-106 aircraft. Special attention was given to the location of the attachment line and the pressure distribution in the immediate vicinity of the wing leading edge. Comparisons were made at three different supersonic flight conditions.

AERODYNAMIC PREDICTIONS: INTRODUCTION

- Objective: Validate usefulness of non-linear full potential method for application to laminar flow research at supersonic speeds

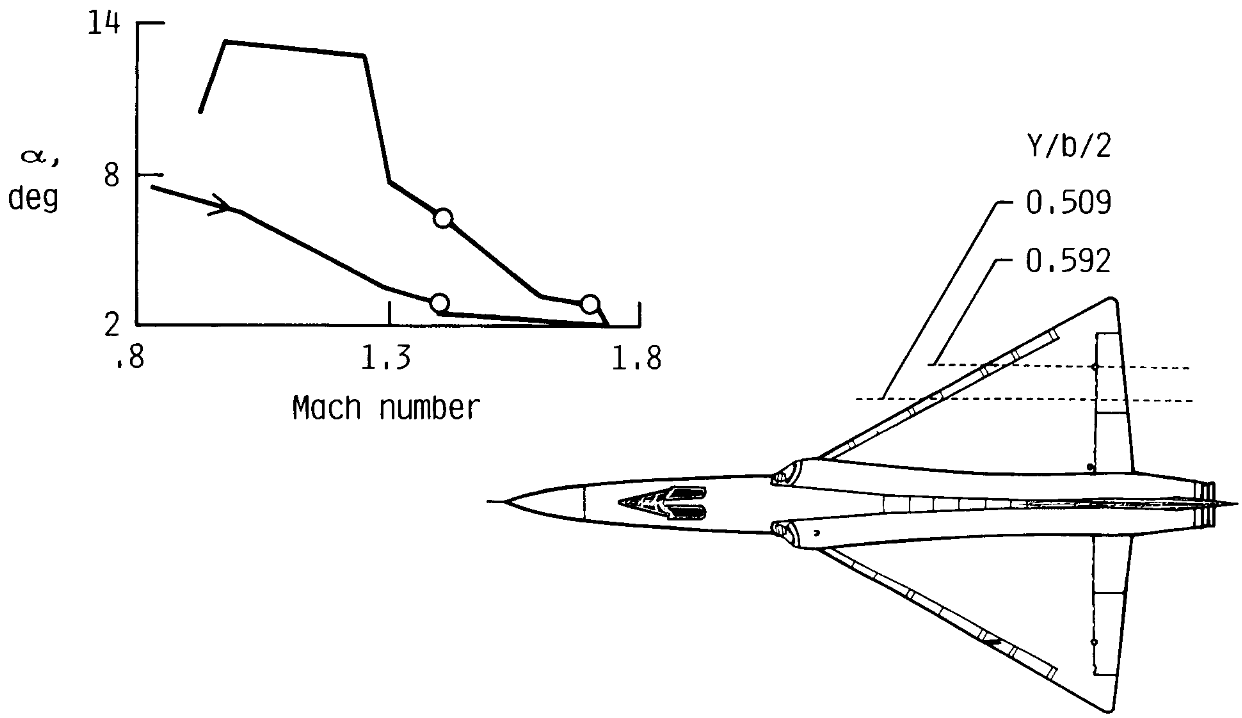
- Approach: Compare full potential solutions and surface pressures measured in flight on F-106 A/C

    - NCOREL code (wing alone and wing body)
    - Comparisons at three flight conditions

FLIGHT PROFILE AND SENSOR LOCATION

The flight profile is shown in the upper portion of the figure in terms of angle of attack and Mach number. The angle of attack ranged from approximately 2 to 4 degrees and the Mach number ranged from approximately 0.80 to 1.75. The three specific flight conditions selected for making the pressure data comparison are indicated by the open symbols. Specifically, the three cases of respective angles of attack and Mach number are: 2.69° and 1.40; 5.92° and 1.43; 2.37° and 1.72.

As shown in the lower portion of the figure, the pressure sensors were arranged streamwise at two locations corresponding to semi-span fractions of 0.509 and 0.592. The pressure sensors were located from less than 1/2 percent chord on the lower surface around the leading edge to approximately 40 percent chord on the upper surface. This arrangement was selected to provide detailed coverage around the leading edge of the wing and on the wing's upper surface.



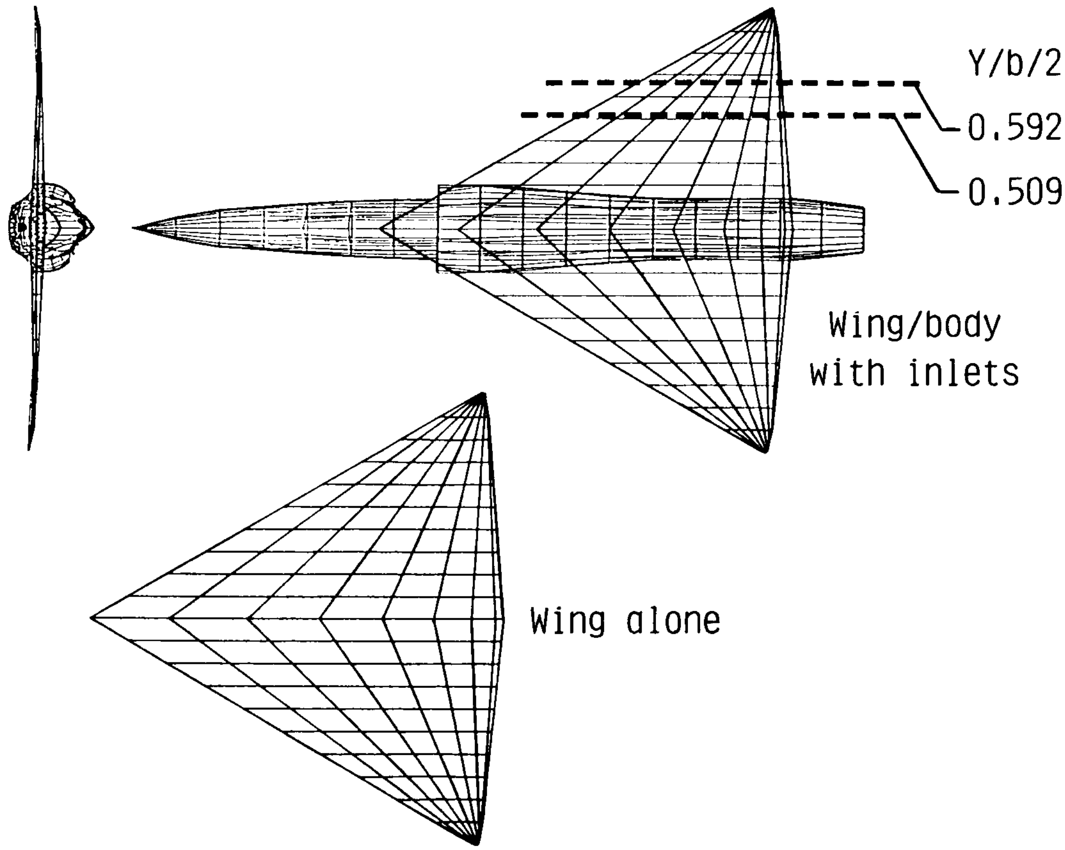
FEATURES OF NONLINEAR FLOW ANLAYSIS CODE (NCOREL)

The essential details of the full-potential flow code (NCOREL) are listed in the figure. This code solves the nonlinear full-potential equation for configurations having supersonic free-stream Mach number and attached bow shocks. The solution procedure uses an implicit marching scheme and is thus limited to flows supersonic in the marching direction. The grid generation is accomplished using conformal mapping techniques and is presently able to treat wing-body-inlet configurations. This grid generation is ideal for studying flow transition because it naturally clusters grid points around the leading edge. The inlet modeling assumes 100 percent captured mass flow, i.e., no spillage. The configuration geometry can be described as discrete points or analytic equations or a combination; the F-106 is described entirely by discrete points. In this study, only surface pressures are examined; however, all flow quantities are available. It will be necessary to have both surface pressures and velocities for application to fully three-dimensional boundary layers.

- Solves non-linear full potential equation
- Supersonic implicit marching scheme
- Configurations may have fuselage, wing, inlet
- Geometry representation can be
    - Pointwise
    - Analytic
    - Mixed
- Internally generated computational grid
- All flow field and surface quantities available

F-106 COMPUTATIONAL GEOMETRY

One of the objectives of the study was to examine the necessary configuration modeling requirements. Thus computational results were obtained for both a complex wing-body-inlet and a simple wing-alone representation. It was estimated that a factor of four in computational time and time required to prepare input could be saved if the wing-alone representation was found to be adequate.



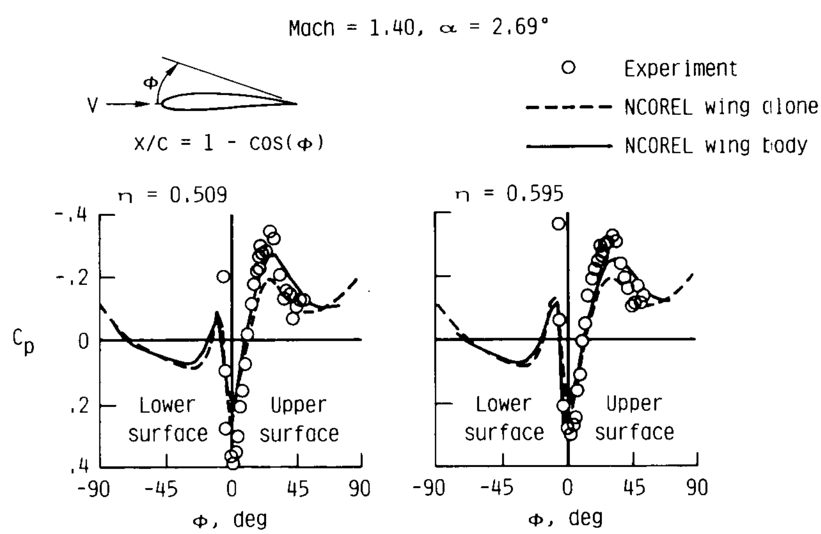
MEASUREMENT/THEORY COMPARISON

(M = 1.4, Alpha = 2.69)

Experimental and theoretical pressures are presented in the next three figures. In each figure, the results are displayed by plotting C_p as a function of ϕ, where ϕ is an angular representation of the chord fraction. As indicated in the sketch in the figure, the value of $\phi = 0^0$ corresponds to the wing leading edge, and positive and negative values correspond to the upper and lower surface respectively.

The F-106 wing has leading-edge camber, and for the Mach number and angle of attack considered here the pressure measurements exhibit extreme variations. In particular, there are two strong suction peaks, one on the lower surface and one on the upper surface in addition to the high pressure value at the attachment line.

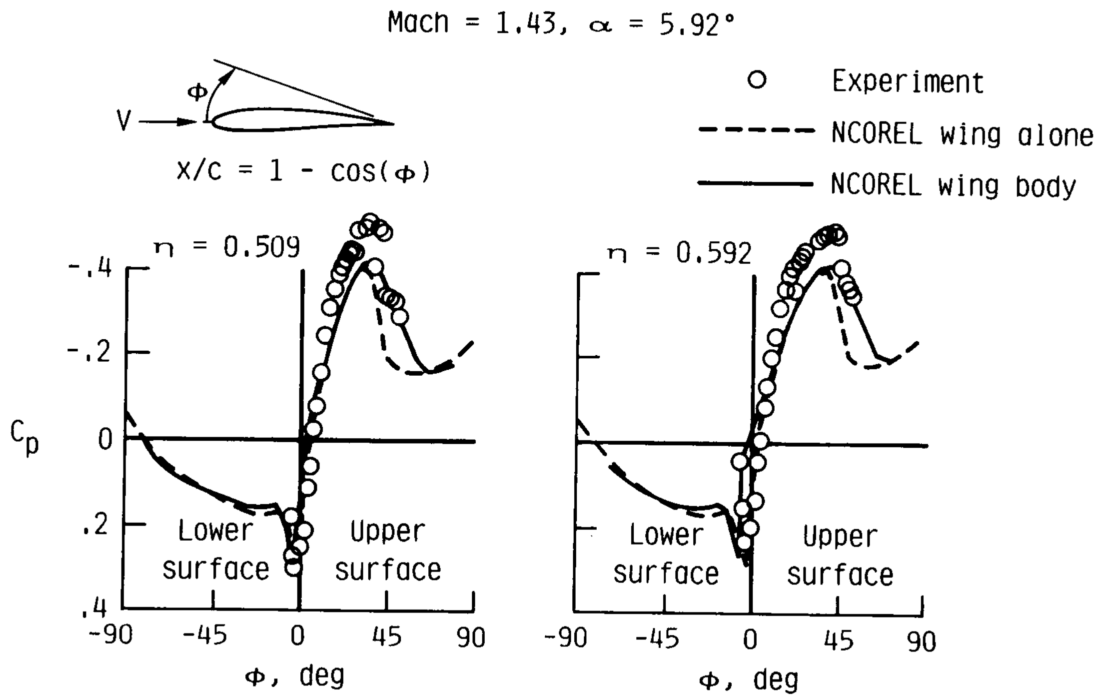
In the region of the leading edge, the character of the highly varying pressure distribution is faithfully predicted by both the wing alone and the wing-body-inlet configurations. The location of the flow attachment line, characterized by the maximum pressure coefficient, and the location of both suction peaks are well predicted. At this condition of Mach number and angle of attack, the pressure magnitude at the attachment line is accurately predicted at the outboard span station but is substantially underpredicted at the inboard station. The magnitudes of the suction peaks are underestimated. In the region of the upper surface suction peak and just downstream the wing-body-inlet pressures are in closer agreement with the experimental data than are the wing-alone pressures.



MEASUREMENT/THEORY COMPARISON

(M = 1.43, Alpha = 5.92)

The results shown in this figure are for a Mach number essentially the same as the previous case, but at a higher angle of attack. At this higher angle of attack, the measured pressures no longer exhibit a suction peak on the lower surface and the upper surface suction peak is significantly larger. The character of the pressure distribution is quite different from the previous case and is well predicted, with good agreement except near the upper surface suction peak where the theory underestimates the suction by about 15 percent. The wing-body-inlet and wing-alone results agree up to the upper surface suction peak which is near d = 40° or 23 percent of the local chord. For the region downstream of the suction peak, the wing-body-inlet results are in good agreement, and the wing alone significantly overpredicts pressure.



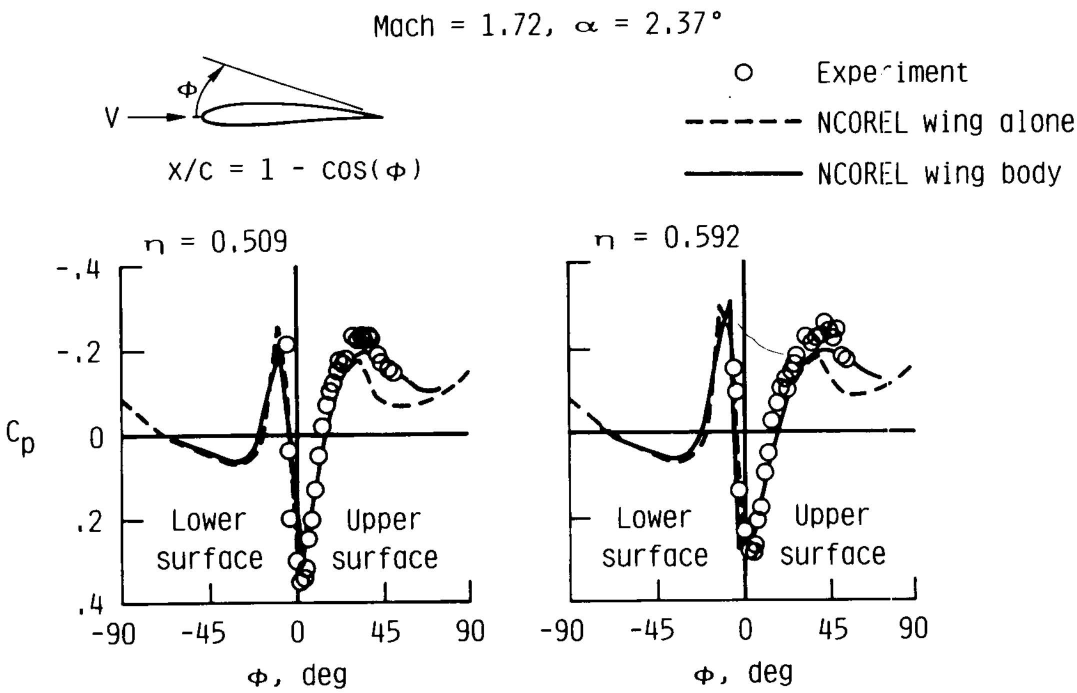
MEASUREMENT/THEORY COMPARISON

(M = 1.72, Alpha = 2.37)

The data shown in this figure are for a Mach number of 1.72 and an angle of attack of 2.37°. At this low angle-of-attack condition, the measured pressures again exhibit two suction peaks as there were for the M = 1.4 and alpha = 2.69 case. For the present case, the two suction peaks are of nearly equal strength.

As in the previous two figures, the character of the pressure distribution, the location of the attachment line, the location of attachment line, the location of the suction peaks, and the stagnation pressure magnitudes are well predicted.

Overall, the agreement between data and theory is closer for this higher Mach number case. Again, the wing alone and wing-body-inlet results agree except for the region downstream of the upper suction peak, which occurs at about $\phi = 40°$ or 23 percent of chord.



AERODYNAMIC PREDICTIONS: SUMMARY

In the leading-edge region, the measured pressure distributions exhibit extreme variations from strong suction peaks to a pressure maximum at the attachment line. These variations occur over short distances on the wing surface, and their character changes with changes in Mach number and angle of attack.

The data/theory comparisons show that the character of the measured pressure distributions is well predicted for every Mach number/angle-of-attack condition considered. There is good agreement between theory and experiment for the location of the attachment line and suction peaks. The pressure magnitudes are well represented in the critical leading-edge region, including the pressure maximum on the attachment line. The wing/body/inlet results agree well with the wing alone back to about 20 percent of chord where the upper surface suction peak typically occurs.

The largest differences between theory and measurement always occur in the vicinity of suction peaks, with the difference being approximately 15 percent or less. In the regions of largest error, the predicted pressures underestimate the suction peak strength for each case considered.

The results show the ability of the NCOREL code to reproduce all the essential characteristics of the wing pressure. Moreover, the wing-alone results agree well enough with the wing-body-inlet to justify use of this simplification at least for preliminary design. Although these results are encouraging, the suction peak magnitudes are underestimated, and the effect of this on the boundary-layer stability analysis must be determined.

REFERENCES

1. Malik, Mujeeb R.: COSAL--A Black Box Compressible Stability Analysis Code for Transition Prediction in Three-Dimensional Boundary Layers. NASA CR-165925, May 1982.

2. Siclari, Michael J.: The NCOREL Computer Program for 3D Nonlinear Supersonic Potential Flow Computations. NASA CR-3694, August 1983.

3. Siclari, Michael J.: Supersonic Nonlinear Potential Flow Analysis--Interim Report. NASA CR-172456, August 1984.