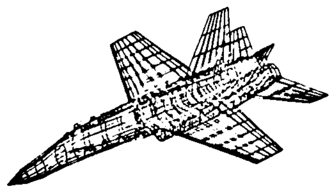
N87-11742

SENSITIVITY ANALYSIS IN COMPUTATIONAL AERODYNAMICS

Dean R. Bristow
McDonnell Aircraft Company
St. Louis, MO

SUBSONIC INVISCID PANEL METHOD



MCAERO

INPUT: GEOMETRY

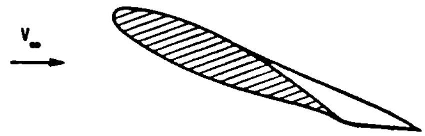
OUTPUT: PRESSURE

DMCAERO

INPUT: GEOMETRY

OUTPUT: $\frac{\partial \text{ PRESSURE}}{\partial \text{ GEOMETRY}}$

INTERACTING VISCIOUS AND INVISCID THEORIES FOR HIGH α



INVISCID THEORY ⟶ $\frac{\partial \text{ PRESSURE}}{\partial \text{ GEOMETRY}}$

VISCOUS THEORY ⟶ $\frac{\partial \text{ GEOMETRY}}{\partial \text{ PRESSURE}}$

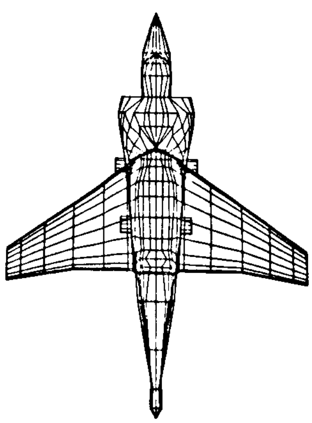
⇩

$$\left[P + \frac{\partial P}{\partial G}\Delta G\right]_{\text{INVISCID}} = \left[P + \left(\frac{\partial G}{\partial P}\right)^{-1}\Delta G\right]_{\text{VISCOUS}}$$

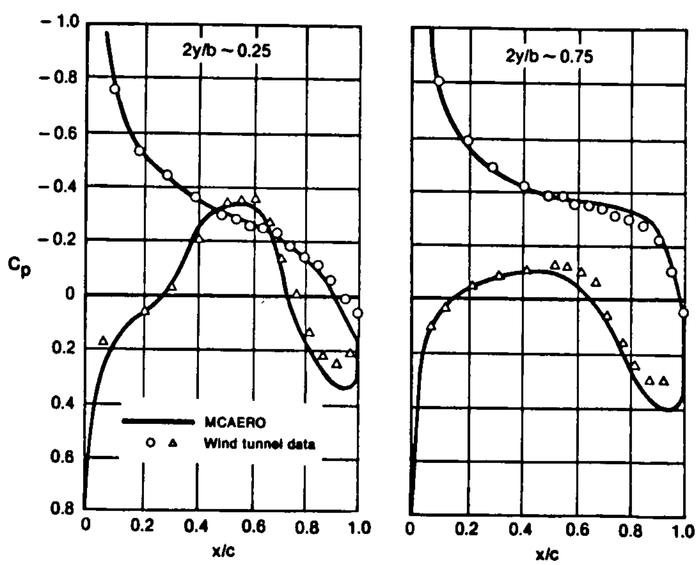
PREDICTION ACCURACY OF MCAERO

CONVENTIONAL ANALYSIS MODE

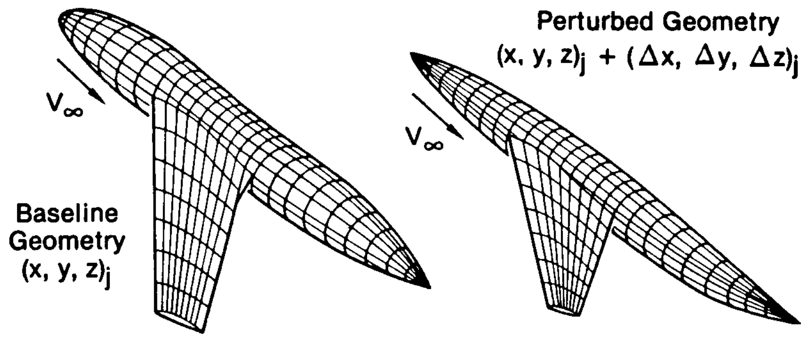
6.4° ANGLE-OF-ATTACK MACH 0.50



YAV-8B Surface Panel Modeling



PERTURBATION ANALYSIS METHOD



Objective

- Subsonic Inviscid Analysis of Multiple Geometry Perturbations at Small Additional Cost

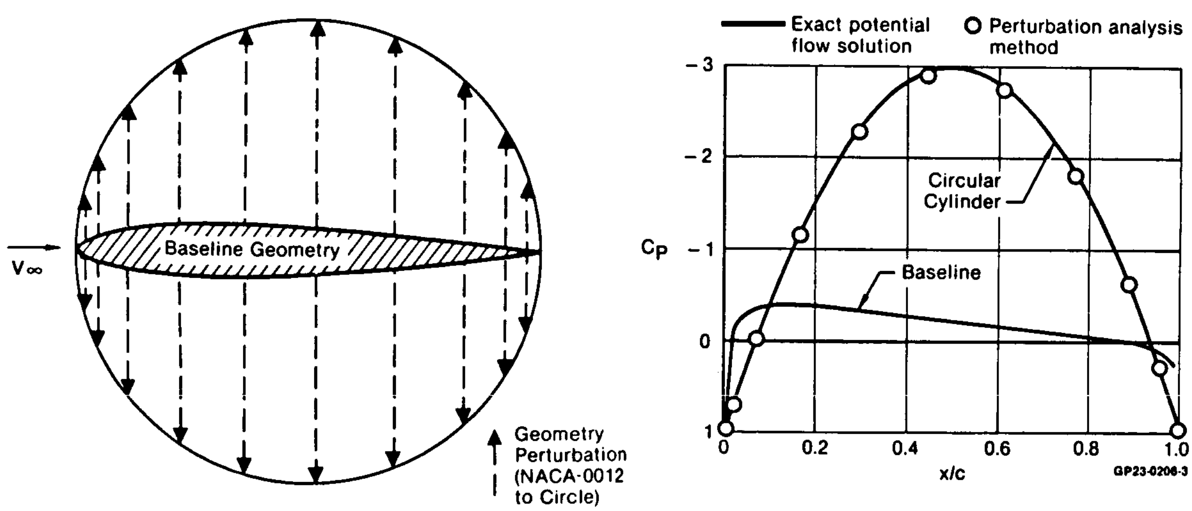
Approach

- Precalculated Baseline Matrix of Potential Derivatives $\left\{\frac{\partial \phi i}{\partial x_j}, \frac{\partial \phi i}{\partial y_j}, \frac{\partial \phi i}{\partial z_j}\right\}$
- Linear Extrapolation

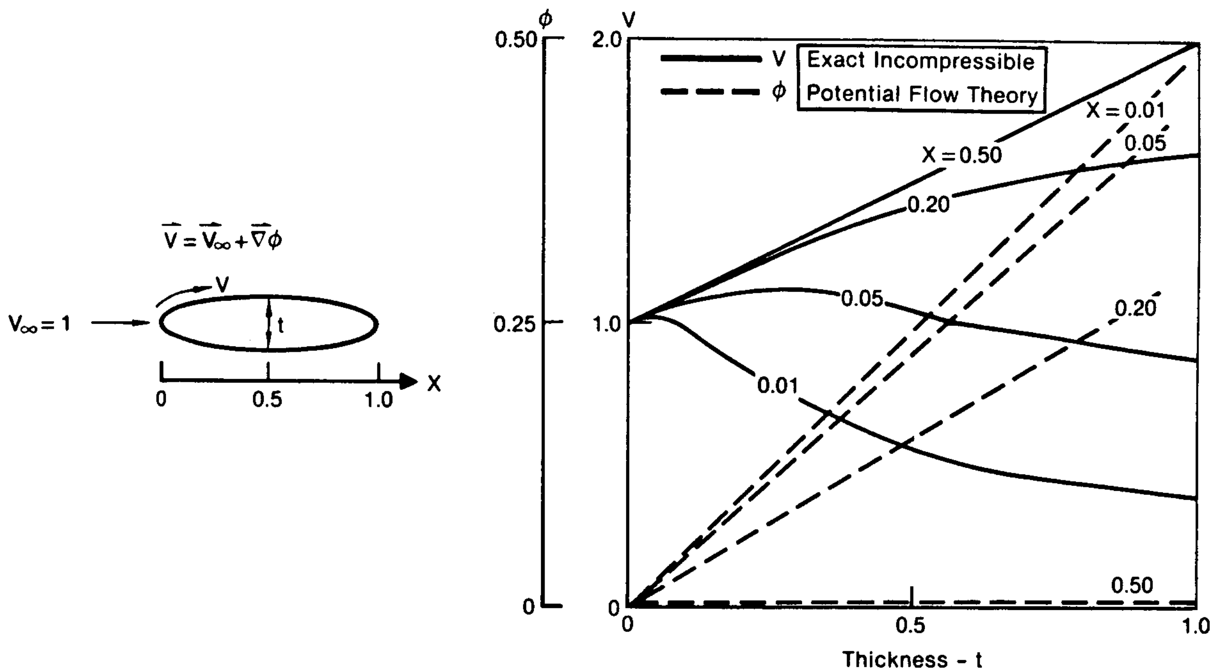
$$(\phi_i + \Delta\phi_i) = \phi_i + \sum_j \left\{\frac{\partial \phi i}{\partial x_j}\,\Delta x_j + \frac{\partial \phi i}{\partial y_j}\,\Delta y_j + \frac{\partial \phi i}{\partial z_j}\,\Delta z_j\right\}$$

SIMPLE DEMONSTRATION OF PERTURBATION ANALYSIS METHOD

2-D INCOMPRESSIBLE FLOW



VARIATION OF FLOW PROPERTIES WITH THICKNESS
ELLIPTICAL CYLINDER AT 0° INCIDENCE



Procedure for Calculating Perturbation Matrix

1. Conventional Panel Method Calculations

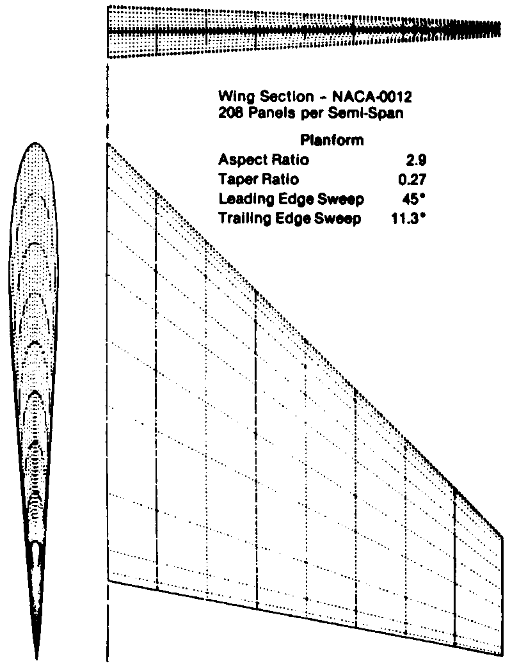
$$[A_{ij}] \cdot \phi_j = BC_i \longrightarrow \phi_i = [A_{ij}]^{-1} \cdot BC_j$$

2. First-Order Expansion

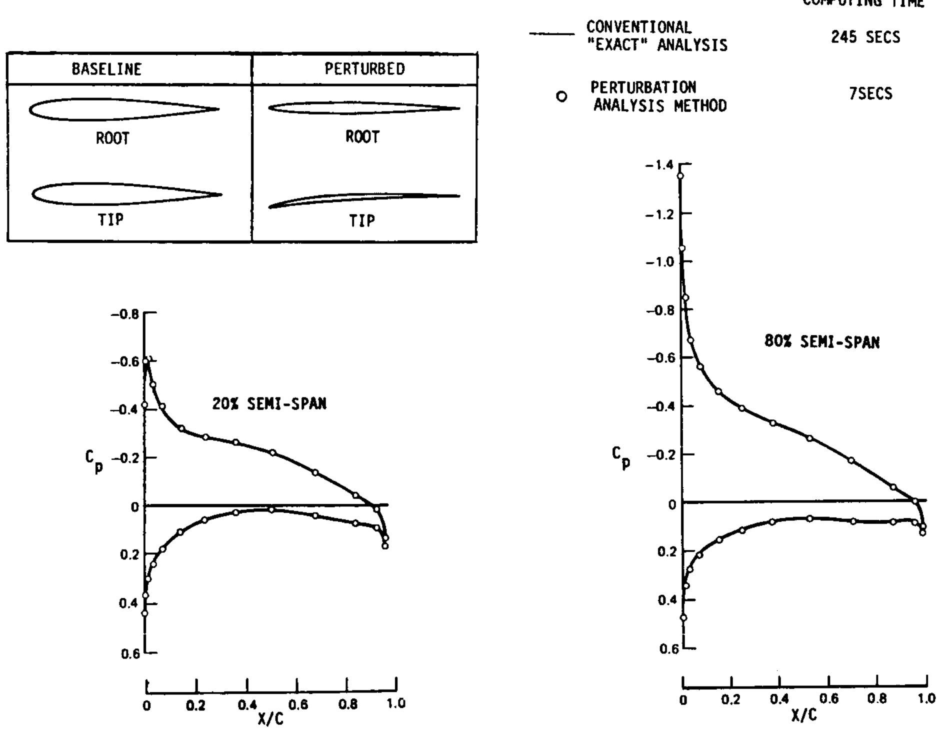
$$[A_{ij}] \cdot \frac{\partial \phi_j}{\partial z_k} + \phi_j \cdot \left[\frac{\partial A_{ij}}{\partial z_k} \right] = \frac{\partial BC_i}{\partial z_k}$$

$$\frac{\partial \phi_i}{\partial z_k} = [A_{ij}]^{-1} \cdot \left\{ \frac{\partial BC_j}{\partial z_k} - \phi_\ell \cdot \left[\frac{\partial A_{j\ell}}{\partial z_k} \right] \right\}$$

BASELINE WING PANELING FOR PERTURBATION ANALYSIS TEST CASES



FIGHTER WING
AT 5° ANGLE OF ATTACK



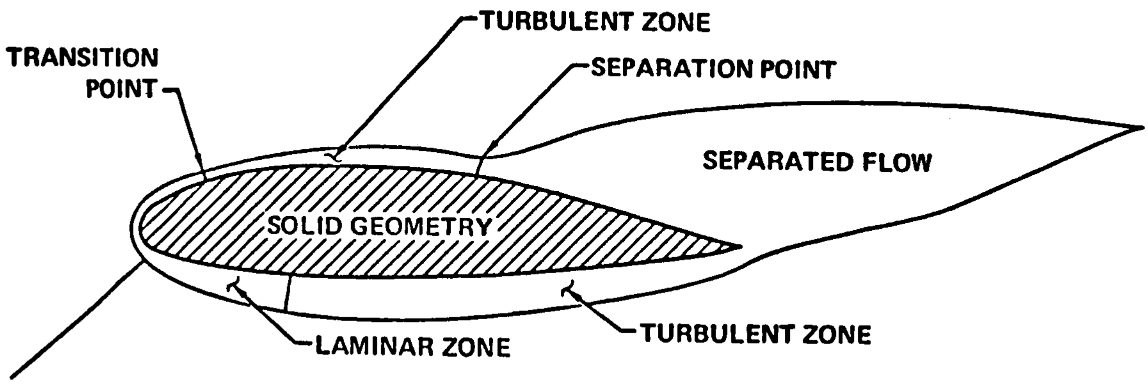
APPLICATIONS OF INVISCID SENSITIVITY MATRIX

- EFFICIENT ANALYSIS OF MULTIPLE GEOMETRY PERTURBATIONS
- PRESCRIBED PRESSURE WING DESIGN
- UNSTEADY AERODYNAMICS
- AERODYNAMIC-STRUCTURAL DESIGN OPTIMIZATION
- STRONG VISCOUS-INVISCID INTERACTIONS

TWO-DIMENSIONAL AIRFOIL VISCOUS AERODYNAMICS (LOW SPEED)

GIVEN

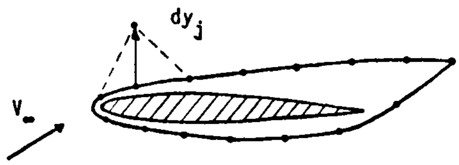
- **SOLID GEOMETRY**
- **REYNOLDS NUMBER**



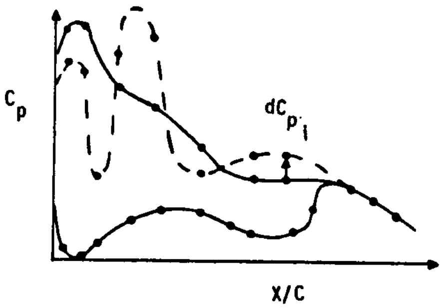
SOLUTION - GENERAL CASE

- **PRESSURE DISTRIBUTION**
- **LIFT, DRAG, AND PITCHING MOMENT**
- **SEPARATION POINT**
- **TRANSITION POINT**

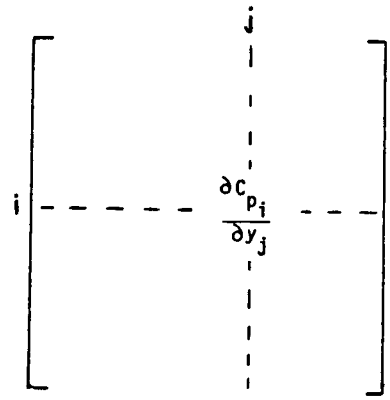
CALCULATED INVISCID PRESSURE GEOMETRY SENSITIVITY MATRIX



PERTURBATION TO y AT POINT j



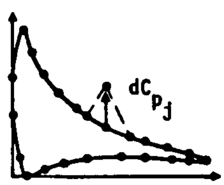
RESULTING PERTURBATION TO C_p DISTRIBUTION



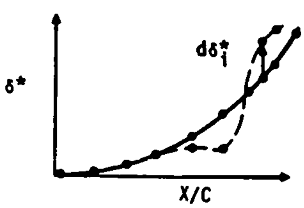
CALCULATED MATRIX

- APPROACH: ANALYTICAL EXPANSION TO MCAIR PANEL METHOD

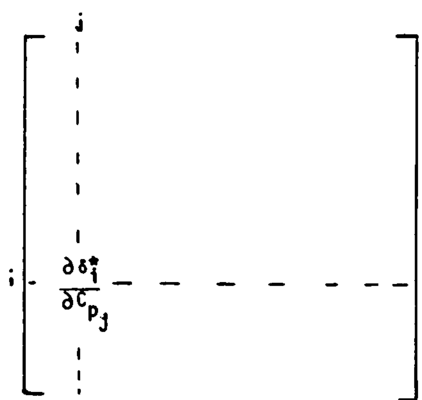
CALCULATED VISCOUS DISPLACEMENT-PRESSURE SENSITIVITY MATRIX



PERTURBATION TO C_p AT POINT j



RESULTING PERTURBATION TO DISPLACEMENT DISTRIBUTION



CALCULATED MATRIX

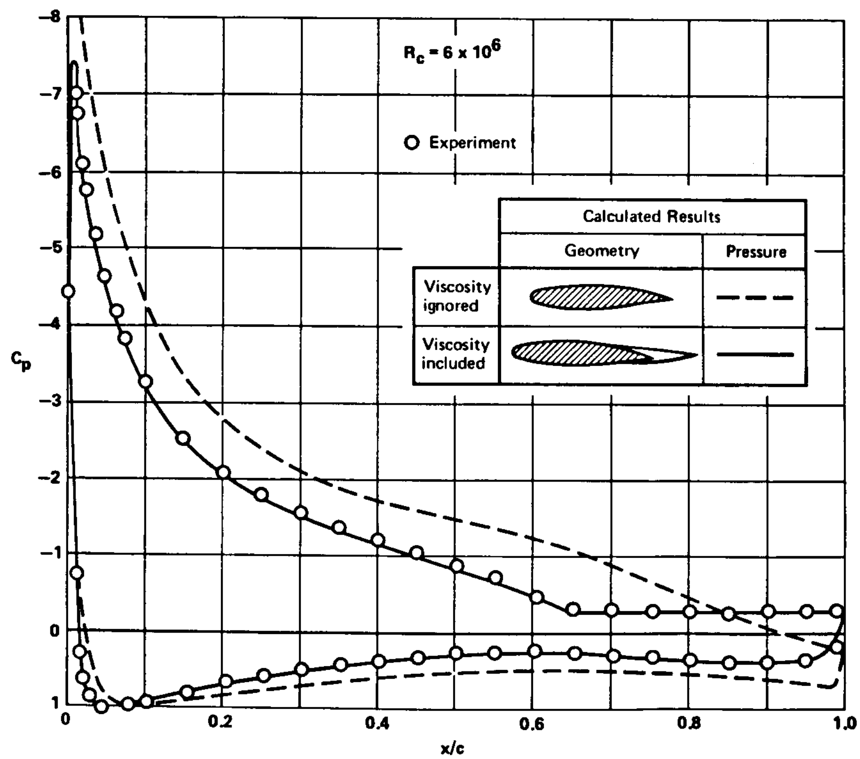
- APPROACH: ANALYTICAL EXPANSION TO BOUNDARY LAYER METHOD

MATCHING PROCEDURE FOR VISCOUS - INVISCID INTERACTION

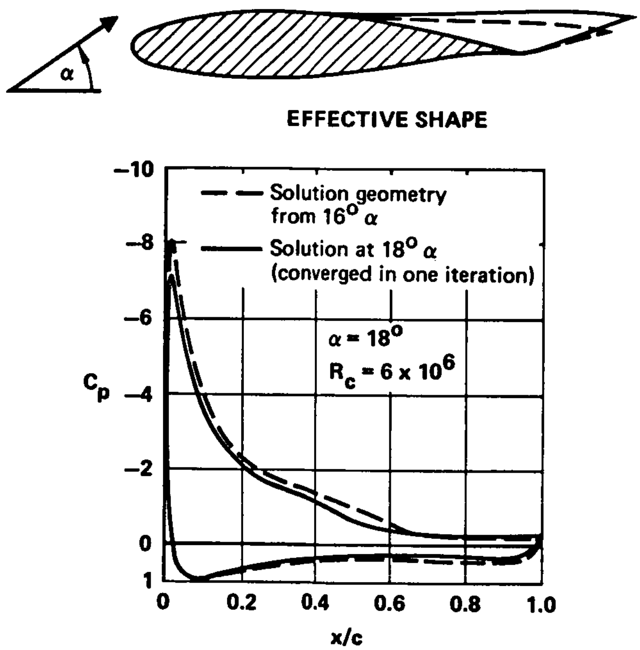
INVISCID THEORY		VISCOUS THEORY
$Y_i + \Delta Y_i$	=	$\delta_i^* + \sum_j \left(\frac{\partial \delta_i^*}{\partial C_{P_j}} \cdot \Delta C_{P_j} \right)$
$C_{P_i} + \sum_j \left(\frac{\partial C_{P_i}}{\partial Y_j} \cdot \Delta Y_j \right)$	=	$C_{P_i} + \Delta C_{P_i}$

PREDICTION ACCURACY AT HIGH ANGLE-OF-ATTACK (16°α)

GA(W)-1 AIRFOIL

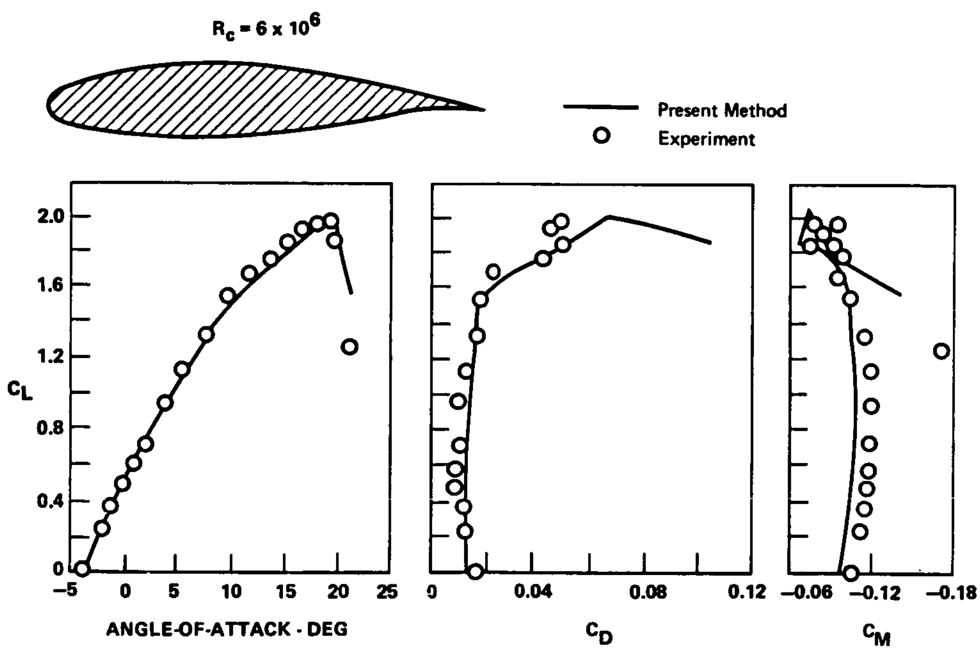


TYPICAL CHANGE BETWEEN SUCCESSIVE ANGLES OF ATTACK

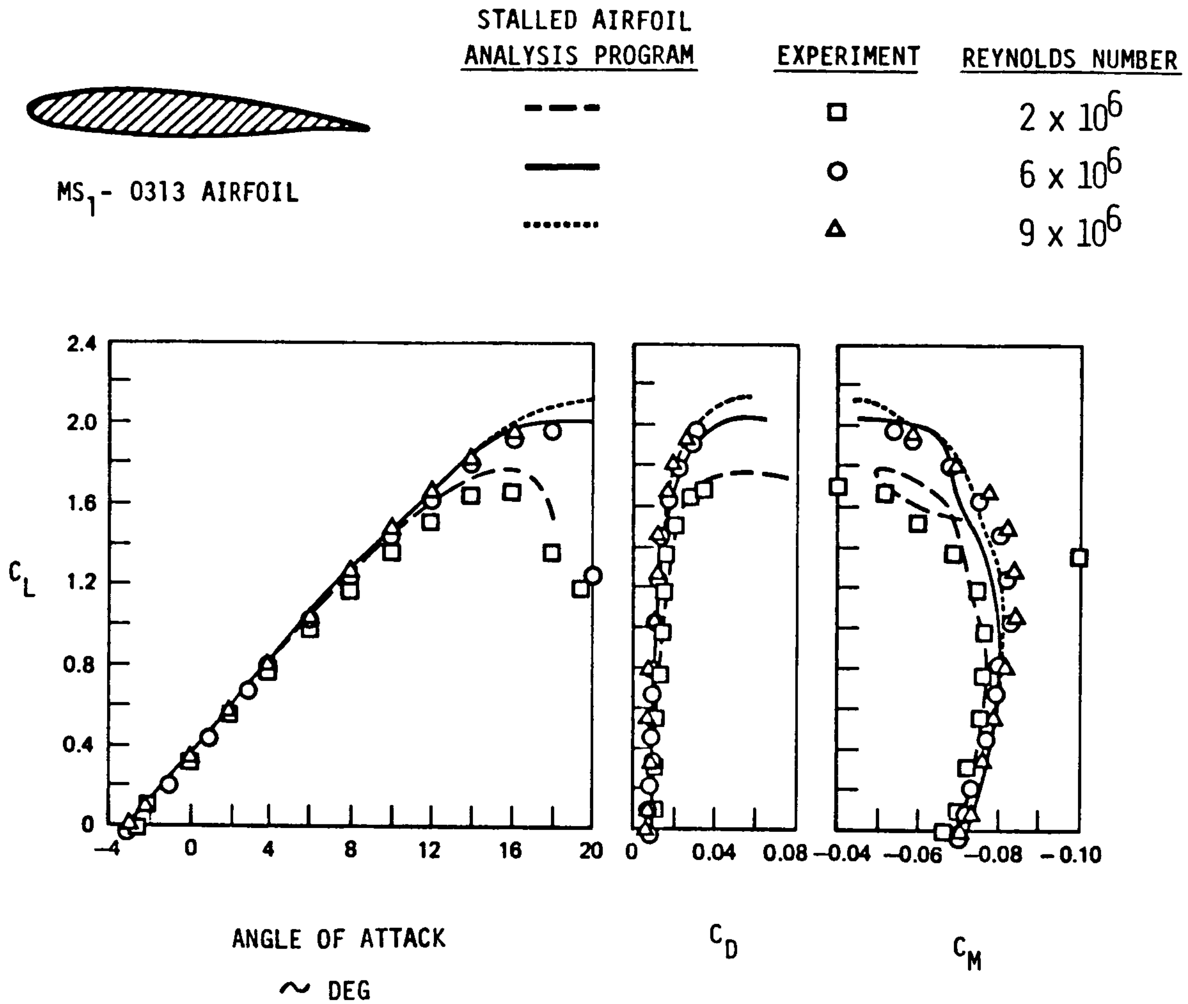


ACCURACY OF FORCE AND MOMENT PREDICTIONS

NASA GA(W)-1



EFFECT OF REYNOLDS NUMBER ON AIRFOIL PERFORMANCE



CONCLUSIONS REGARDING SENSITIVITY ANALYSIS APPROACH

- POWERFUL EXTRAPOLATION TOOL
- APPROPRIATE FOR STRONG INTERACTION BETWEEN DISTINCT THEORIES