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THREE-DIMENSIONAL VISCOUS DRAG PREDICTION FOR ROTOR BLADES

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SUMMARY

The state-of-the-art in rotor blade drag prediction involves the use of two-dimensional airfoil tables to calculate the drag force on the blade. One of the most serious problems with the current methods is that they cannot be used for airfoils that have yet to be tested. Most of the drag prediction methods also do not take the Reynolds number or the rotational effects of the blade into account, raising doubts about the accuracy of the results. This project addresses these problems with the development of an analytical method which includes the shape of airfoil, the effects of Reynolds number, and the rotational motion of the blade.

OBJECTIVES

- PROVIDE AN EFFICIENT ANALYSIS FOR ROTOR BLADE DRAG PREDICTION
- ENABLE ACCURATE DESIGN OF NEW, ADVANCED ROTOR SYSTEMS WITH IMPROVED PERFORMANCE

MOTIVATIONS

ROTOR BLADE DRAG PREDICTION CURRENTLY USES TWO-DIMENSIONAL AIRFOIL TABLES

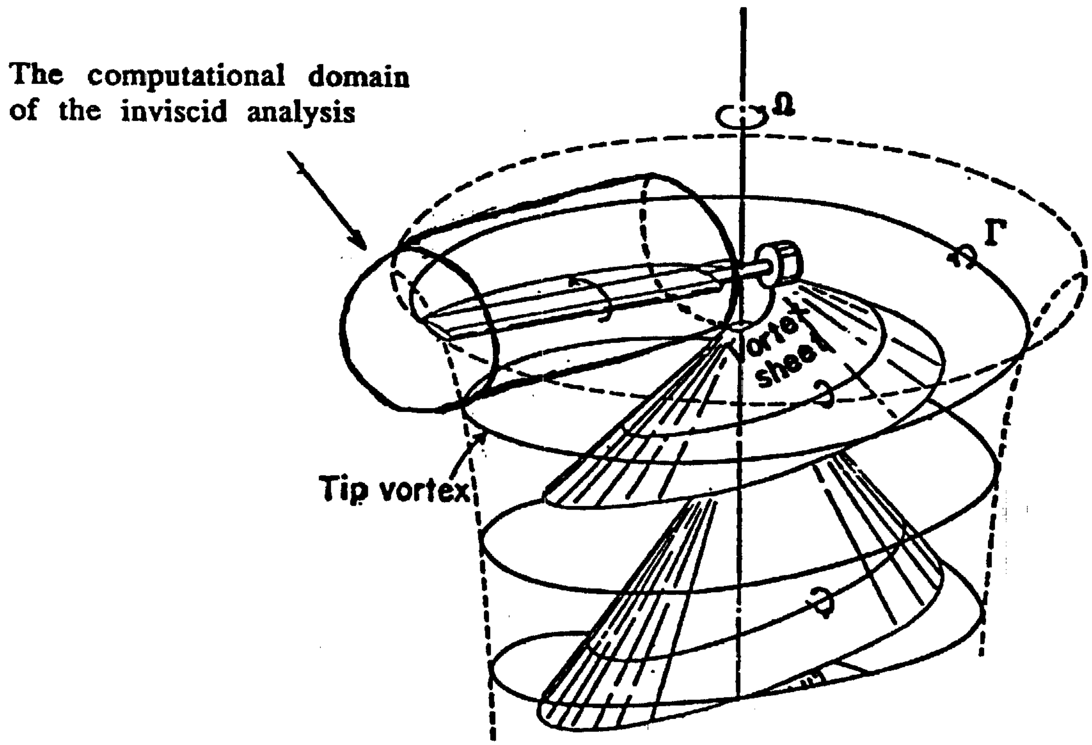
MAJOR SHORTCOMINGS:

- CANNOT BE USED FOR AIRFOILS NOT YET TESTED
- NO REYNOLDS NUMBER OR ROTATIONAL EFFECTS INCLUDED

CURRENT APPROACH INCLUDES:

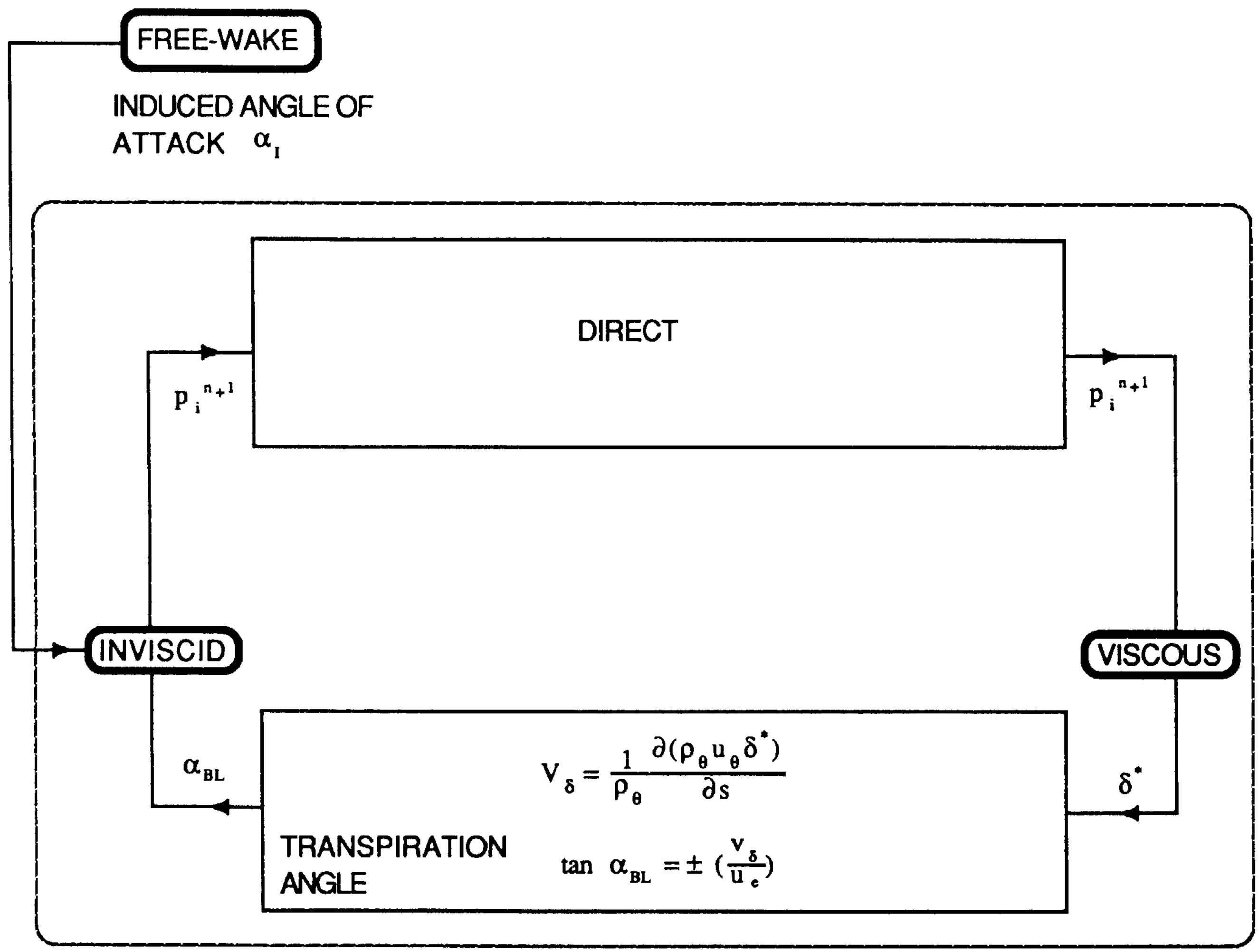
- AIRFOIL SHAPE
- REYNOLDS NUMBER EFFECTS
- ROTATIONAL MOTION OF BLADE

RELATION OF COMPUTATIONAL DOMAIN OF INVISCID ANALYSIS AND ROTOR WAKE



THE COUPLING SCHEME OF VISCOUS, INVISCID, AND FREE-WAKE METHODS

DIRECT APPROACH



UNSTEADY, COMPRESSIBLE, THREE-DIMENSIONAL BOUNDARY-LAYER EQUATIONS

ROTATING REFERENCE FRAME

X-MOMENTUM EQUATION

$$\rho(u_t + uu_x + vu_y + wu_z - 2w\Omega - x\Omega^2) = -p_x + (\mu u_y)_y$$

Z-MOMENTUM EQUATION

$$\rho(w_t + uw_x + vw_y + ww_z + 2u\Omega - z\Omega^2) = -p_z + (\mu w_y)_y$$

PERFECT GAS RELATION

$$p = \rho RT$$

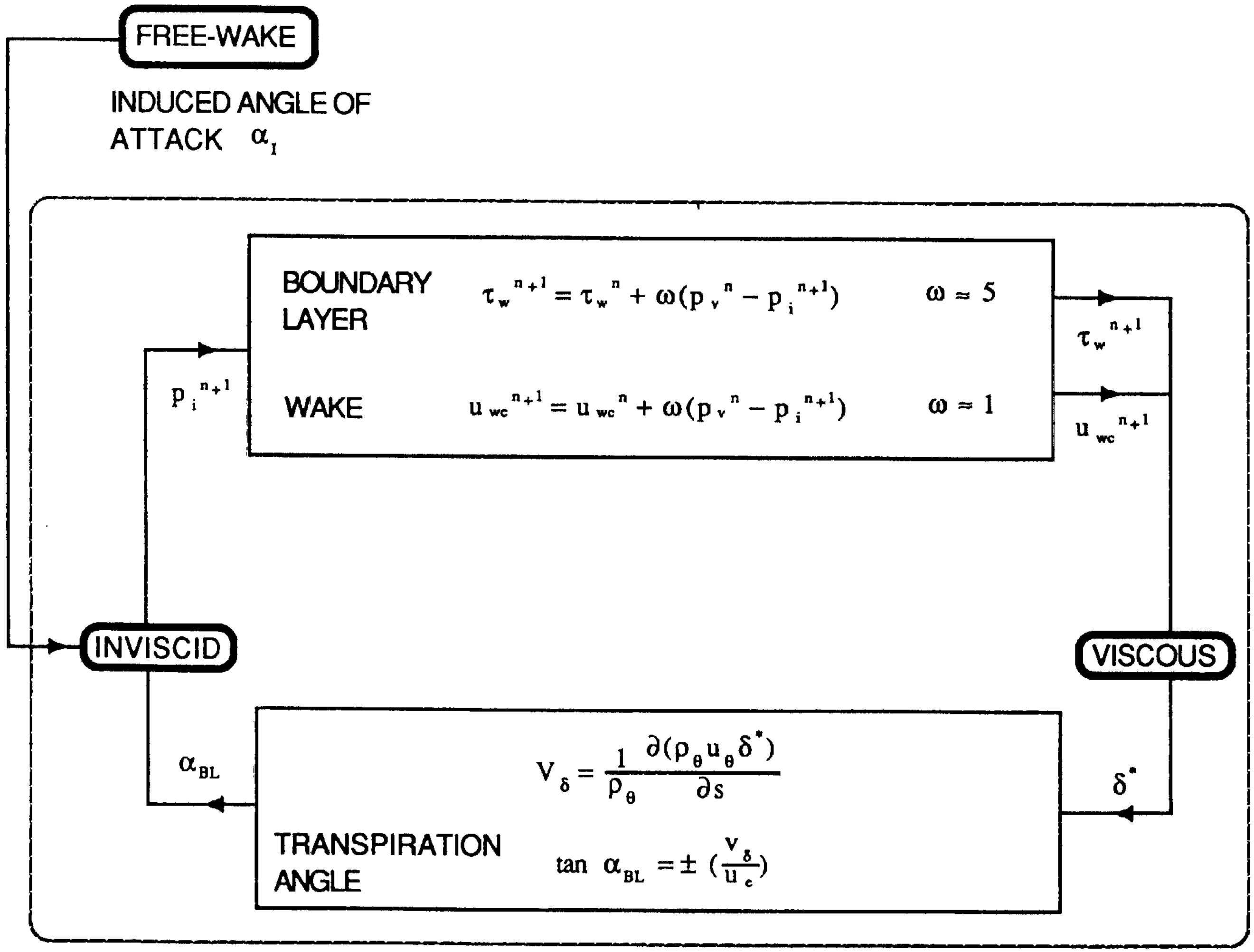
ENERGY EQUATION

$$CpT + \frac{1}{2}(u^2 + v^2 + w^2) = CONST$$

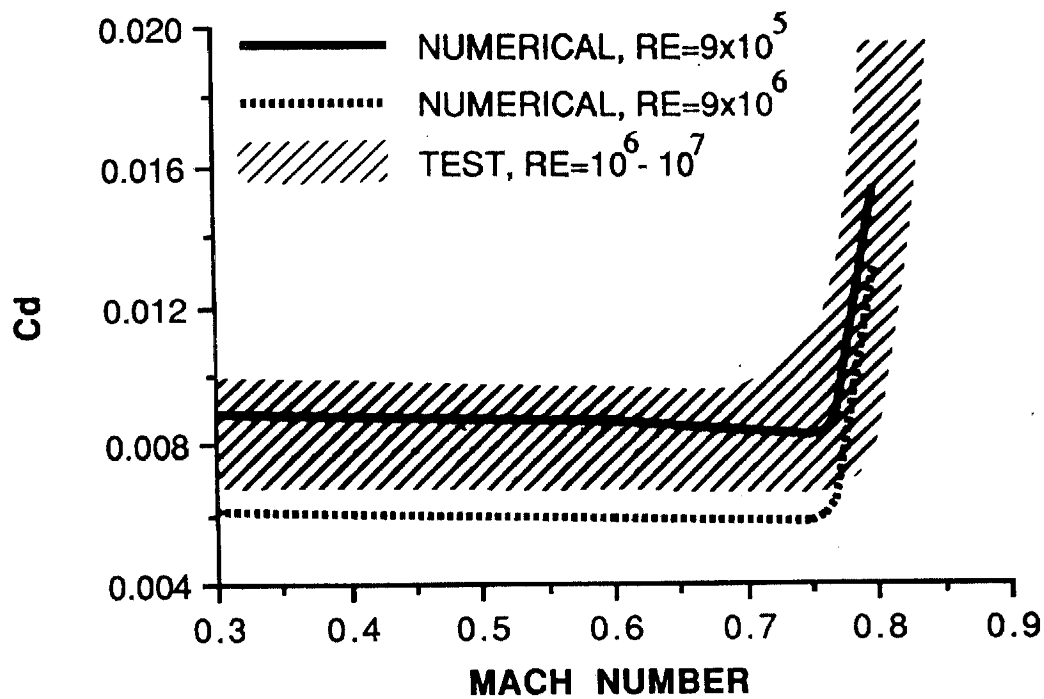
CONTINUITY EQUATION

$$\rho_t + (\rho u)_x + (\rho v)_y + (\rho w)_z = 0$$

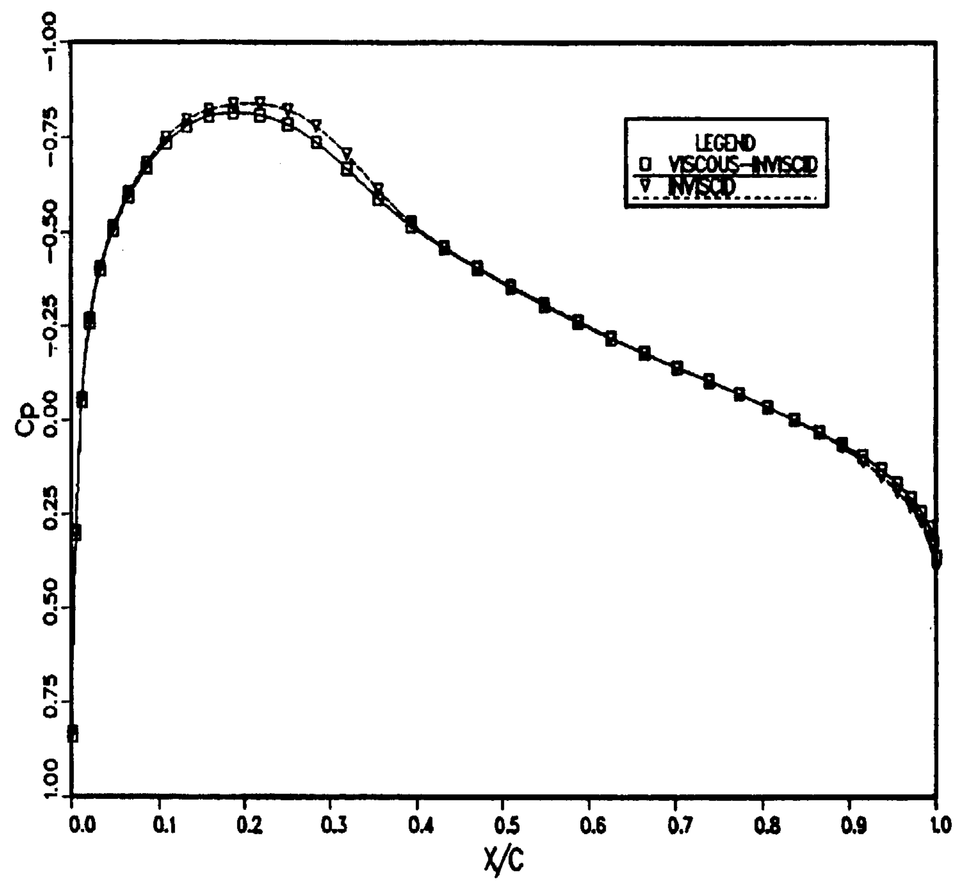
THE COUPLING SCHEME OF VISCOUS, INVISCID, AND FREE-WAKE METHODS
INVERSE APPROACH



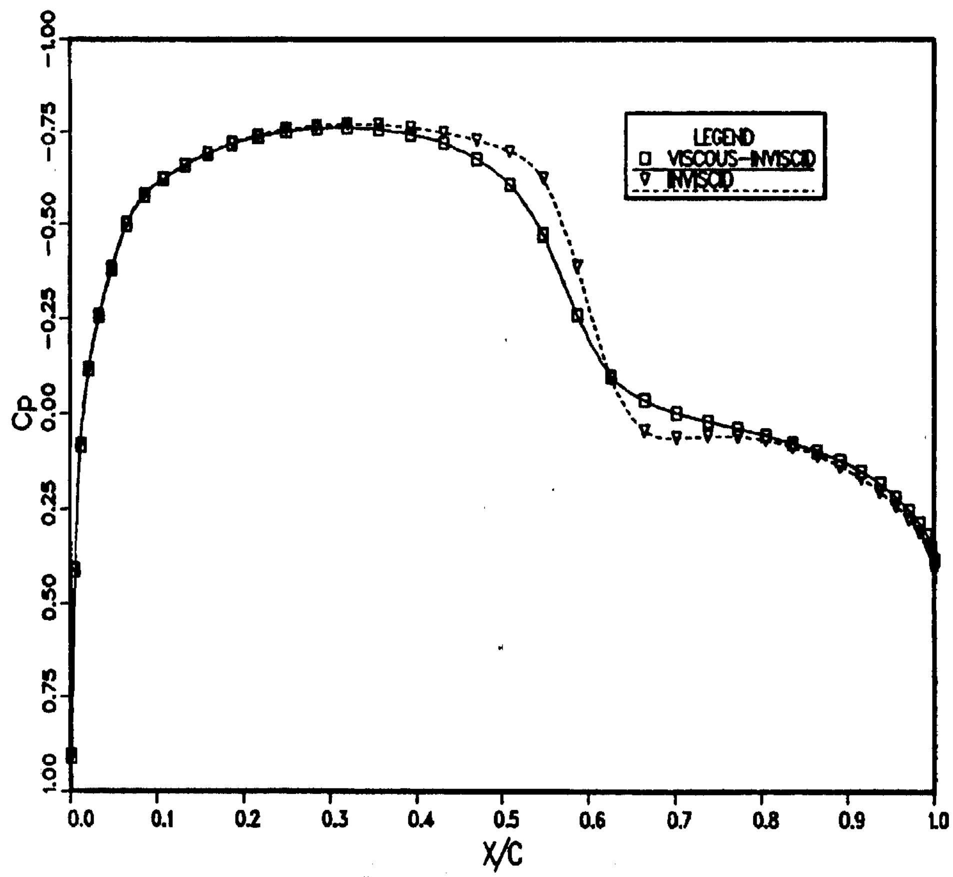
COMPARISON OF PREDICTED AND MEASURED DRAG COEFFICIENT
FOR NACA 0012 TWO-DIMENSIONAL AIRFOIL FLOWS



COMPARISON OF Cp DISTRIBUTION WITH AND WITHOUT
BOUNDARY-LAYER INTERACTION
TIP MACH NUMBER = 0.9, r/R = 0.8453

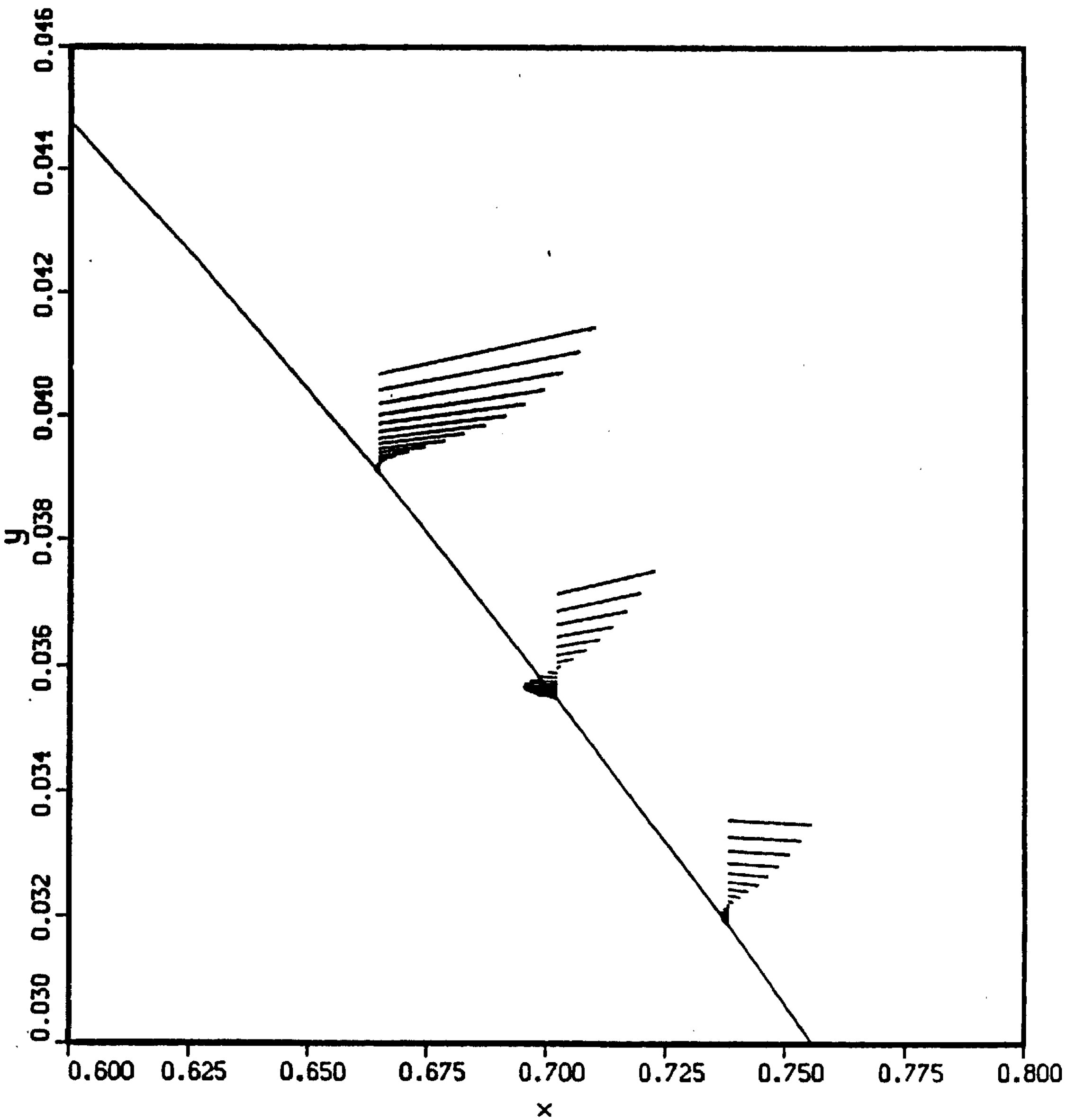


COMPARISON OF Cp DISTRIBUTION WITH AND WITHOUT
BOUNDARY-LAYER INTERACTION
TIP MACH NUMBER = 0.9, r/R = 0.9759

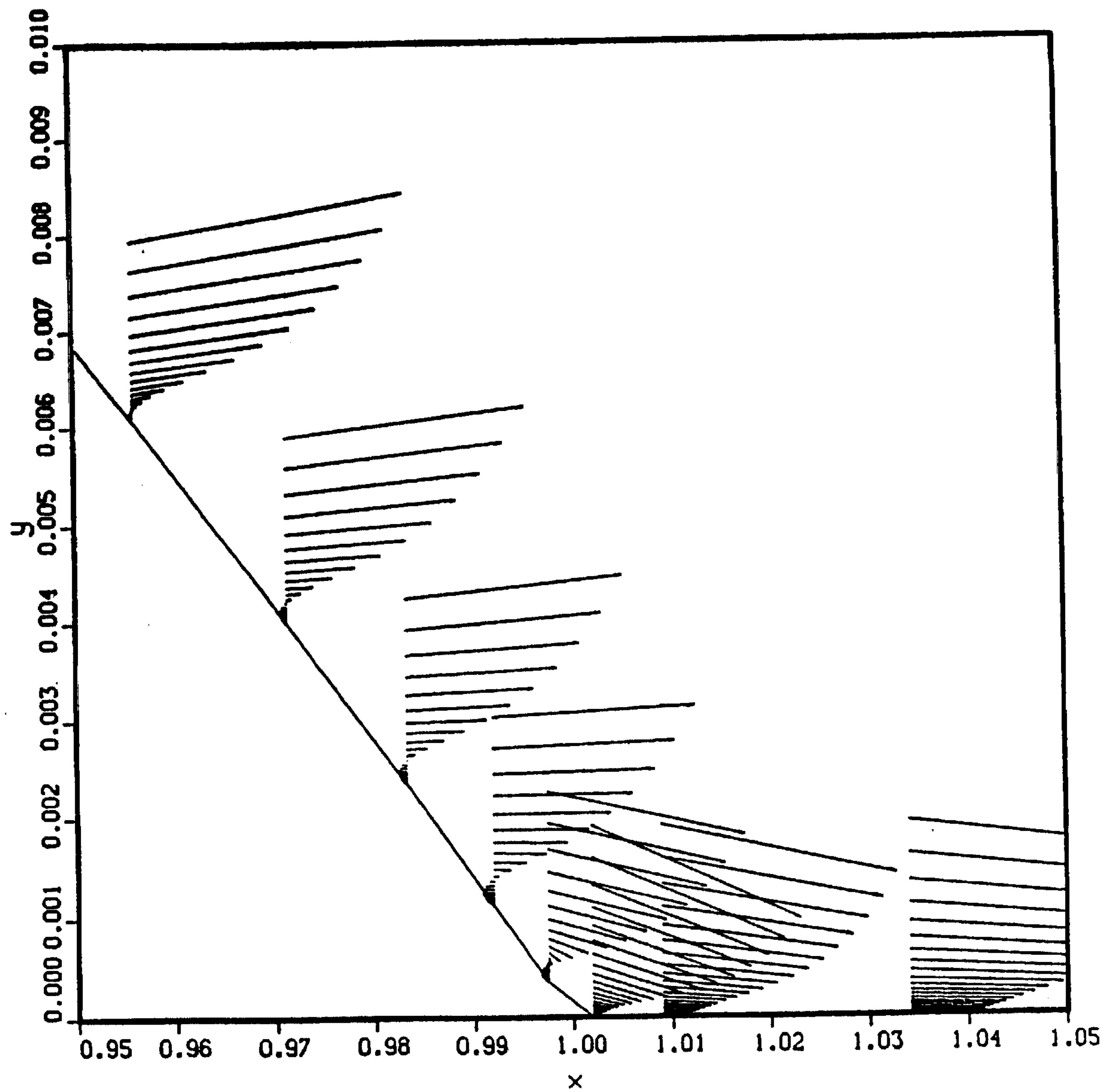


VELOCITY VECTOR PLOT SHOWING SEPARATION BUBBLE AT ROOT OF SHOCK

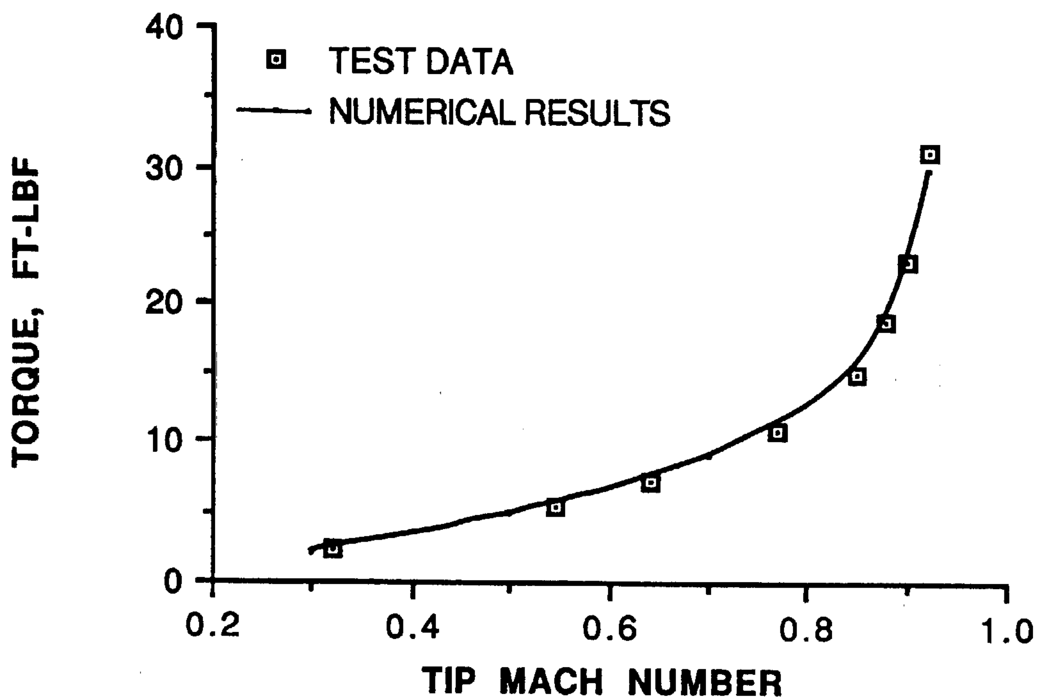
TIP MACH NUMBER = 0.925, r/R = 0.9759, AR = 13.71



VELOCITY VECTOR PLOT SHOWING SEPARATION REGION
AT TRAILING EDGE
TIP MACH NUMBER = 0.925, r/R = 0.9759, AR = 13.71



COMPARISON OF PREDICTED AND MEASURED TORQUE
FOR A NONLIFTING, HOVERING ROTOR
TWO BLADES, RECTANGULAR NACA 0012 BLADE,
RADIUS = 3.428 FT, AR = 13.71



FUTURE WORK

- SIMULATE NONLIFTING ROTOR FLOWS WITH ADVANCED BLADE PLANFORMS, AIRFOILS, AND TWIST DISTRIBUTIONS
- INCORPORATE FREE-WAKE ANALYSIS INTO VISCOUS-INVISCID APPROACH TO SIMULATE LIFTING ROTOR FLOWS
- INVESTIGATE EFFECTS OF ROTATIONAL MOTION ON DEVELOPMENT OF BOUNDARY-LAYER