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2-D AND 3-D TIME MARCHING TRANSONIC POTENTIAL FLOW METHOD FOR PROPFANS

Marc H. Williams
School of Aeronautics and Astronautics
Purdue University
West Lafayette, IN

ABSTRACT

Prediction of aeroelastic behavior is possible only if adequate methods are available for the prediction of the unsteady aerodynamic loads that result from vibration and/or inflow disturbances. The aerodynamic analysis of propfans is complicated by several factors: the inherent three dimensionality of the flow field; the presence of strong compressibility effects at cruise Mach numbers; the importance of aerodynamic coupling between blades; and the inherently unsteady interactions between a rotor and the rest of the vehicle (e.g. the wing, nascelle, pylon or a second counter-rotating blade row.)

Previous work under this grant has led to the development of a general three-dimensional lifting surface code based on linear small disturbance theory and the assumption of simple harmonic fields (Williams and Hwang, 1986) While this method has proven to be successful in predicting propfan flutter (Kaza et. al., 1987a,b), it is restricted to single rotation configurations and does not include the effects of transonic nonlinearities.

Therefore recent efforts have concentrated on the development of aerodynamic tools for the analysis of rotors at transonic speeds, and of configurations involving relative rotation. Basically three distinct approaches have been taken: (1) extension of the lifting surface method of Williams and Hwang (1986) to relative rotation; (2) development of a time marching linear potential method for counter rotation; and (3) development of 2 and 3 dimensional finite volume potential flow schemes for single rotation. Results from each of these approaches will be described.

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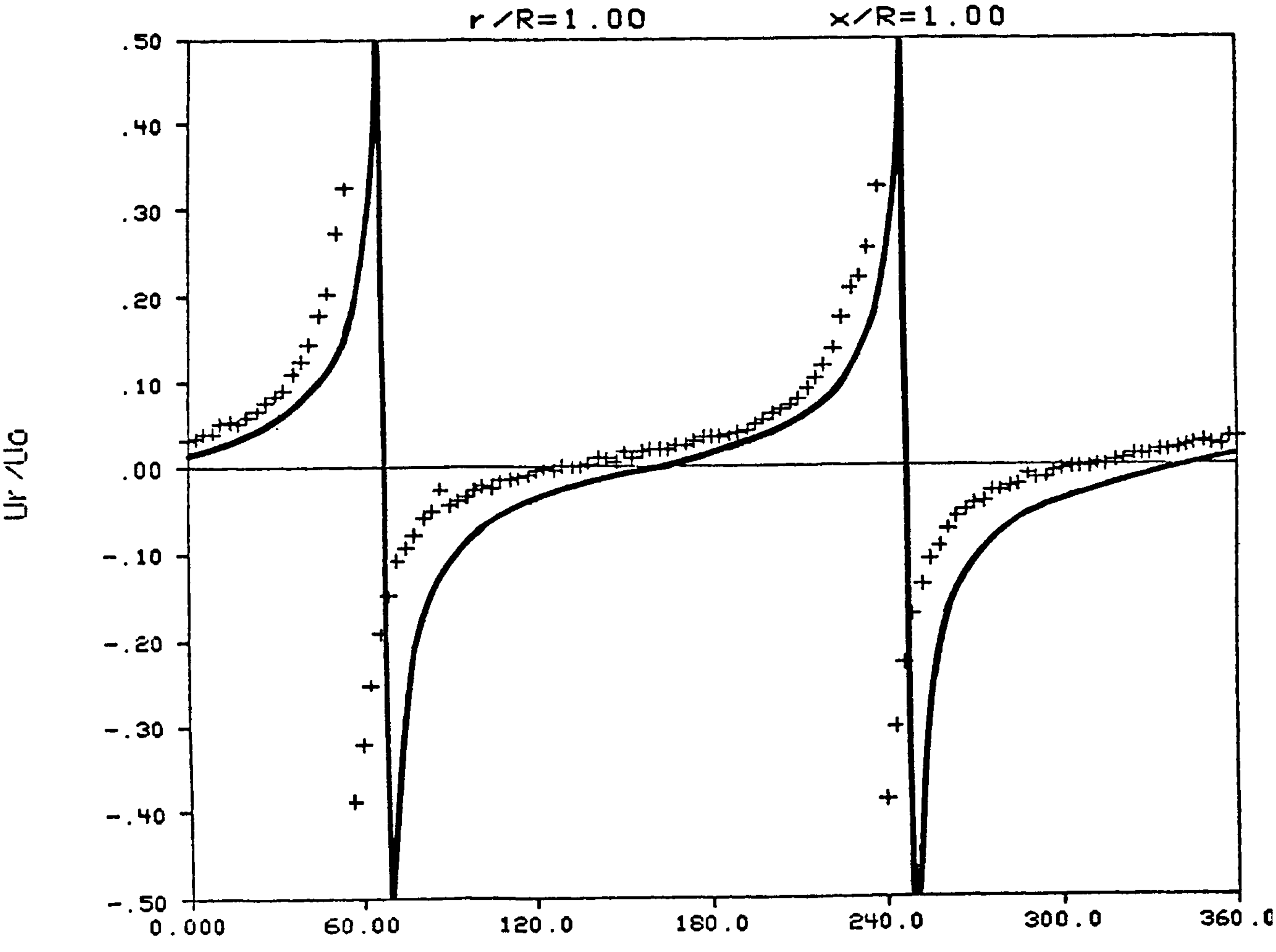
Propeller Velocity Field Predictions

The lifting surface method described in Williams and Hwang (1986) has been modified to give the velocity field surrounding a rotor. A detailed validation study was made using extensive LDV measurements taken by Sundar and Sullivan (1986) on a low speed 2 bladed propeller. The figure shows the configuration and the predicted and measured radial velocities at a station one radius downstream from the tip. The agreement is excellent, even near the tip vortex cores. The slight phase shift is thought to be due to the neglect of vortex roll-up in the mathematical model.

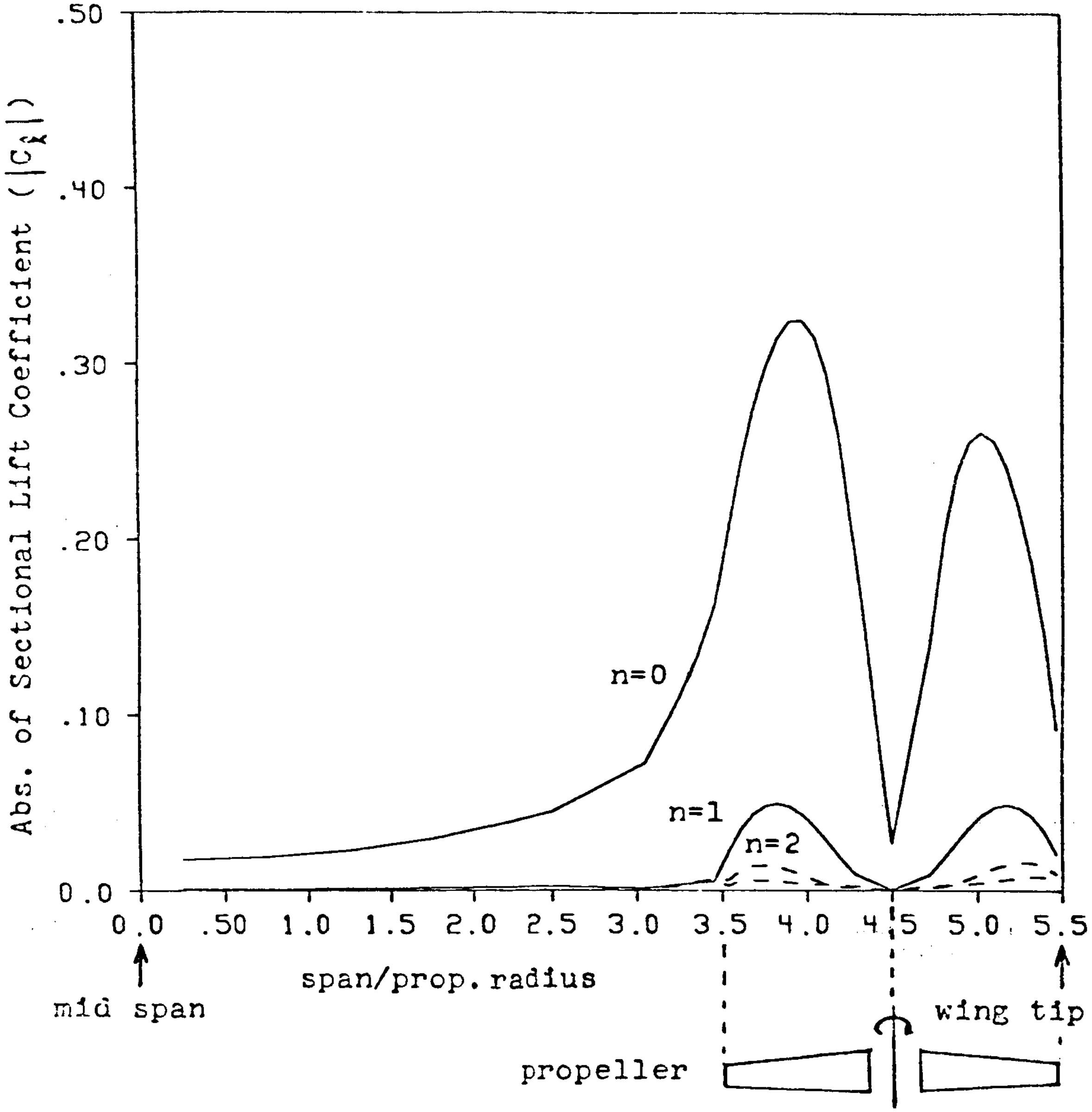


Radial Velocity

Wing Prop Interaction

The lifting surface method has been used to predict the unsteady loads on a tractor mounted wing-prop system. In this figure, the first three harmonics of the spanwise loading on the wing are shown (the wing is at zero incidence.) The zeroth harmonic agrees reasonably well with measured mean loads, though unsteady experimental data is not available for the higher harmonics.

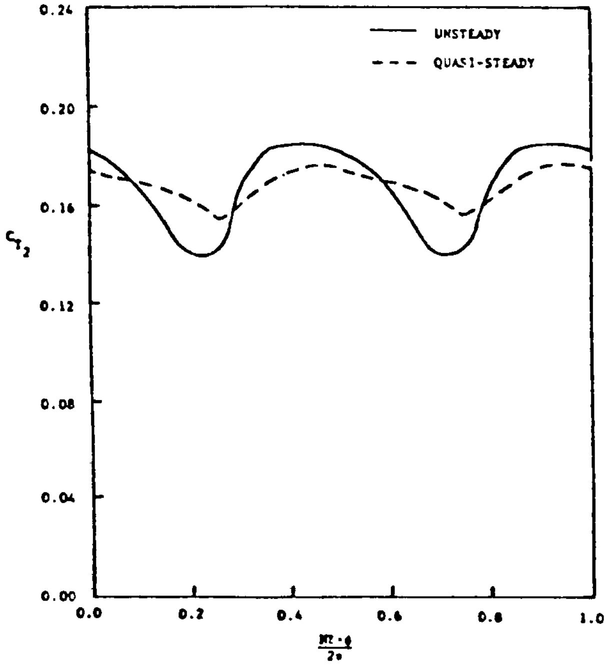
We plan to apply this scheme to the prediction of generalized forces for aeroelastic flutter and forced response analysis with relative rotation.



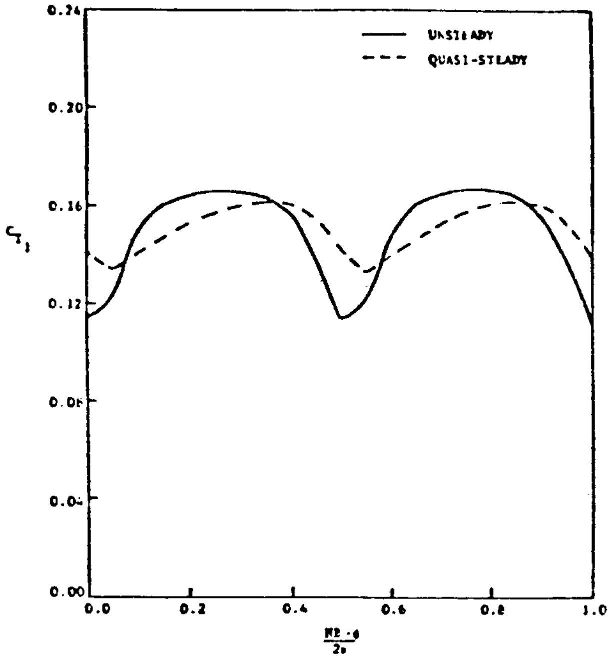
Sectional Lift Coefficients along Wing Span
Induced by Loads on the Propeller in front

Time Marching Linearized Counter Rotation Analysis

A time marching panel method was developed, Chen and Williams (1987), to study the unsteady loads on counter rotating propellers. Substantial unsteady load fluctuations were found on both the front and rear blade rows. These fluctuations were not well predicted by a quasi-steady analysis (Lesieutre and Sullivan, 1986), though the mean loads agree. Details are in Chen (1987).



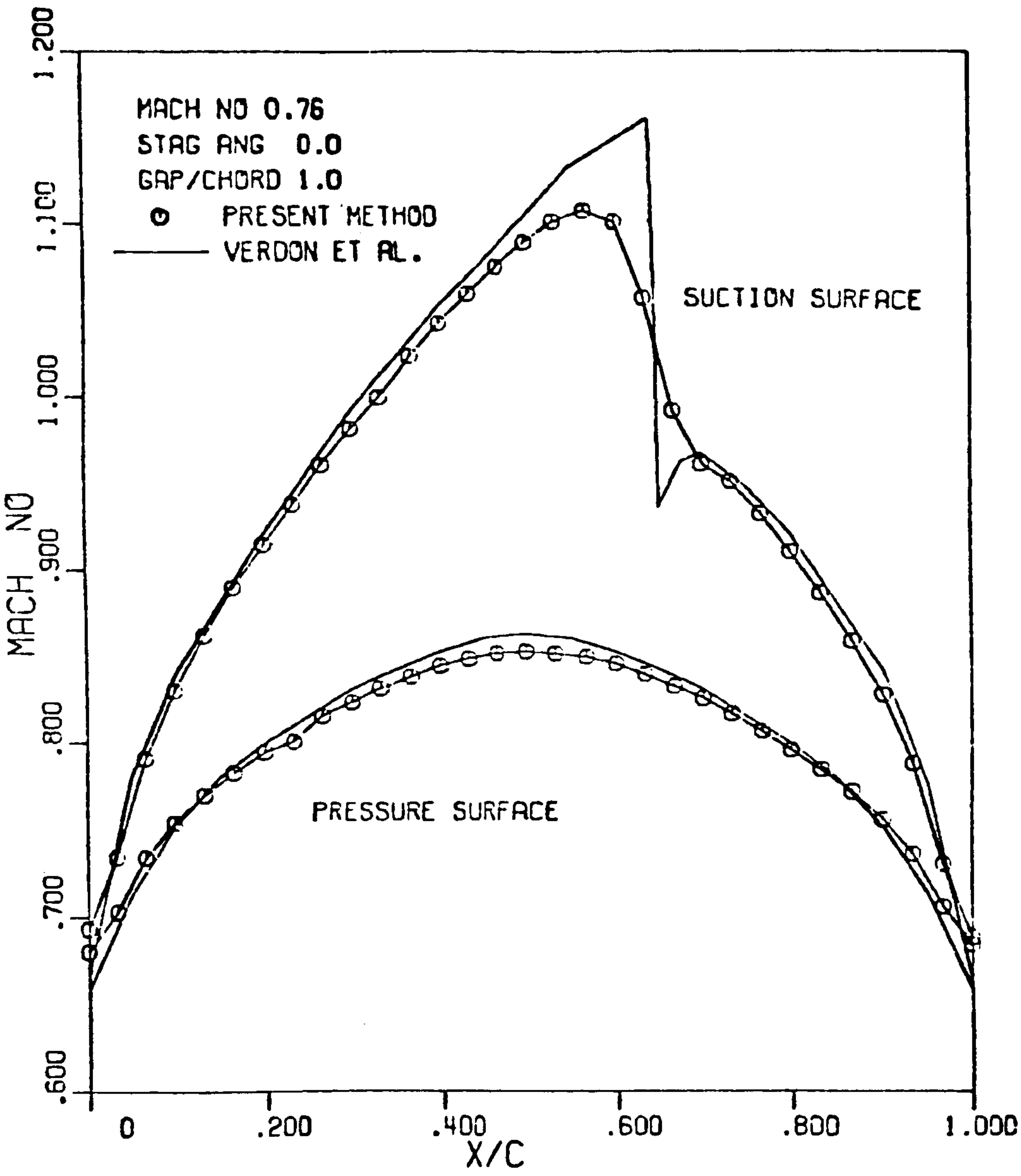
Unsteady thrust loading on rear rotor ($\beta_{3/4}$ = 41.34°, $N_B = 4 \times 4$, J = 1.633, SR2)



Unsteady thrust loading on front rotor ($\beta_{3/4}$ = 41.34°, $N_B = 4 \times 4$, J = 1.633, SR2)

2-D Transonic Cascade Analysis

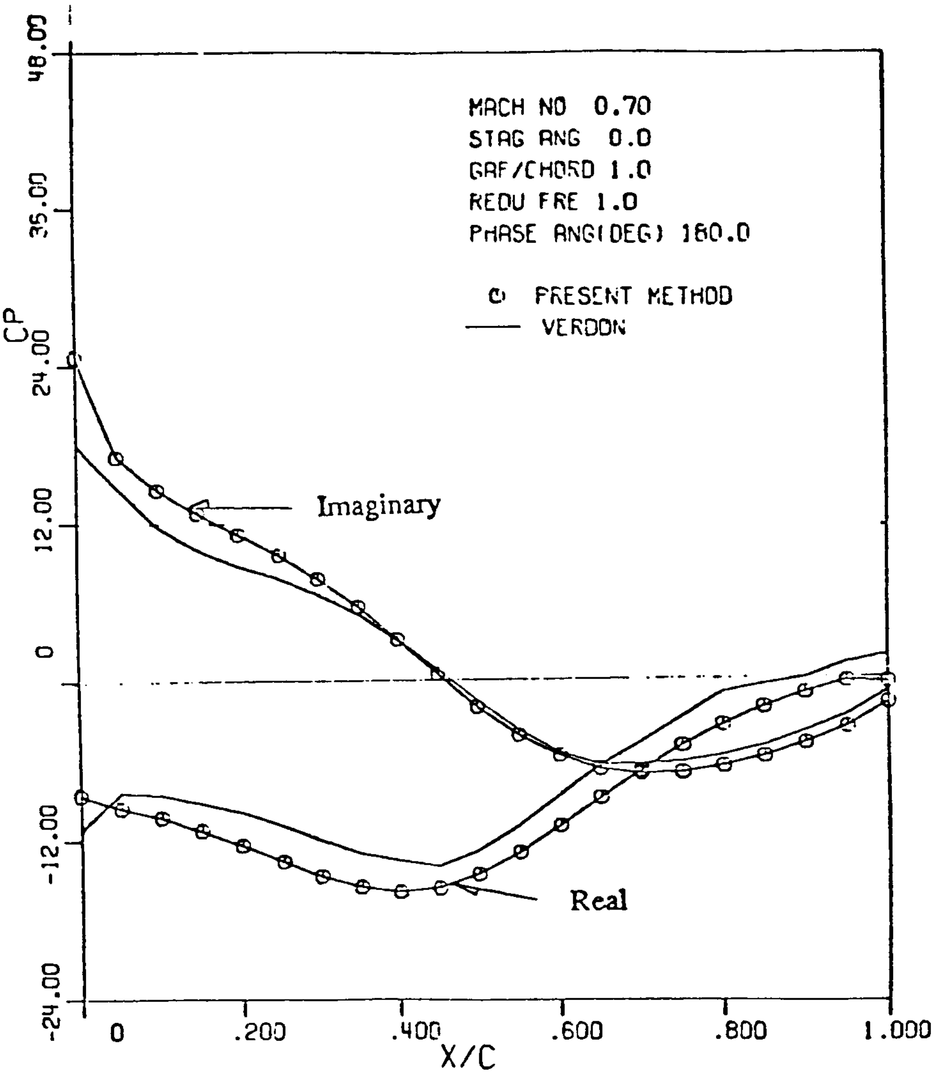
A 2-D time marching method has been developed using a finite volume discretization of the nonlinear potential flow equation. The scheme is an extension of the work by Shankar et. al. (1985) to cascades. The method captures shockwaves, as indicated in the figure below. Verdon (1982) used a very fine grid near the shock for better resolution, while our shock is smeared by the course grid.



Local Mach number distributions of unstaggered half-circular-arc cascade in supercritical flow.

Interblade Phasing and Multiple Passage

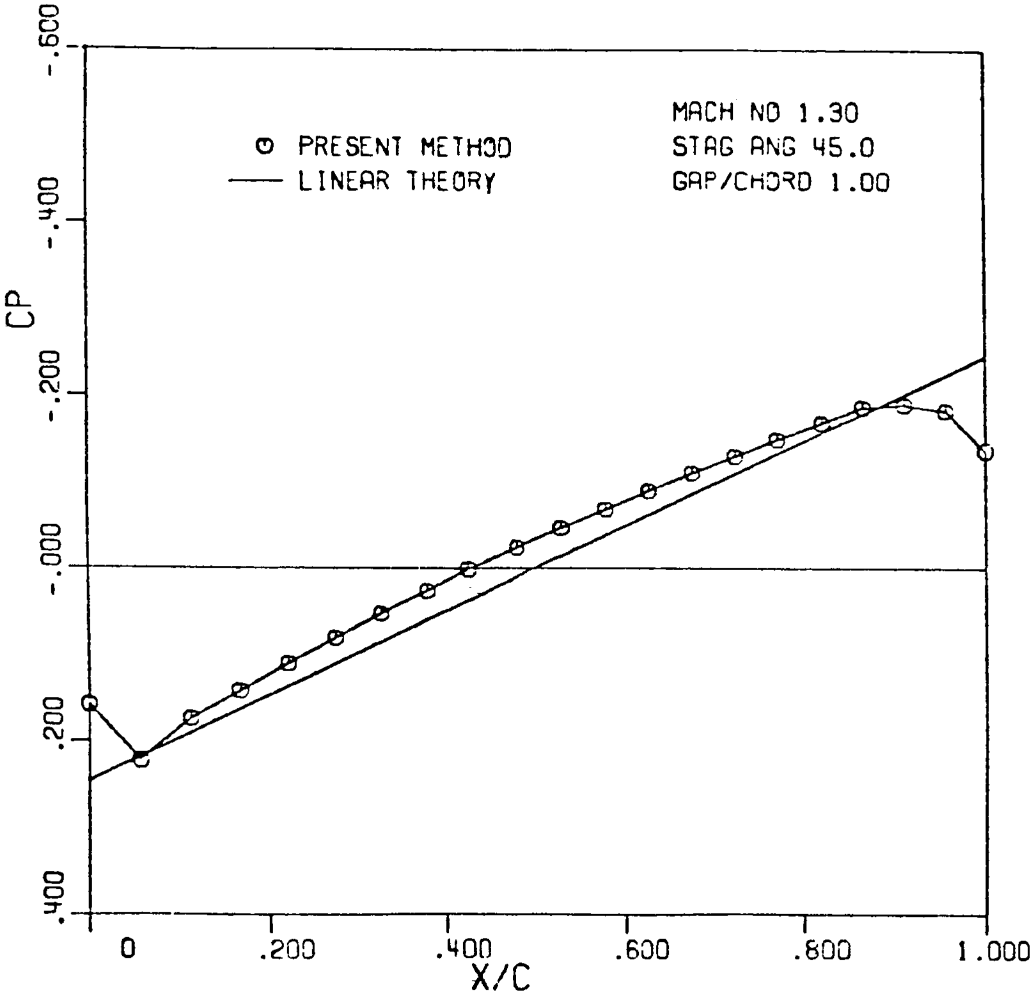
The time marching scheme uses a time shearing method described by Giles (1987) to account for interblade phase lag. This can require modeling more than one passage. The calculation shown below used two passages, because of the large interblade phase angle. To avoid this a method is being developed to allow arbitrary phase angles in a single passage model.



Unsteady pressure distributions due to out-of-phase torsional motion for unstaggered half-circular-arc cascade.

Supersonic Cascades

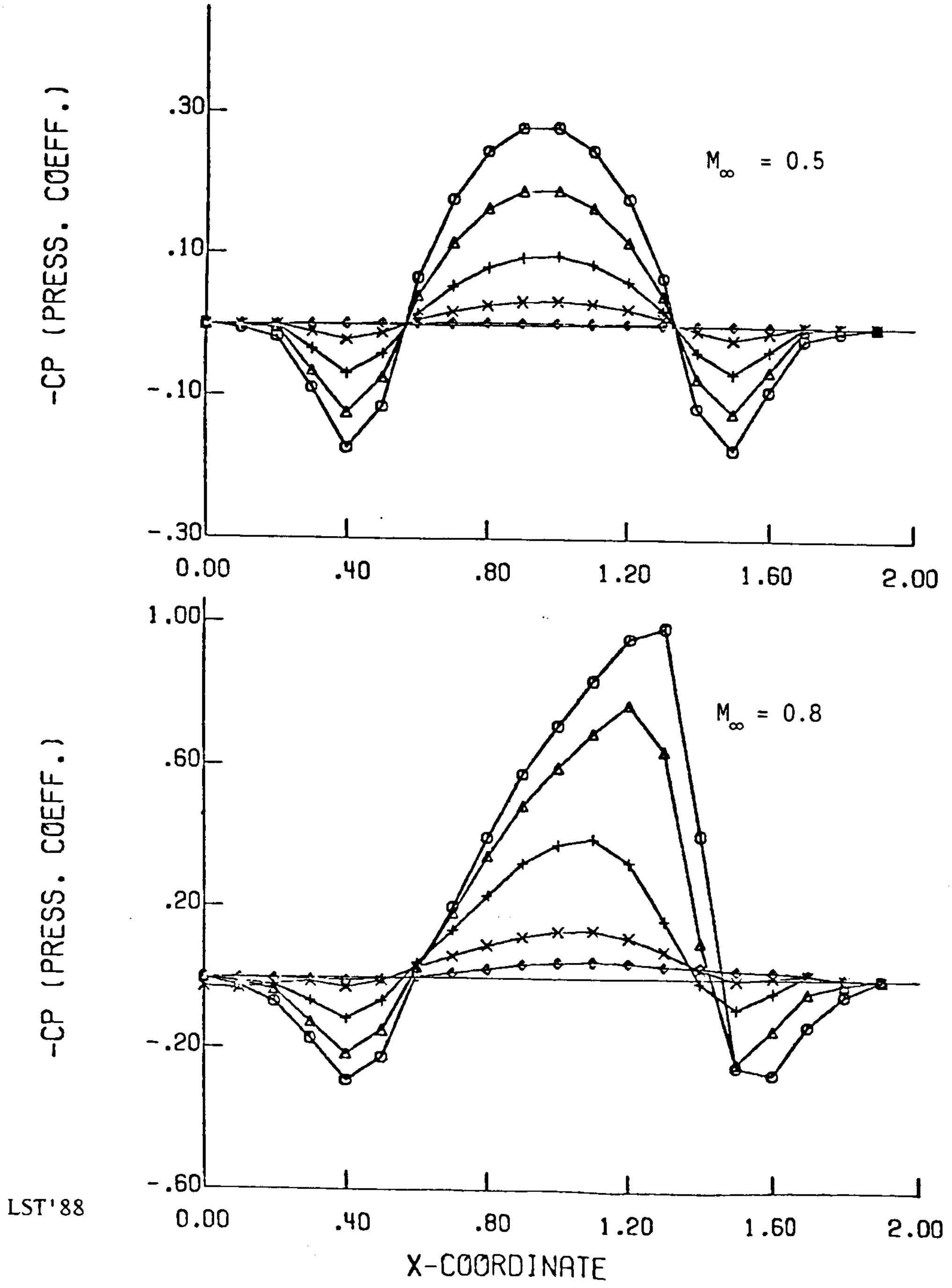
The full potential analysis can be used at both subsonic and supersonic speeds. Shown below is the steady upper surface pressure distribution on a semi-circular arc blade at Mach 1.3, with a comparison to linear theory. This cascade has a subsonic leading edge. Some minor code modifications (in progress) are required to allow supersonic leading edges.



Comparison of surface pressure distributions.

Three Dimensional Full Potential Analysis

The time marching algorithm described for cascades has been implemented in three dimensions as well. Results have been obtained for relatively simple configurations. The case shown below is a rotating helical channel with a uniform axial flow. A constriction is placed in the channel to simulate a rotating blade, and the resulting steady pressure distribution is plotted at three spanwise locations. The analysis is now being extended to realistic rotor geometries. The code uses a fully moving grid network, so application to vibrating blades should be straightforward.



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