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Numerical Analysis of Flow Through Oscillating Cascade Sections

by Dennis L. Huff

NASA Lewis Research Center

The design of turbomachinery blades requires the prevention of flutter for all operating conditions. However, flow field predictions used for aeroelastic analysis are not well understood for all flow regimes. The present research focuses on numerical solutions of the Euler and Navier-Stokes equations using an ADI procedure to model two-dimensional, transonic flow through oscillating cascades. The model prescribes harmonic pitching motions for the blade sections for both zero and non-zero inter-blade phase angles. The code introduces the use of a deforming grid technique for convenient specification of the periodic boundary conditions. Approximate nonreflecting boundary conditions have been coded for the inlet and exit boundary conditions. Sample unsteady solutions have been performed for an oscillating cascade and compared to experimental data. Also, test cases were run for a flat plate cascade to compare with an unsteady, small-perturbation, subsonic analysis.

The predictions for oscillating cascades with non-zero inter-blade phase angles are in good agreement with experimental data and small-perturbation theory. The zero degree inter-blade phase angle cases, which were near a resonant condition, differ from the experiment and theory. Studies on reflecting versus non-reflecting inlet and exit boundary conditions show that the treatment of the boundary can have a significant effect on the first harmonic, unsteady pressure distributions for certain flow conditions. This code is expected to be used as a tool for reviewing simpler models that do not include the full non-linear aerodynamics or as a final check for designs against flutter in turbomachinery.

OBJECTIVE:

- DEVELOP AN UNSTEADY, VISCOUS, TRANSONIC FLOW ANALYSIS METHOD FOR CASCADED AIRFOILS WITH PITCHING MOTIONS

TECHNIQUE:

- A COMPRESSIBLE, FULL NAVIER-STOKES, FINITE DIFFERENCE CODE IS DEVELOPED TO MODEL OSCILLATING CASCADES FOR BOTH ZERO AND NON-ZERO INTER-BLADE PHASE ANGLES

- A UNIQUE DEFORMING GRID TECHNIQUE IS INTRODUCED TO CAPTURE BLADE MOTIONS

- APPROXIMATE NON-REFLECTING BOUNDARY CONDITIONS ARE USED TO MINIMIZE WAVE REFLECTIONS FROM THE OUTER BOUNDARIES

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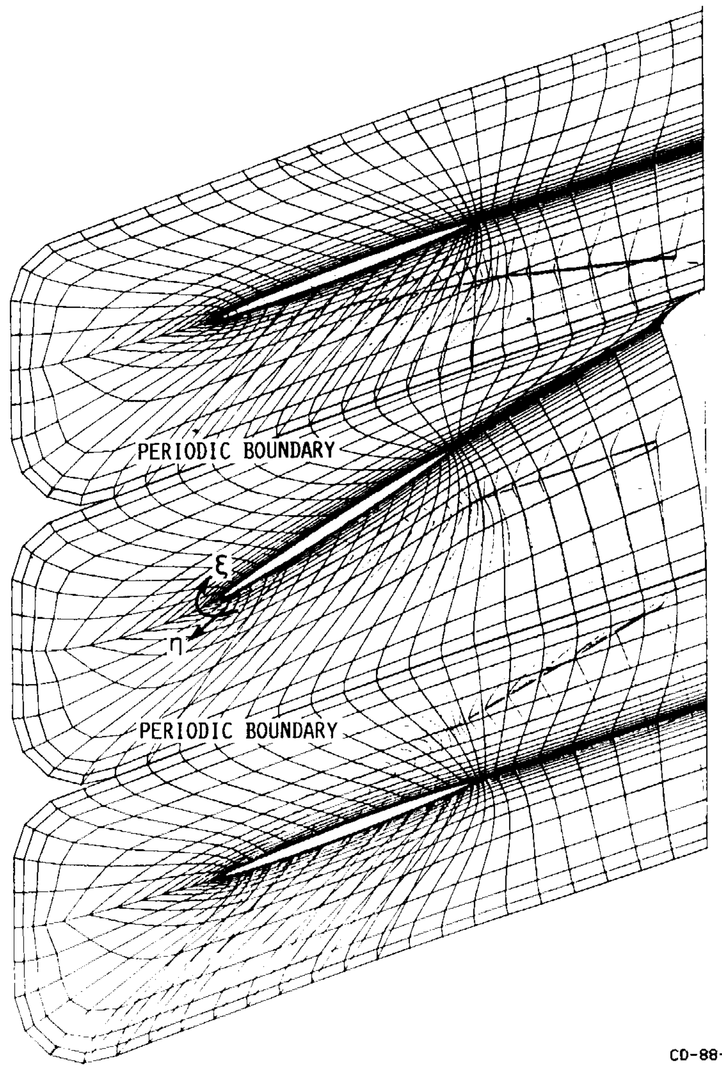
DEFORMING GRID TECHNIQUE, SIMPLIFIED GRID WITH EXAGGERATED MOTION



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BOUNDARY CONDITIONS

INLET:

- SPECIFY DENSITY, VELOCITY, AND FLOW ANGLE
- SOLVE THE CHARACTERISTIC FORM OF THE GOVERNING EQUATIONS TO DETERMINE THE ENERGY

EXIT:

- FOR VISCOUS FLOWS, SPECIFY STATIC PRESSURE AND EXTRAPOLATE DENSITY AND VELOCITY FROM THE INTERIOR
- FOR INVISCID FLOWS, SPECIFY STATIC PRESSURE AND SOLVE THE CHARACTERISTIC FORM OF THE GOVERNING EQUATIONS TO DETERMINE DENSITY AND VELOCITY

PERIODIC BOUNDARIES FROM BLADE-TO-BLADE

SOLID WALL BOUNDARIES ON AIRFOIL SURFACE

AVERAGE FLOW PROPERTIES ACROSS THE WAKE

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RESULTS

1. NACA 65-SERIES CASCADE, $M = 0.17$, TWO INTER-BLADE PHASE ANGLES, COMPARISONS WITH EXPERIMENT
2. FLAT PLATE CASCADE, $M = 0.65$ AND 0.80, THREE INTER-BLADE PHASE ANGLES, COMPARISONS WITH SMALL-PERTURBATION THEORY
3. NASA LEWIS CASCADE, $M = 0.65$ AND 0.80, THREE INTER-BLADE PHASE ANGLES, BOUNDARY CONDITION STUDY, NUMERICAL TIME ACCURACY STUDY, COMPARISONS WITH EXPERIMENT.

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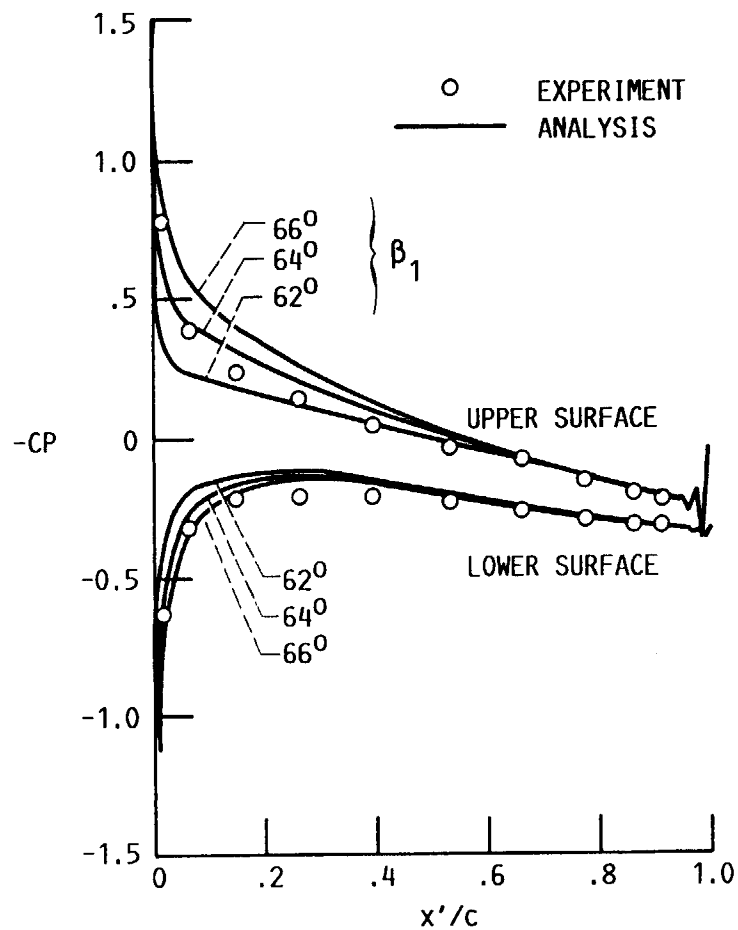
MEAN FLOW PRESSURE DISTRIBUTION FOR NACA 65-SERIES CASCADE

$M_1 = 0.17$, $\gamma = 55^0$, $g/c = 0.75$, $\tau' = 0.06$



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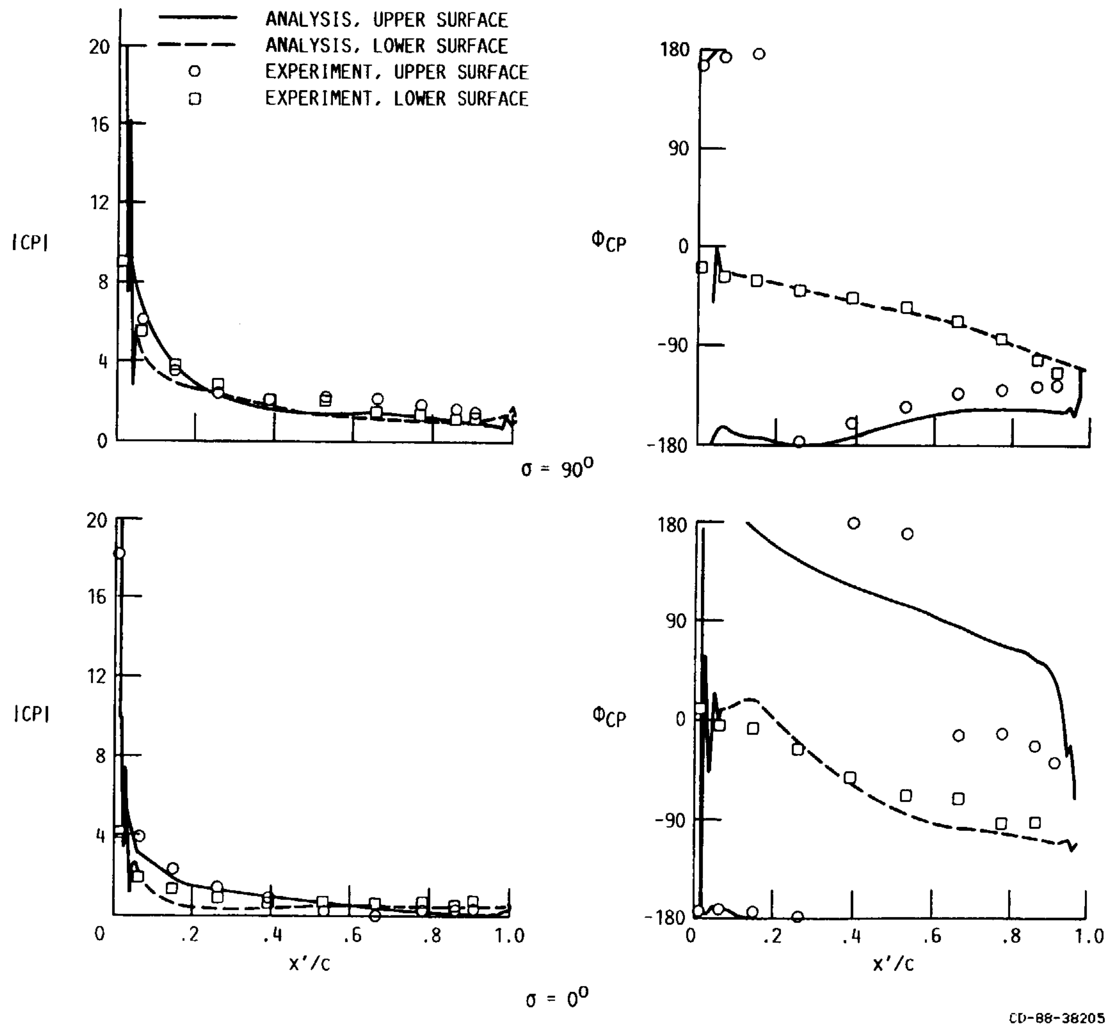
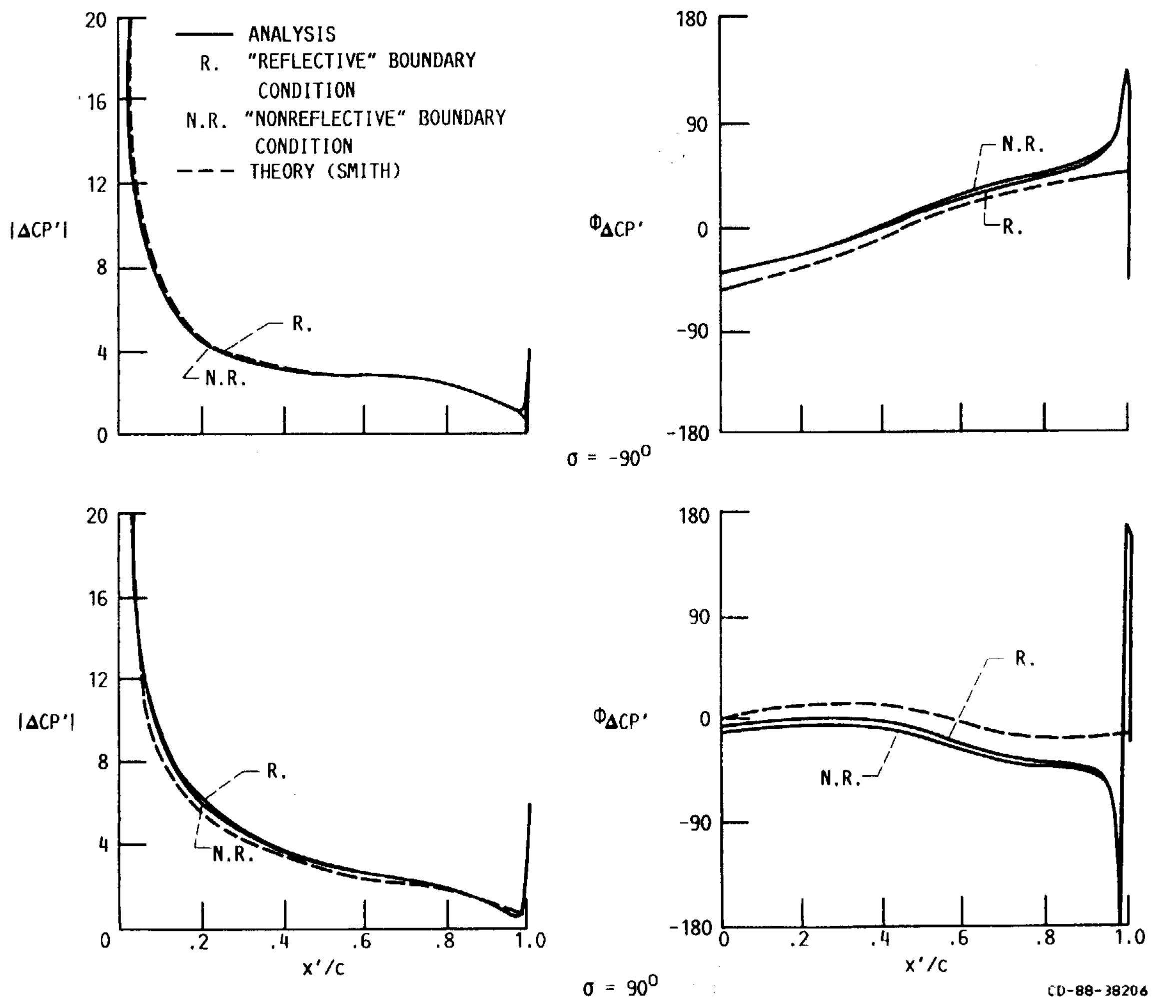
FIRST HARMONIC PRESSURE DISTRIBUTION FOR NACA 65-SERIES OSCILLATING CASCADE

$M_1 = 0.17,\ \beta_1 = 64^{o} \pm 2^{o},\ k = 0.123$



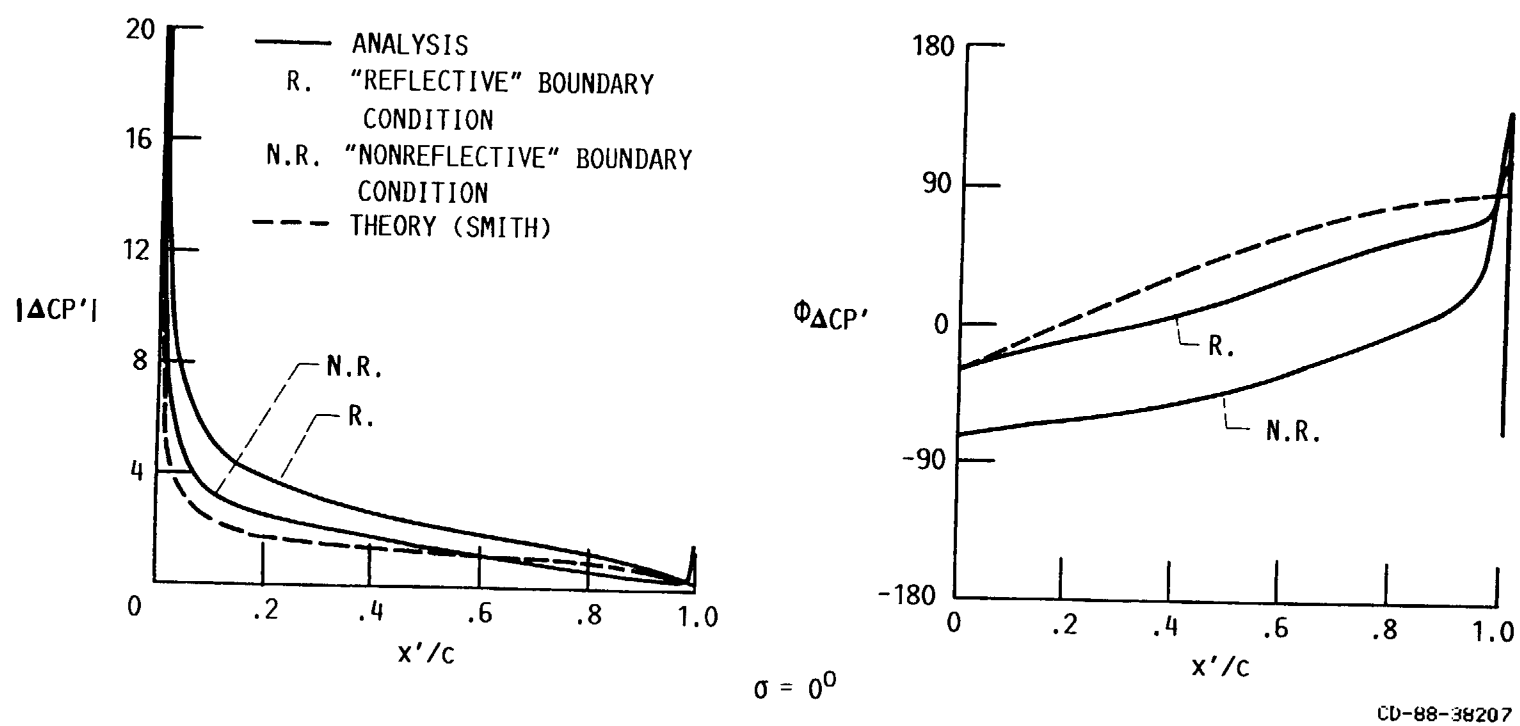
BOUNDARY CONDITION AND THEORY COMPARISON FOR FLAT PLATE CASCADE

$M_1 = 0.65$, $\beta_1 = 53^0 \pm 0.10^0$, $k = 0.221$



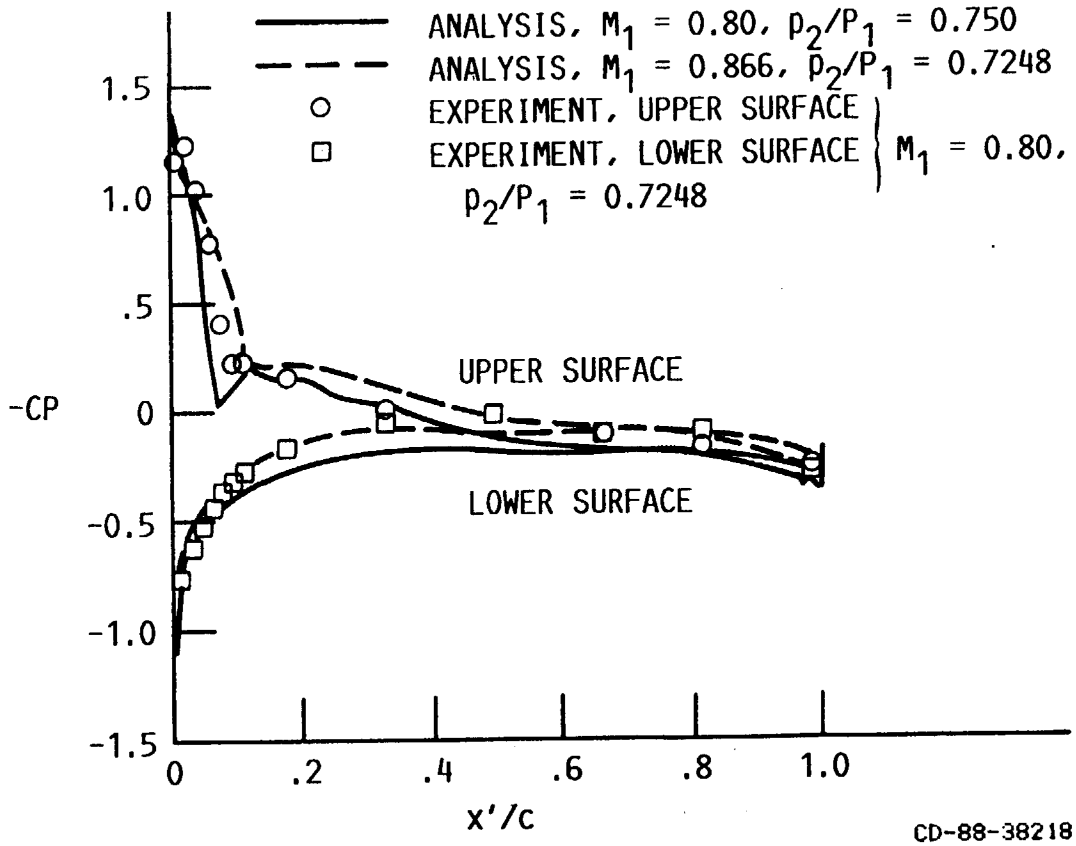
BOUNDARY CONDITION AND THEORY COMPARISON FOR FLAT PLATE CASCADE

$M_1 = 0.65$, $\beta_1 = 53^0 \pm 0.10^0$, $k = 0.221$



MEAN FLOW PRESSURE DISTRIBUTION FOR BICONVEX AIRFOIL CASCADE

$\beta_1 = 60^0, \gamma = 53^0, g/c = 0.767, \tau' = 0.07$



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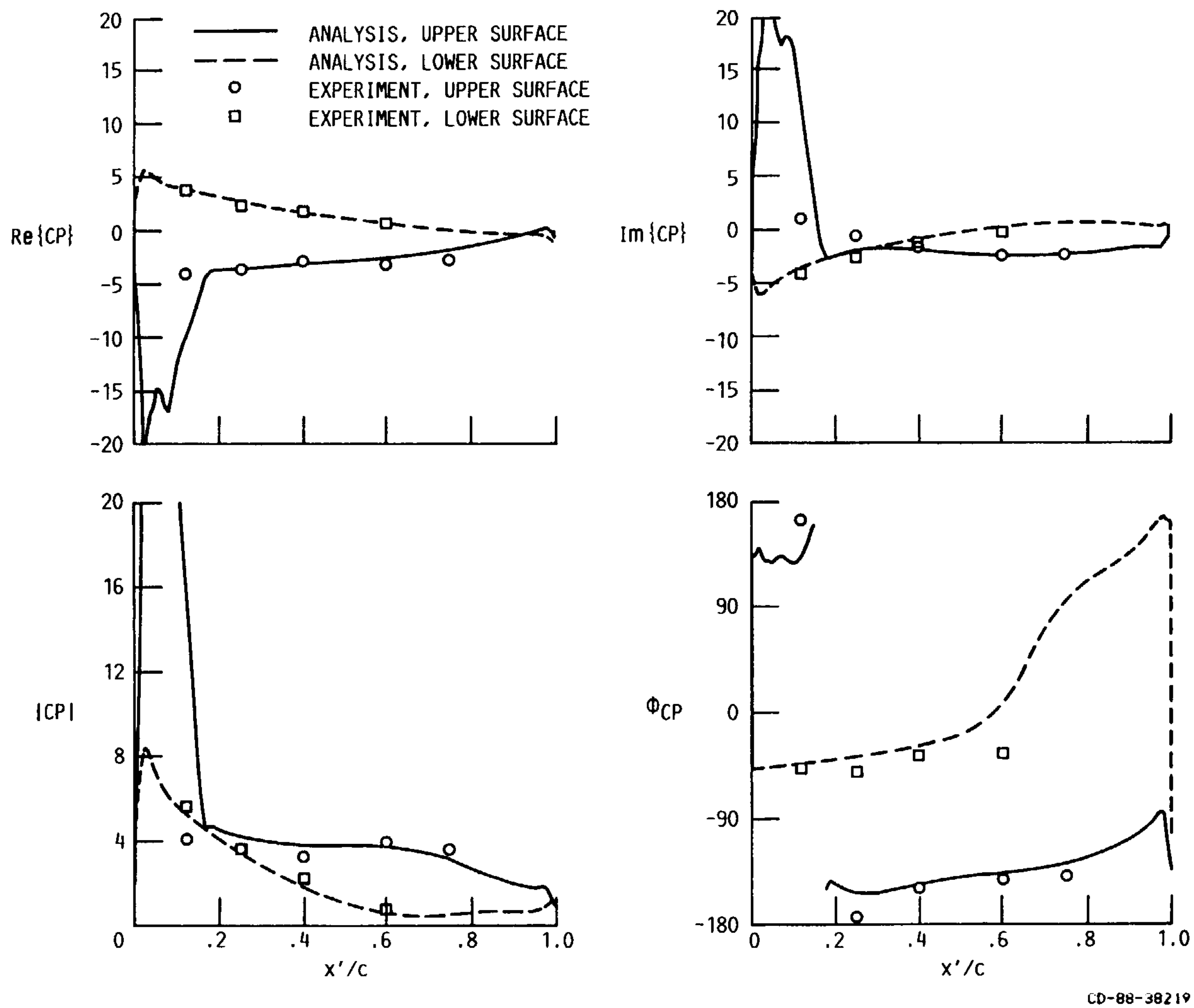
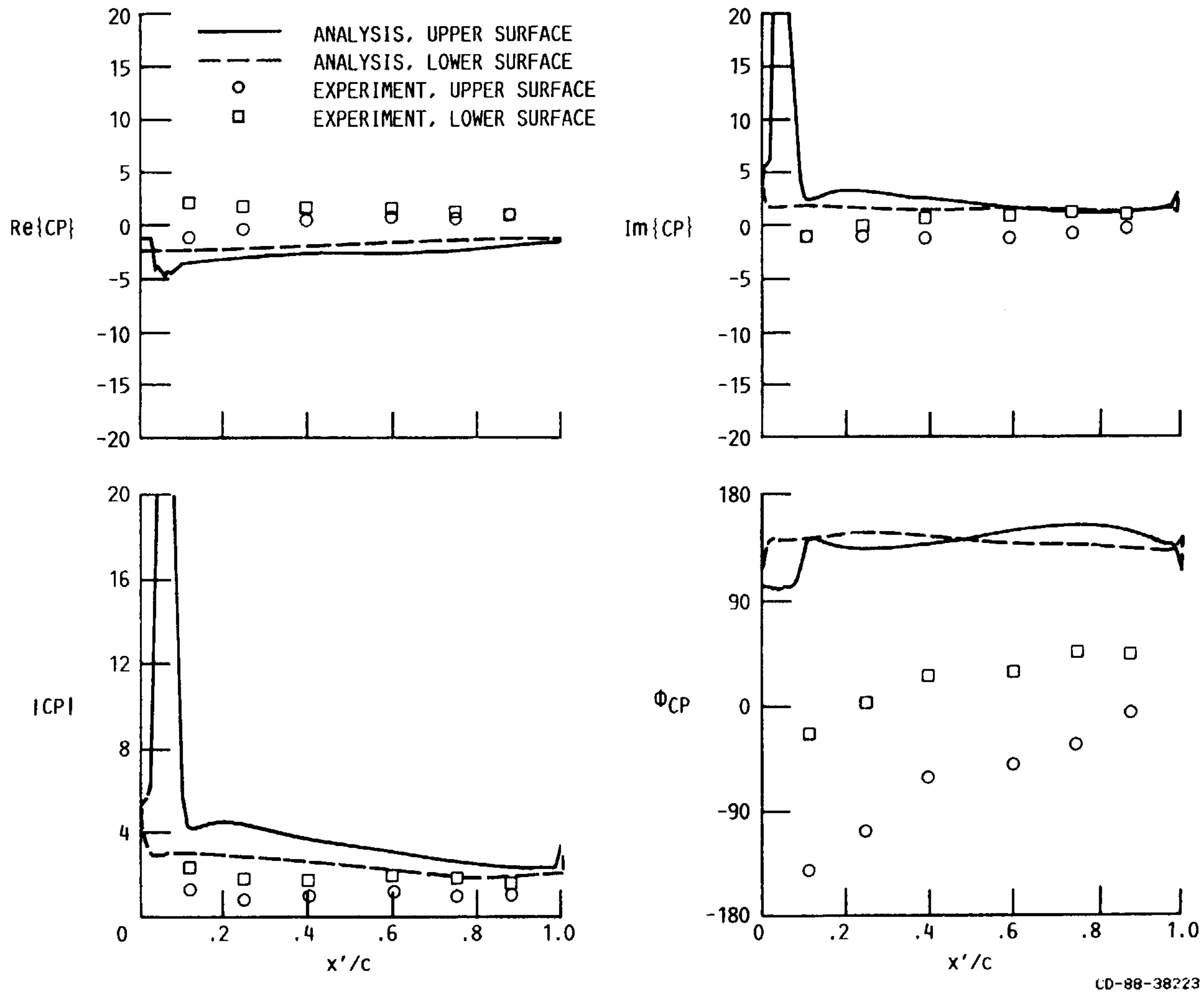
FIRST HARMONIC PRESSURE DISTRIBUTION FOR BICONVEX AIRFOIL CASCADE

$M_1 = 0.80$, $\beta_1 = 60^0 \pm 1.2^0$, $k = 0.185$, $\sigma = -90^0$



FIRST HARMONIC PRESSURE DISTRIBUTION FOR BICONVEX AIRFOIL CASCADE

$M_1 = 0.80,\ \beta_1 = 60^{\circ} \pm 1.2^{\circ},\ k = 0.185,\ \sigma = 0^{\circ}$



CONCLUSIONS

- A COMPRESSIBLE EULER OR NAVIER-STOKES, FINITE-DIFFERENCE CODE HAS BEEN DEVELOPED FOR THE ANALYSIS OF OSCILLATING CASCADES
- A DEFORMING GRID TECHNIQUE IS USED TO CAPTURE THE MOTION OF THE AIRFOILS FOR BOTH ZERO AND NON-ZERO INTER-BLADE PHASE ANGLES
- APPROXIMATE TWO-DIMENSIONAL, UNSTEADY CHARACTERISTIC BOUNDARY CONDITIONS ARE USED AT THE INLET AND EXIT TO MINIMIZE WAVE REFLECTIONS
- IN GENERAL, PREDICTIONS WITH NON-ZERO-INTER-BLADE PHASE ANGLES ARE IN GOOD AGREEMENT WITH THE EXPERIMENTAL DATA AND SMALL-PERTURBATION THEORY
- PREDICTIONS FOR ZERO DEGREE INTER-BLADE PHASE ANGLE CASES, WHICH WERE NEAR AN ACOUSTIC RESONANT CONDITION, DIFFER FROM THE EXPERIMENT AND THEORY
- THE TYPE OF BOUNDARY CONDITION USED AT THE INLET AND EXIT CAN HAVE A SIGNIFICANT EFFECT ON THE FIRST HARMONIC, UNSTEADY PRESSURE DISTRIBUTIONS
- FIRST-ORDER AND SECOND-ORDER TEMPORAL ACCURACY RESULTS DO NOT SHOW SIGNIFICANT DIFFERENCES IN THE UNSTEADY PRESSURE DISTRIBUTIONS

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