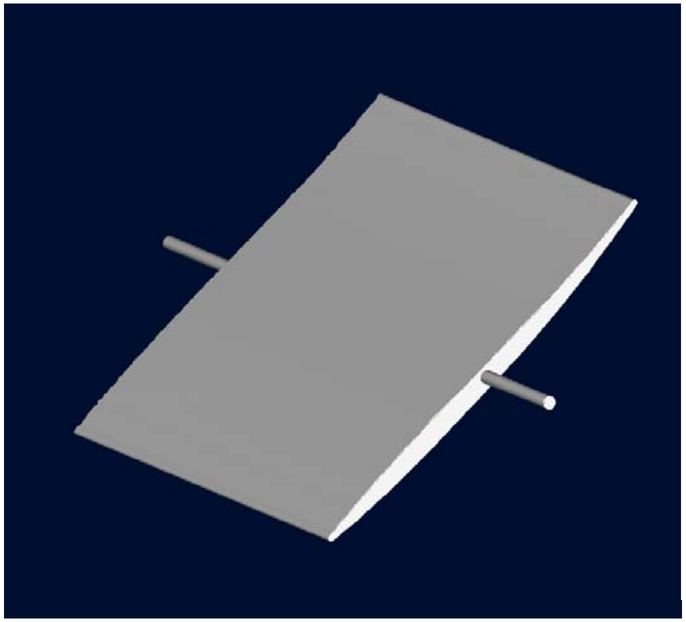
Evaluation of Codes LEO and WAND



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Introduction

- Simulations using code LEO were performed using the experimental data from the NASA Glenn Research Center Transonic Flutter Cascade

  - Transonic compressor airfoil cross-section typical of what would be found in the outboard region of a low aspect ratio fan blade

- Two different flow conditions were examined

  - High incidence angle case, which had a large separation region
  - Low incidence angle case

- WAND recommended grid presets were used for all calculations

  - 2D and 3D simulations were conducted
  - Due to the similarity of the 2D and 3D solutions, the 2D solutions are presented

- The LEO calculations were compared to the experimental data, plus solutions from the NPHASE (2D) flow solver

Experimental Facility

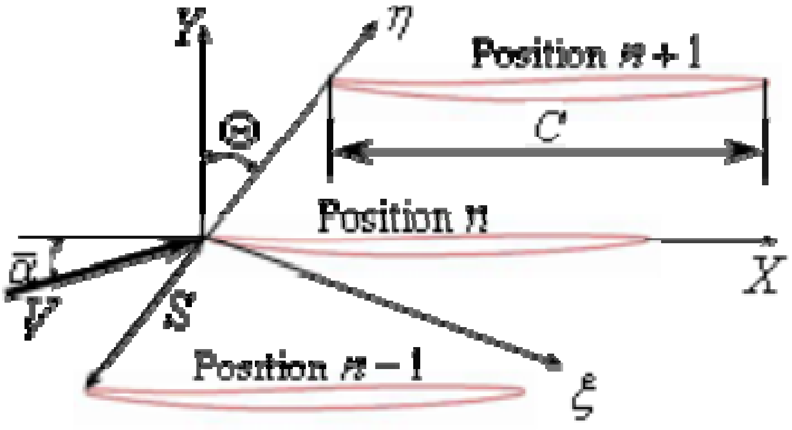
The NASA Glenn Research Center Transonic Flutter Cascade was a linear cascade wind tunnel that could operate at transonic Mach numbers

- Nine airfoil cascade wind tunnel
- Mid-span surface static pressure taps located between 6% and 95% of the airfoil chord length
- Conventional temperature and pressure instrumentation upstream and downstream of the test section was used to determine the cascade performance

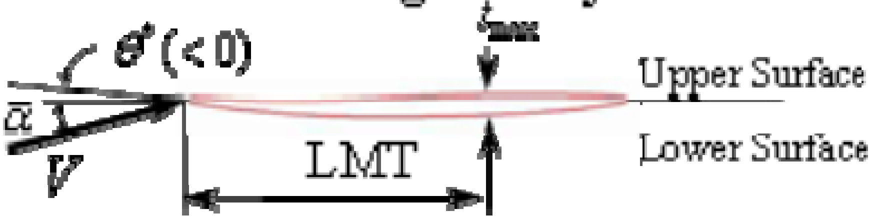
Airfoil Design

The airfoil cross section is similar to that found in the tip region of current low-aspect-ratio fan blades

Chord, C	8.89 cm
Maximum Thickness, t_{max}	0.048C
Maximum Thickeness Location, x_{max}	0.625C
Leading Edge Camber Angle, θ^*	-9.5°
Number of Airfoils	9
Stagger Angle, Θ	60°
Solidity, C/S	1.52
Pitching Axis (x_{pitch} , y_{pitch})	(0.5C, -0.017C)
Blade Height,h	9.59 cm



Cascade geometry



Airfoil geometry

Operating Conditions:

Mach = 0.5

$Re_C \approx 0.9$ Million

Buffum, D.H., Capece, V.R., King, A.J., and EL-Aini, Y.M., 1998, “Oscillating Cascade Aerodynamics at Large Mean Incidence,” *ASME Journal of Turbomachinery*, Vol. 120, No. 1, January, pp. 122-130.

NPHASE 2D Computational Model

- Originally developed at Mississippi State University
- Two-dimensional
- Structured sheared H-meshes
- Nonlinear steady and unsteady flows
- Euler/Thin layer Navier-Stokes
- Baldwin-Lomax turbulence model
- Gust (Ayers and Verdon) and oscillating airfoil unsteady aerodynamics
- Spalart-Allmaras turbulence model
- Solomon-Walker-Gostelow transition model
- Dhawan and Narashima transition model

Note: Only fully turbulent calculations were conducted with NPHASE

2D Flow Conditions

Low Incidence

LEO Pressure Ratio	0.92
Exp. Pressure Ratio	0.93
Inlet Mach Number	0.5
Inlet Flow Angle	61°
Re_C	0.9 Million

Grid Points

Fine Mesh	9010
Very Fine Mesh	13522
Super Fine Mesh	19090

High Incidence

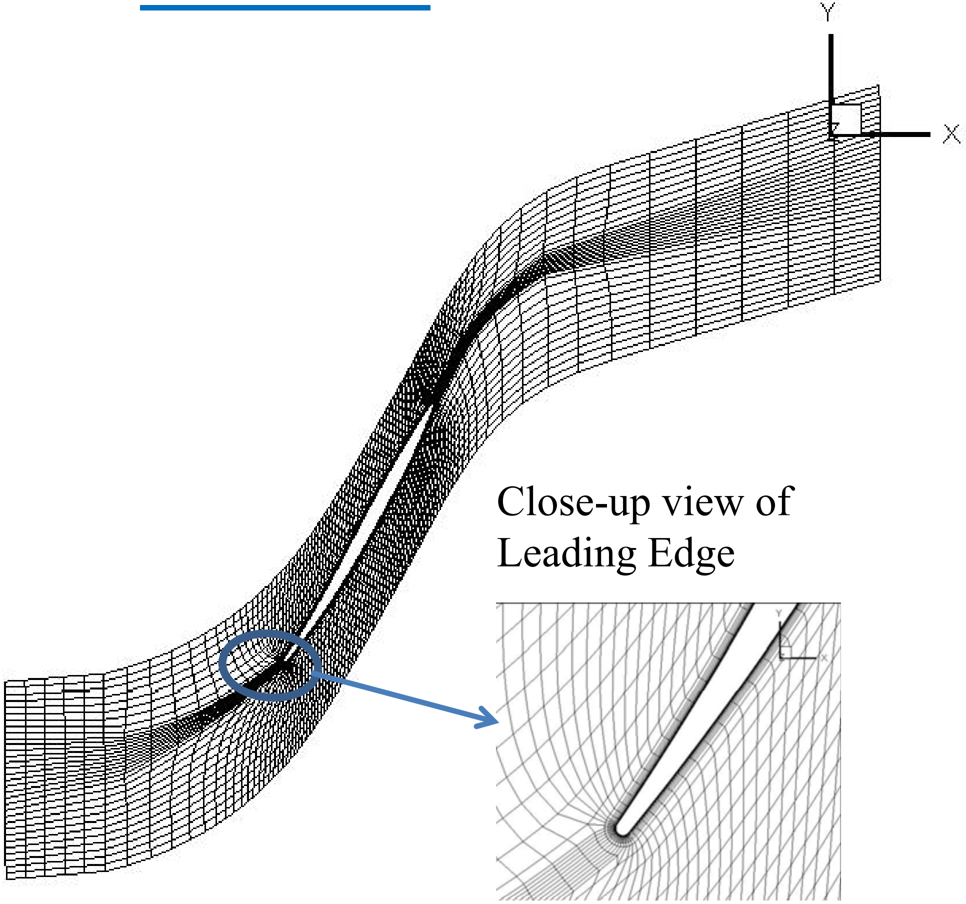
LEO Pressure Ratio	1.02
Exp. Pressure Ratio	1.03
Inlet Mach Number	0.5
Inlet Flow Angle	67.5°
Re_C	0.9 Million

Grid Points

Fine Mesh	9010
Very Fine Mesh	13522
Super Fine Mesh	19090

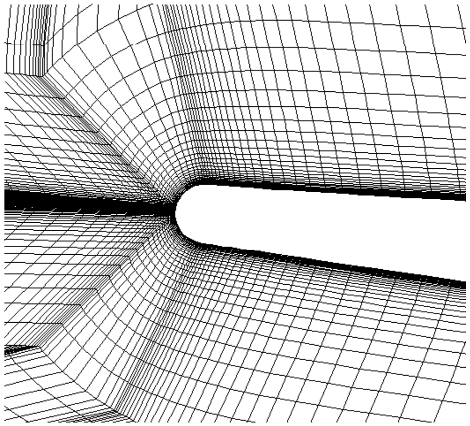
2D Computational Meshes

WAND/LEO



Close-up view of Leading Edge

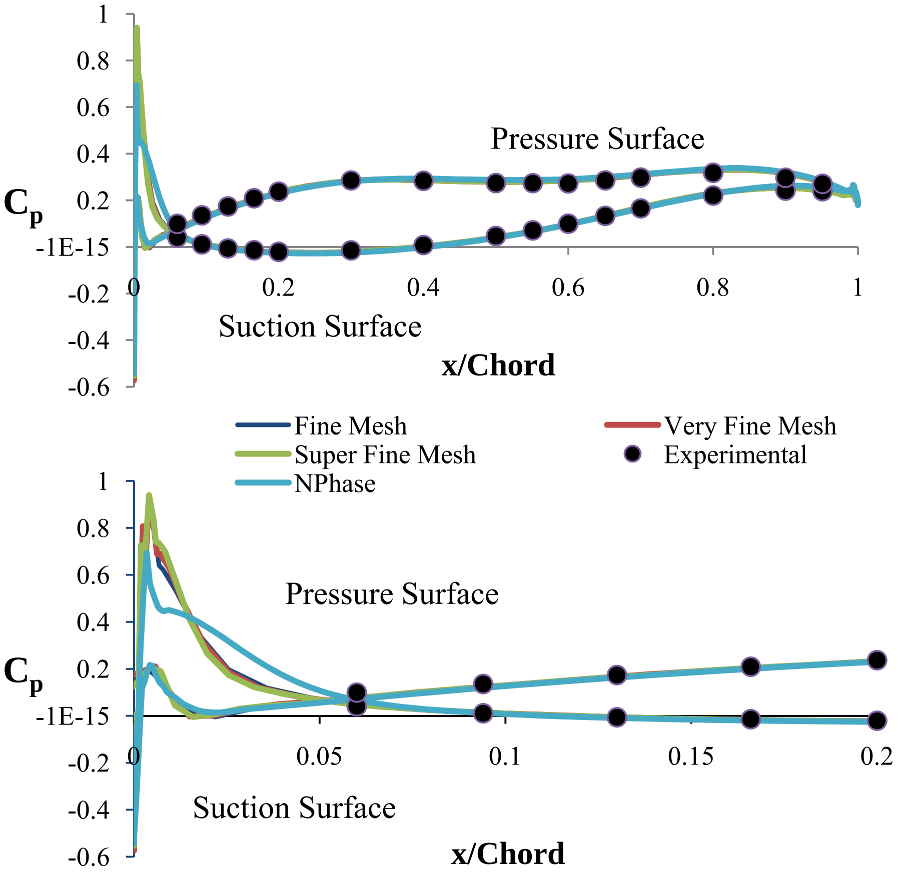
NPHASE



- Grid Generator: Pointwise™
- All 2D work using NPHASE and Pointwise™ was conducted by Vivek Hariharan
- Grid Size:193 x 101
- View of airfoil leading edge

2D Low Incidence Angle Pressure Distribution

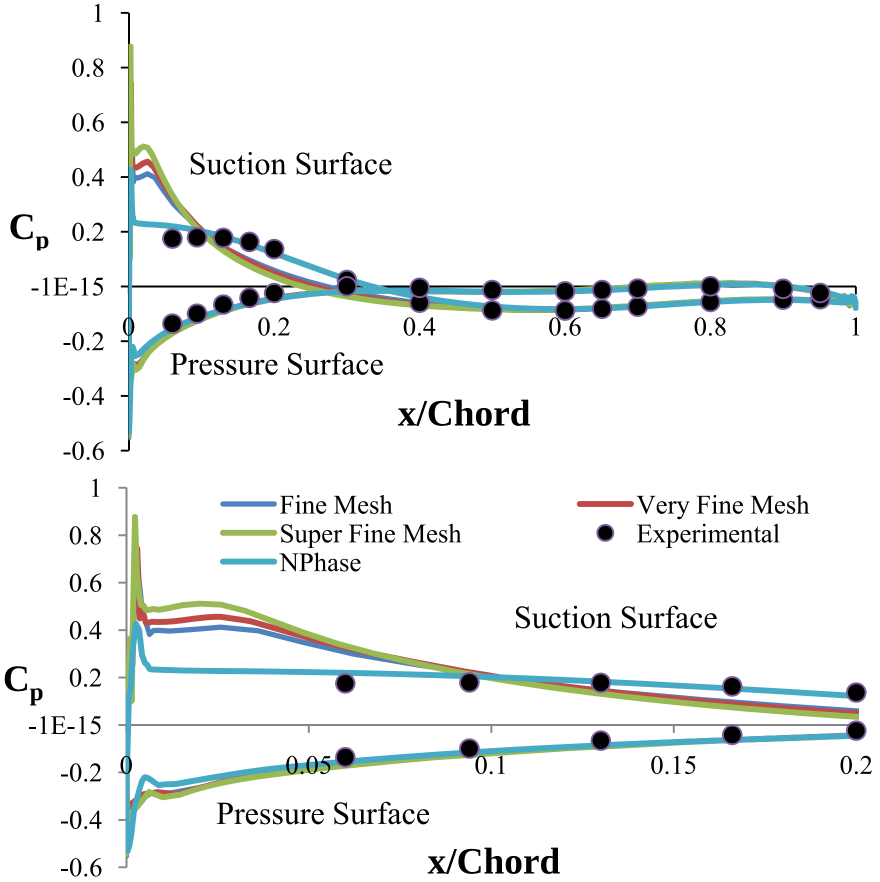
LEO solutions closely match the experimental data and the three mesh densities correlate with each other



- Some disagreement between LEO and NPHASE in the leading edge region where a small separation bubble is predicted
- Experimental data not available for x/C < 0.06 due to instrumentation limitations
- Since experimental data is not available for x/C < 0.06 no conclusions can be reached on which solution is correct

2D High Incidence Angle Pressure Distribution

Experimental flow visualization indicated flow separation to 40% chord on the suction surface



- LEO predicts a smaller separation bubble than NPHASE
- This discrepancy most likely due to the turbulence model
- LEO reattachment points determined from velocity vectors, NPHASE from skin friction

	Reattachment Point			
	LEO			**NPHASE**
Mesh	FM	VFM	SFM	193 x 101
x/Chord	0.26	0.22	0.19	0.445

Iteration Speed

Two different computer systems were used for the NPHASE and LEO flow solvers

2D			
Mesh	**Grid Points**	**Iterations/second**	**Machine**
Fine	9010	37.97	3Ghz Intel Core Duo 4 Gb Ram
Very Fine	13522	28.57	
Super Fine	19090	22.51	
NPHASE	19493	0.42	AMD Dual Processor 1.7 Ghz 2 Gb Ram

The processing speeds of the different computer systems will have an affect on Iterations/ second.

Summary

- Codes WAND and LEO were very easy to set up and execute
- Effective grids can be generated with code WAND quickly using the recommended preset values for mesh density
- LEO is robust and generated solutions in a timely fashion
- Generally, code LEO correlates well with the experimental data and other flow simulators.
    - There are some discrepancies in the leading edge region where the flow is separated and some additional grid refinement studies are warranted
    - Deviation from the experimental data for the high incidence case is attributed to the k-ω turbulence model