DRAG PREDICTION WORKSHOP RESULTS USING THE PARALLEL UNSTRUCTURED MULTIGRID SOLVER NSU3D

D. J. Mavriplis

ICASE

NASA Langley Research Center

Hampton, VA 23681-21997

USA

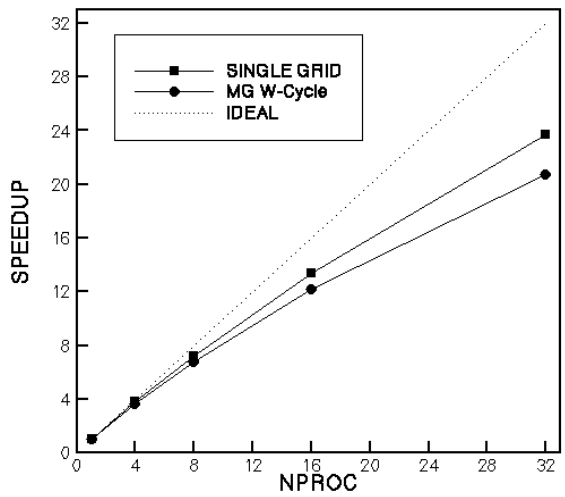
AIAA Drag Prediction Workshop

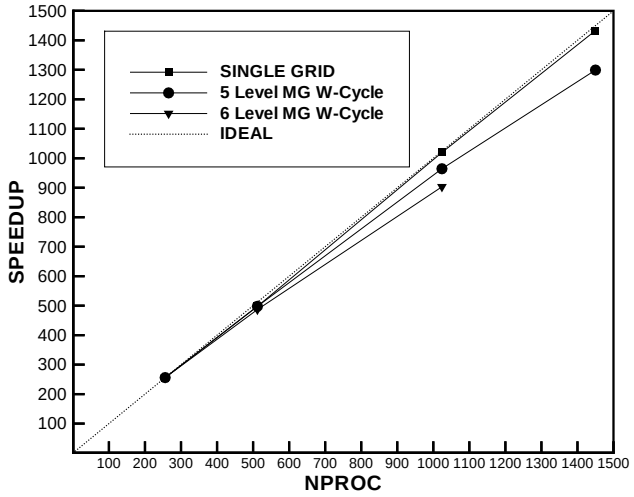
June 9-10, Anaheim, CA

NSU3D SOLVER

- *Discretization*
  - *Mixed Element Unstructured Grid Solver*
  - *Edge-Based Data-Structure*
  - *Roe-Rieman Solver (Matrix Dissipation)*
- *Solution Technique*
  - *Agglomeration Multigrid*
  - *Line / Point(Jacobi) Preconditioning*
  - *Optional Low Mach Number Preconditioning*
- *Hardware Compatibility*
  - *Vector or Cache Based Optimizations*
  - *Shared or Distributed Memory Parallelization*
  - *Combined MPI-OpenMP Parallelization*

SCALABILITY ON SMALL AND LARGE MACHINES





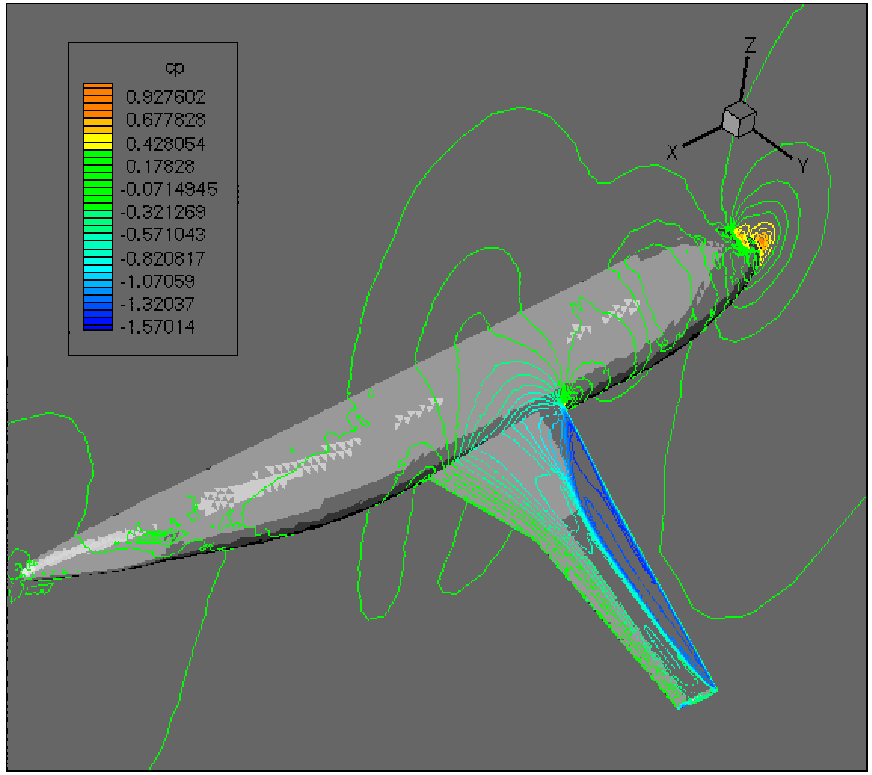
- *3 million point problems in 5 to 6 hours on commodity cluster*
- *Up to 25 million point in 1 hour on 1450 cpu T3E*

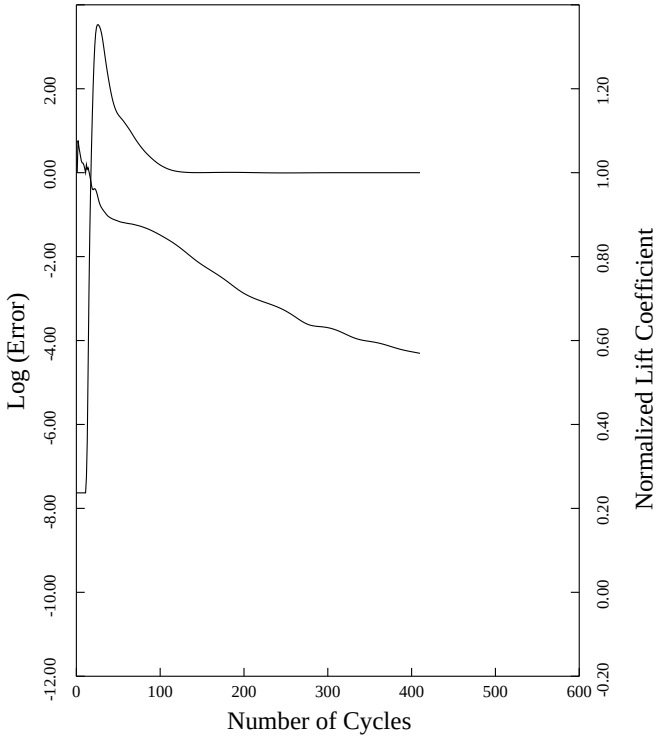
DLR-F4 UNSTRUCTURED GRIDS

- *Computations Performed on 3 Unstructured Grids*
  - *Baseline Workshop Grid: 1.6 million points*
  - *Uniform Refinement : 13 million points*
  - *Intermediate Grid : 3 million points*
    - *Generated and Computed by D. Levy, Cessna Aircraft*
      - *(not included herein)*

- *Tetrahedral Grids (VGRID) Converted to Mixed Prism-Tetrahedral Grids by Merging Thin Tet Layers in Boundary Layer Regions*
  - *Baseline : 1.65 million points, 9.7 million Tetrahedra*
    - *2 million Prisms, 3.6 million Tetrahedra*
  - *Fine Grid: 13 million points, 77.6 million Tetrahedra*
    - *16 million Prisms, 28.8 million Tetrahedra*

SAMPLE SOLUTION AND CONVERGENCE RATE





- *Force Coefficients Converged in 250 Cycles for this case*
- *Higher Incidences May Require More Cycles*
- *All Cases run 500 to 600 Multigrid Cycles*

REQUIRED COMPUTATIONAL RESOURCES

- *Baseline Grid: 1.6 million points : 500 MG cycles*
  - *3 Gbytes, 3 hours on 32 800MHz Pentiums*
  - *3.3 Gbytes, 45 minutes on 64 Procs of SGI Origin 2000(400MHz)*
- *Refined Grid: 13 million points : 500 MG cycles*
  - *27 Gbytes, 4 hours on 128 Procs of SGI Origin 2000(400MHz)*

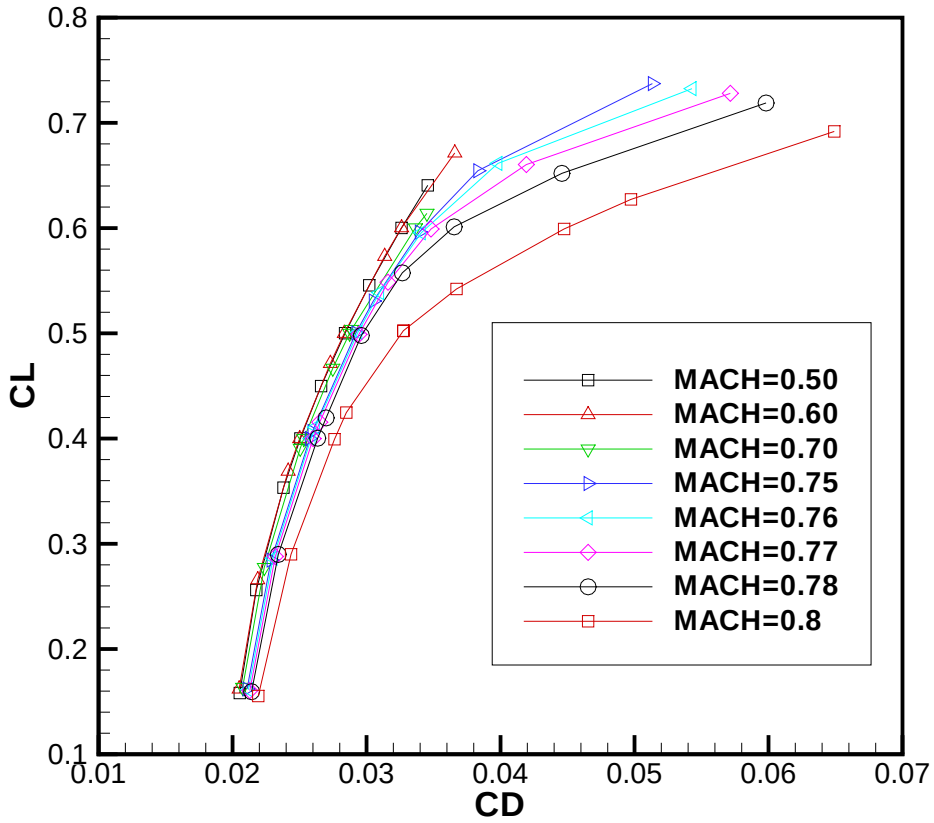
CONSTANT CL CASES

- *Compute Full Drag Polars for Each Mach Number*
- *Get Interpolated Incidence on Polar for Prescribed Lift Value*
  - *Cubic Spline Fit (in TECPLOT)*
- *Recompute Flow at Interpolated Incidence Value*
- *Interpolate Force Coefficient from Closest Points on Polar to Prescribed Lift Value*
  - *Interpolated Incidence Value Very Close to Prescribed Lift Value*
  - *Minimal Interpolation Errors*

CASES RUN

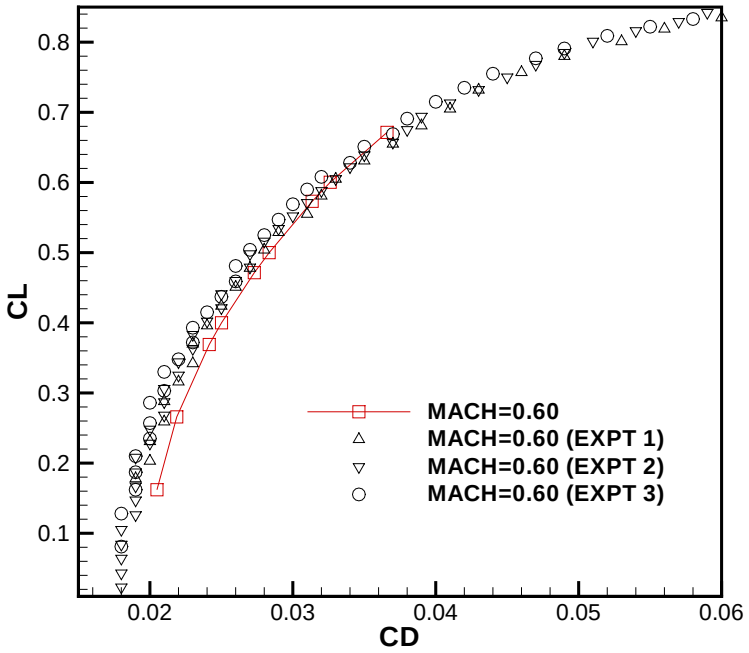
- *BASELINE GRID: 1.6 million points*
  - *Full Drag Polars for Each Mach Number*
  - *Interpolated Incidence on Polars at Prescribed Lift Value*
  - *Total: 72 cases*
- *FINE GRID: 13 million points*
  - *Computed Drag Polar at Mach = 0.75*
  - *Computed C_L=0.5 case at Mach=0.75*
  - *Total: 6 cases*

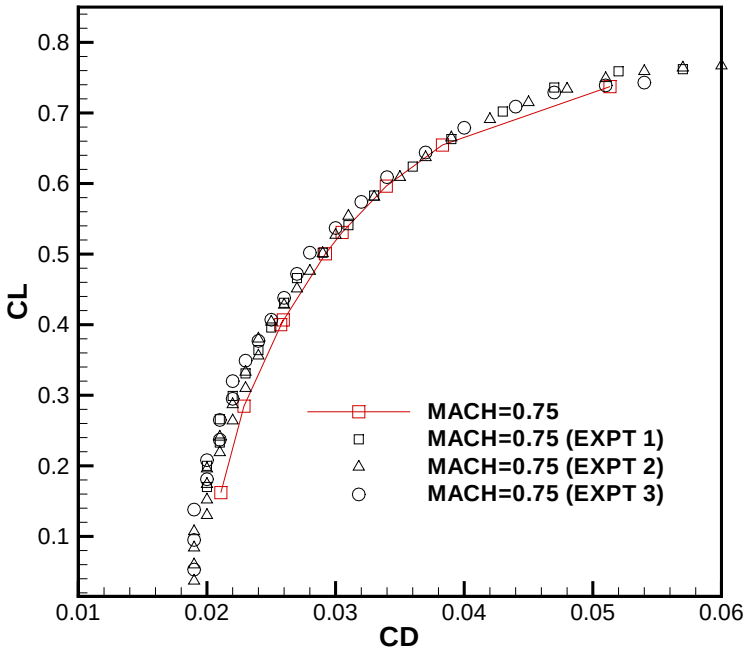
BASELINE GRID CASES



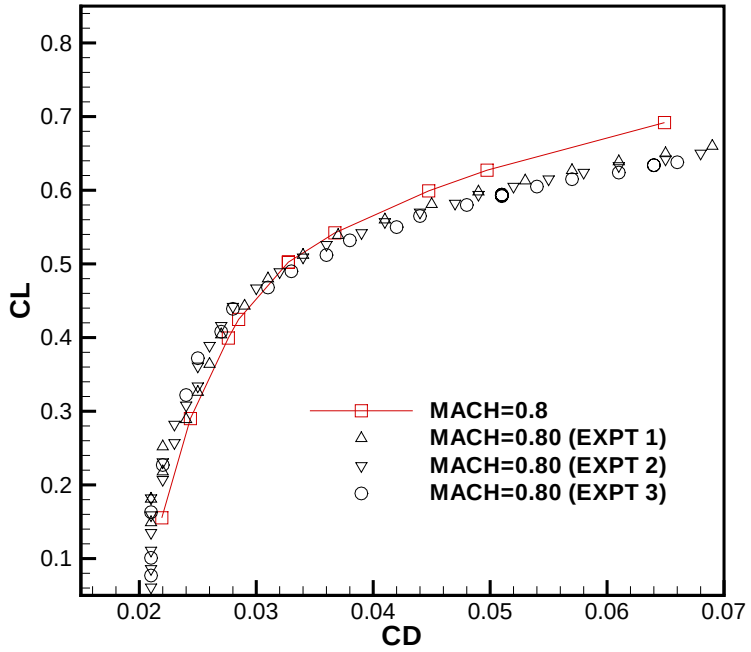
- *Full Polars for All Mach Numbers*
- *Total of 72 Cases*
- *About 1 Week on Pentium Cluster*

DRAG POLAR COMPARISON WITH EXPERIMENTAL DATA



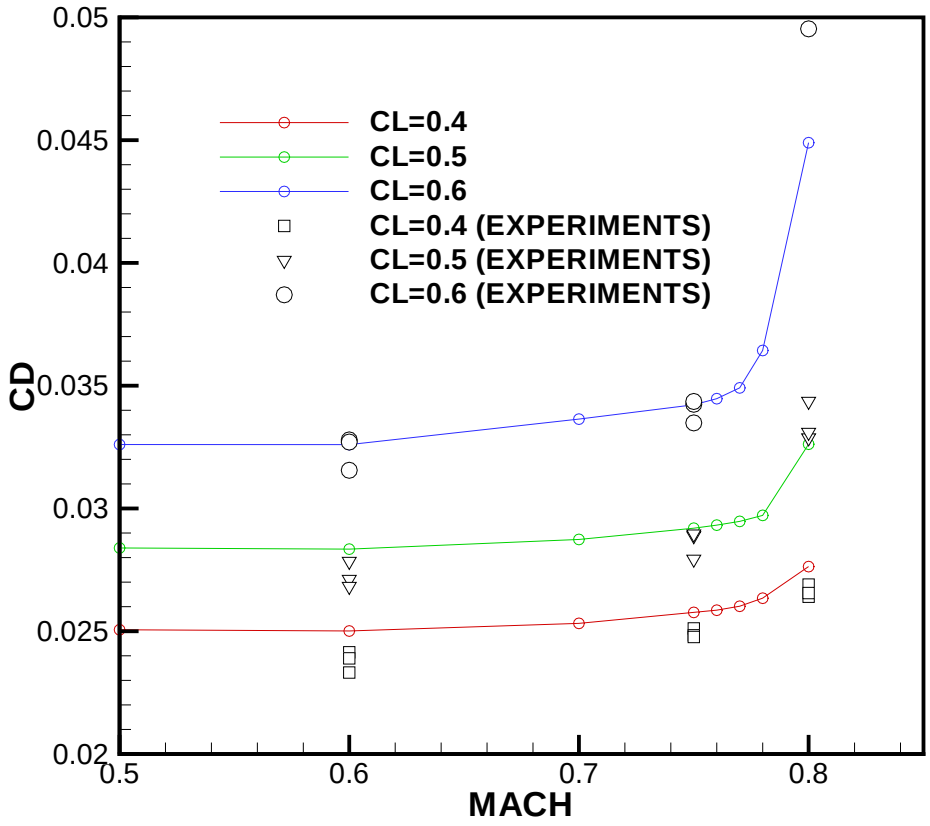


DRAG POLAR COMPARISON WITH EXPERIMENTAL DATA



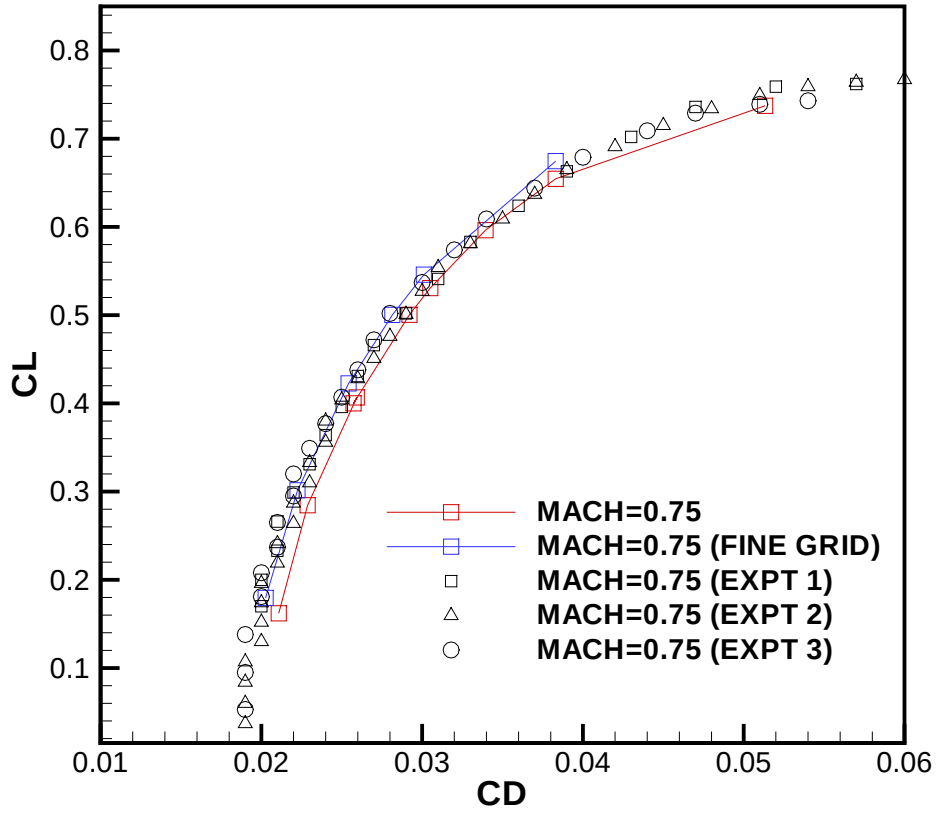
- *Increased Discrepancies at Higher Mach Number and Lift*

DRAG RISE COMPARISON WITH EXPERIMENTAL DATA



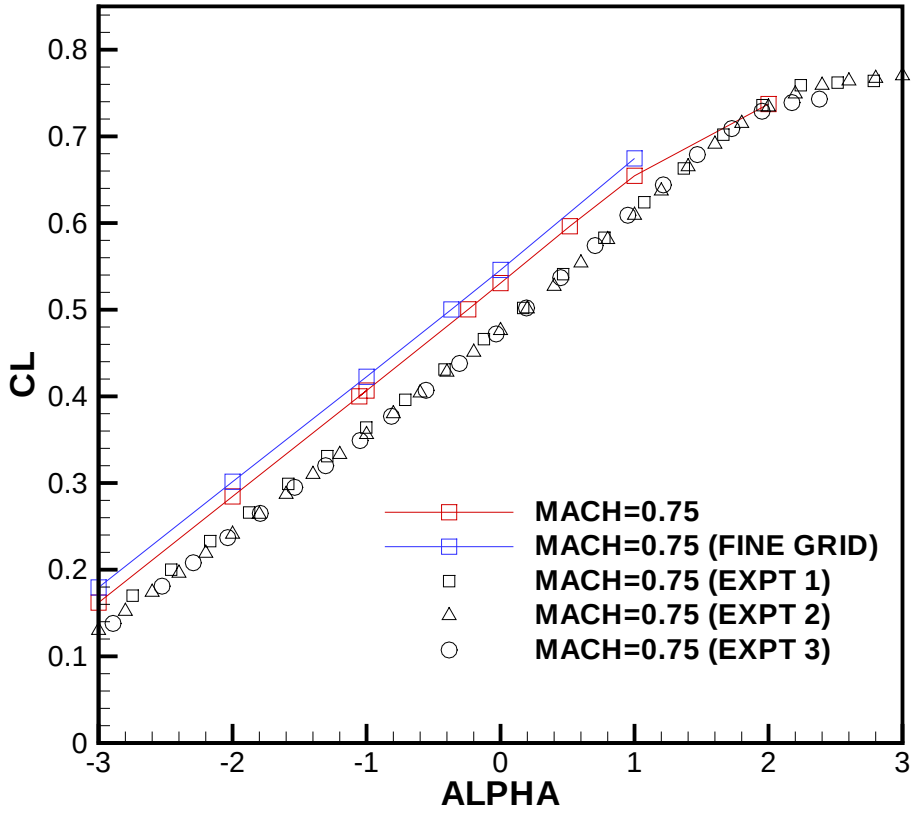
- *Reasonable Overall Comparison for Relatively Coarse Grid*
- *Increased Discrepancies at Higher Mach Number and Lift*

FINE GRID IMPROVEMENT OF M=0.75 DRAG



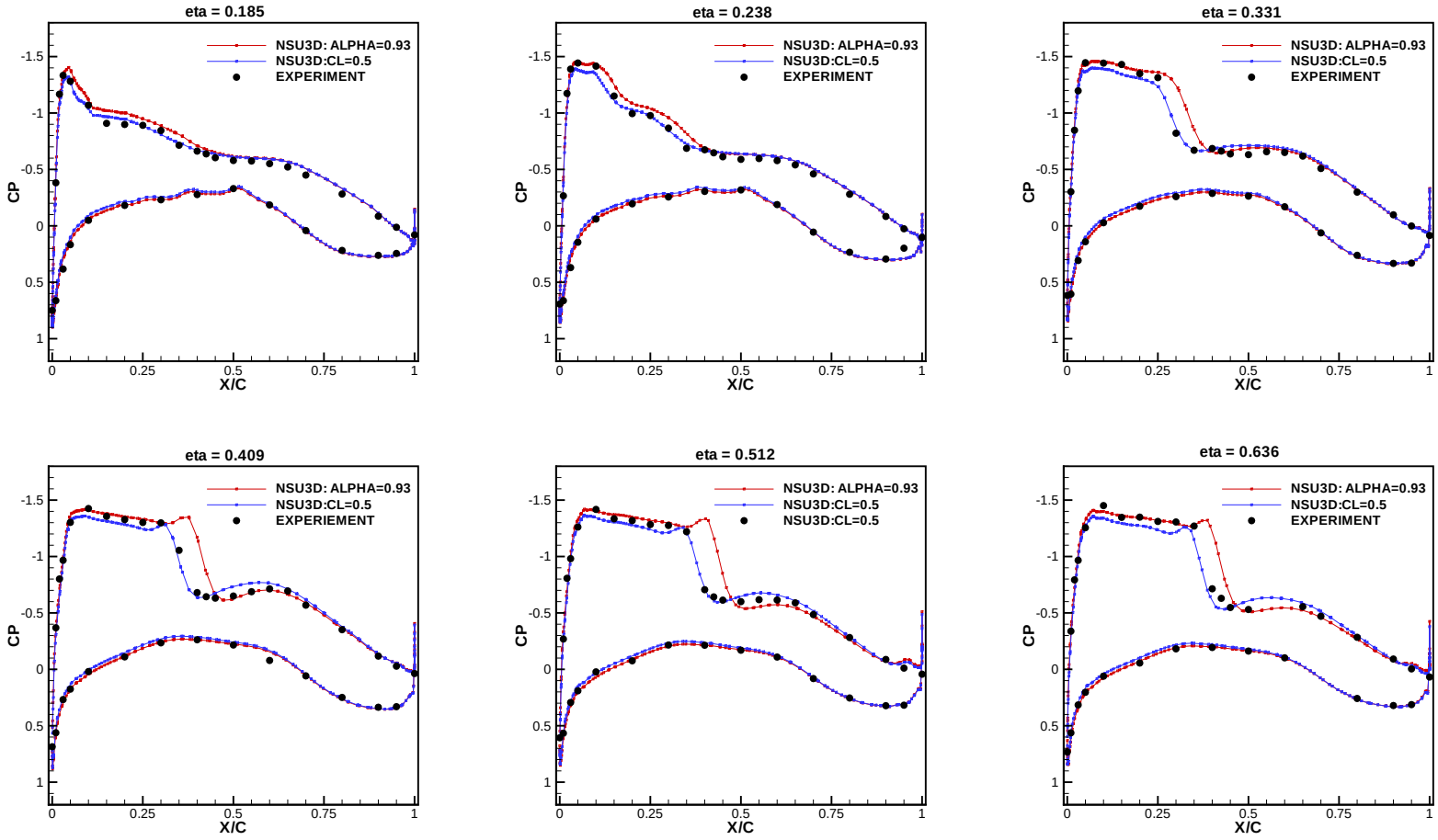
- *Fine Grid (13 million pts) is 8 way Refinement of Baseline Grid*
  - *Improved Drag prediction throughout Polar*

DISCREPANCY IN LIFT FOR BOTH GRIDS



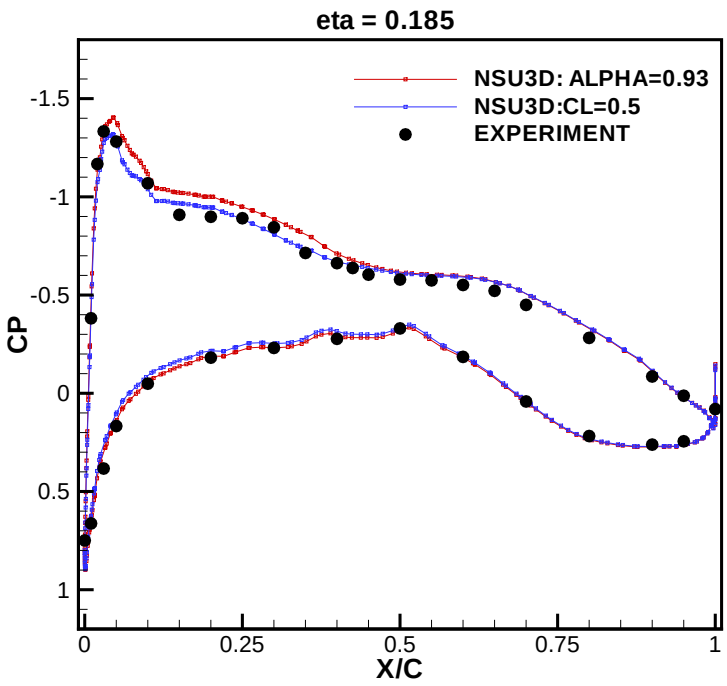
- *Fine Grid (13 million pts) 8 way Refinement of Baseline Grid*
  - *Increased Lift on Fine Grid at Same Incidence*

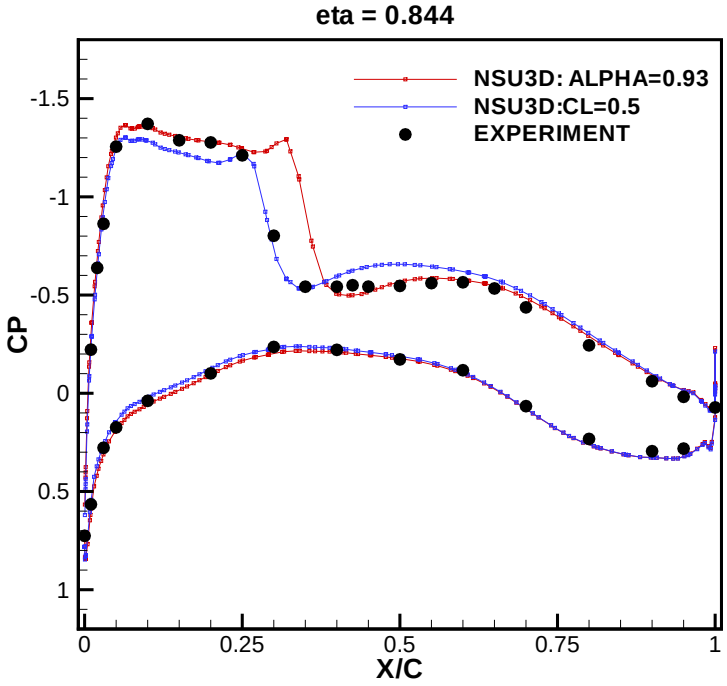
STATION CP PLOTS AT M=0.75, CL=0.6



- *Compare CFD and Experimental Results*
  - *Matching Incidences*
  - *Matching Lift Values*

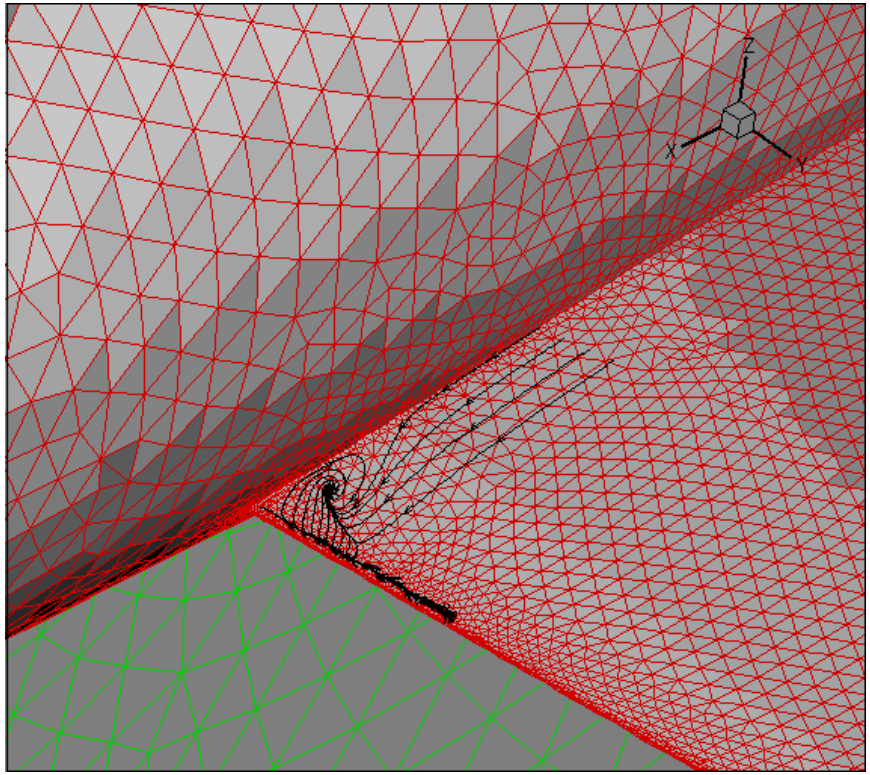
STATION CP PLOTS AT M=0.75, CL=0.6

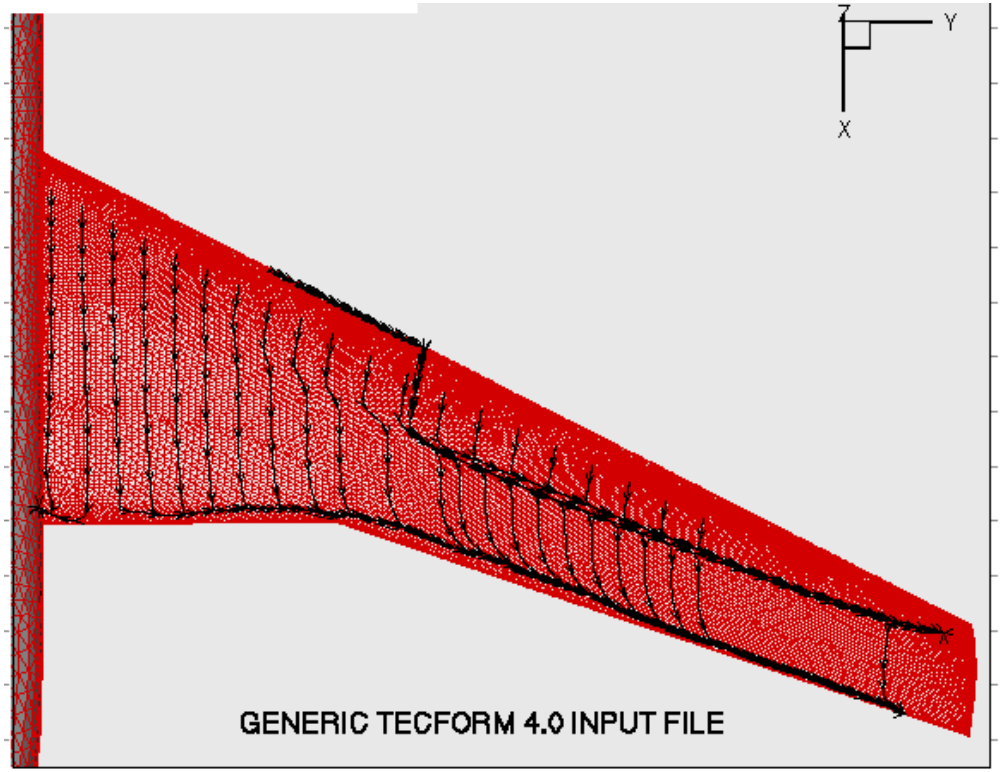




- *Shock Location Agrees for Matched C_L Case*
- *Expansion Rooftop Agrees for Matched Incidence Cases*
- *Biggest Differences at Outboard Stations*

CAPTURED FLOW DETAILS AT M=0.75, CL=0.6





- *Small Separation at Shock and Trailing Edge*
- *Vortex at Wing Root*

SUMMARY

- *Baseline Grid (1.6 million pts) Provides Reasonable Overall Prediction of Force Coefficients and Drag Rise*
- *Enables Parameter Studies on Inexpensive Cluster Machines*
  - *72 cases run in 1 week*
- *Enhanced Accuracy with Finer Grids*
  - *3 million points, 13 million points*
  - *Grid Resolution Effect Requires more Quantification*
- *Experimental Lift Values Lower than CFD*
  - *Transition*
  - *Turbulence Modeling*
- *Combined Results (with D. Levy) to be presented at Reno 2002*