Drag Prediction with the Zeus/CFL3D System

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Objective

Investigate the use of a “Production Navier-Stokes Analysis System” for CFD Drag Prediction

-Major interest is in the prediction of drag increments

-Use “standard” processes as much as possible

Acknowledgement

None of this work would have been possible without the considerable contributions of:

N. Jong Yu

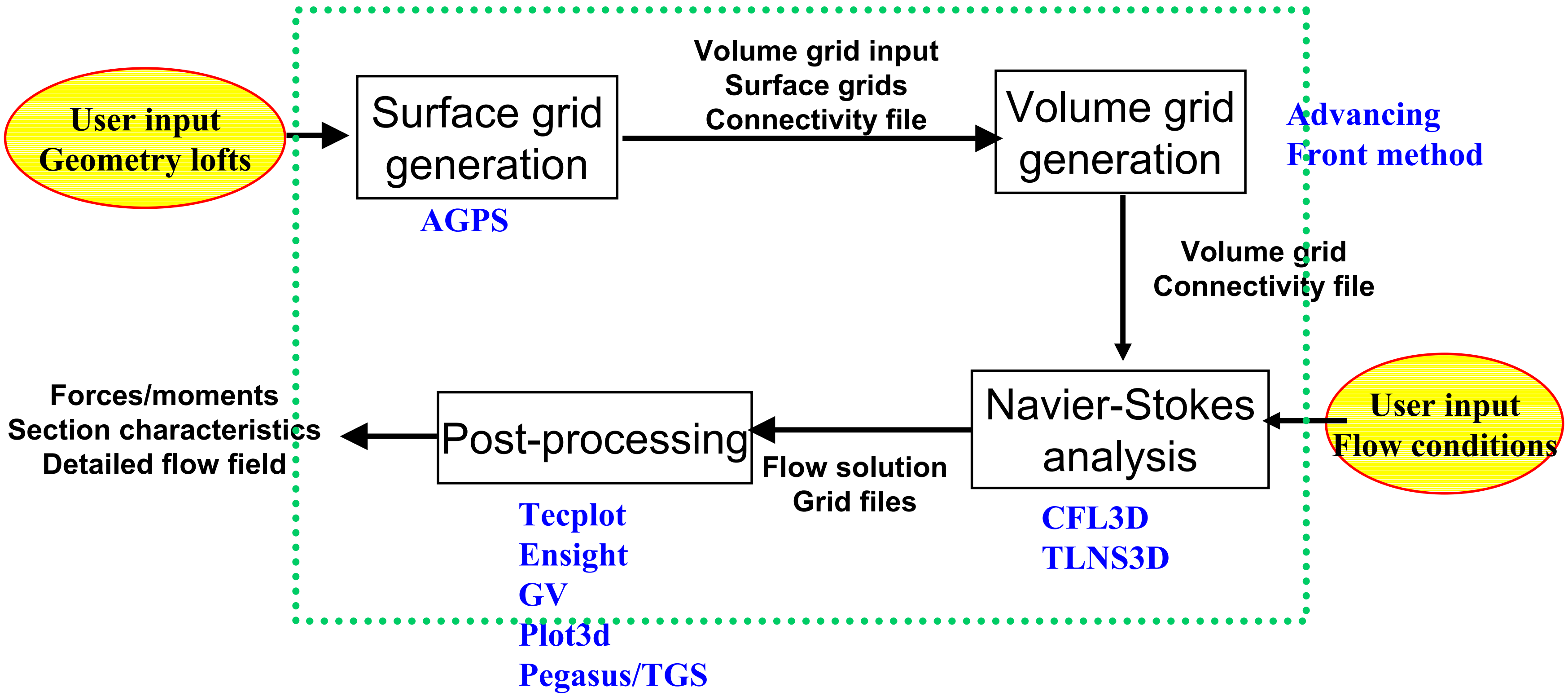
Tsu-Yi Bernard Su

Tsong-Jhy Kao

Emanuel R Setiawan

ZEUS/CFL3D

Driver for Surface Grid Generation, Volume Grid Generation, Navier-Stokes Analysis, and Post-processing



CFL3D – Thin Layer Navier-Stokes Code

- Developed at NASA Langley (Jim Thomas, Kyle Anderson, Bob Biedron, Chris Rumsey, & …)
- Finite volume
- Upwind biased and central difference
- Multigrid and mesh sequencing for acceleration
- Multiblock with 1-1 blocking, patched grid, and overlap-grid
- Numerous turbulence models
  - Spalart-Almaras SA Model
  - Menter's k-ω SST Model
- Time accurate with dual-time stepping
- Runs efficiently on parallel machines through MPI

Limited comparisons also made with:

- TLNS3D – Thin Layer Navier-Stokes Code
- TRANAIR – Full Potential + Coupled Boundary Layer

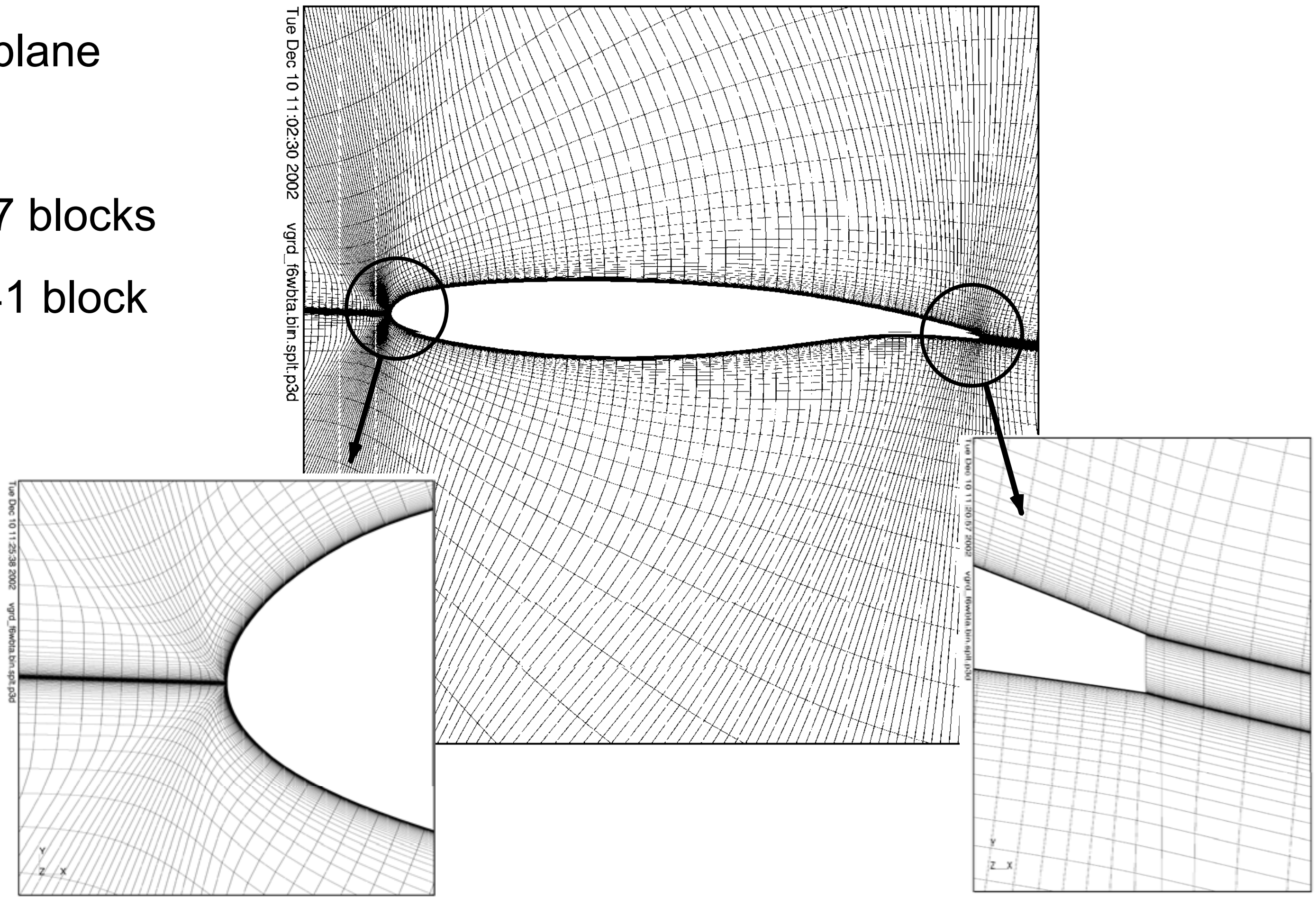
Typical Wing-Body Grid - 3.9 Million Cells

Wing K-plane

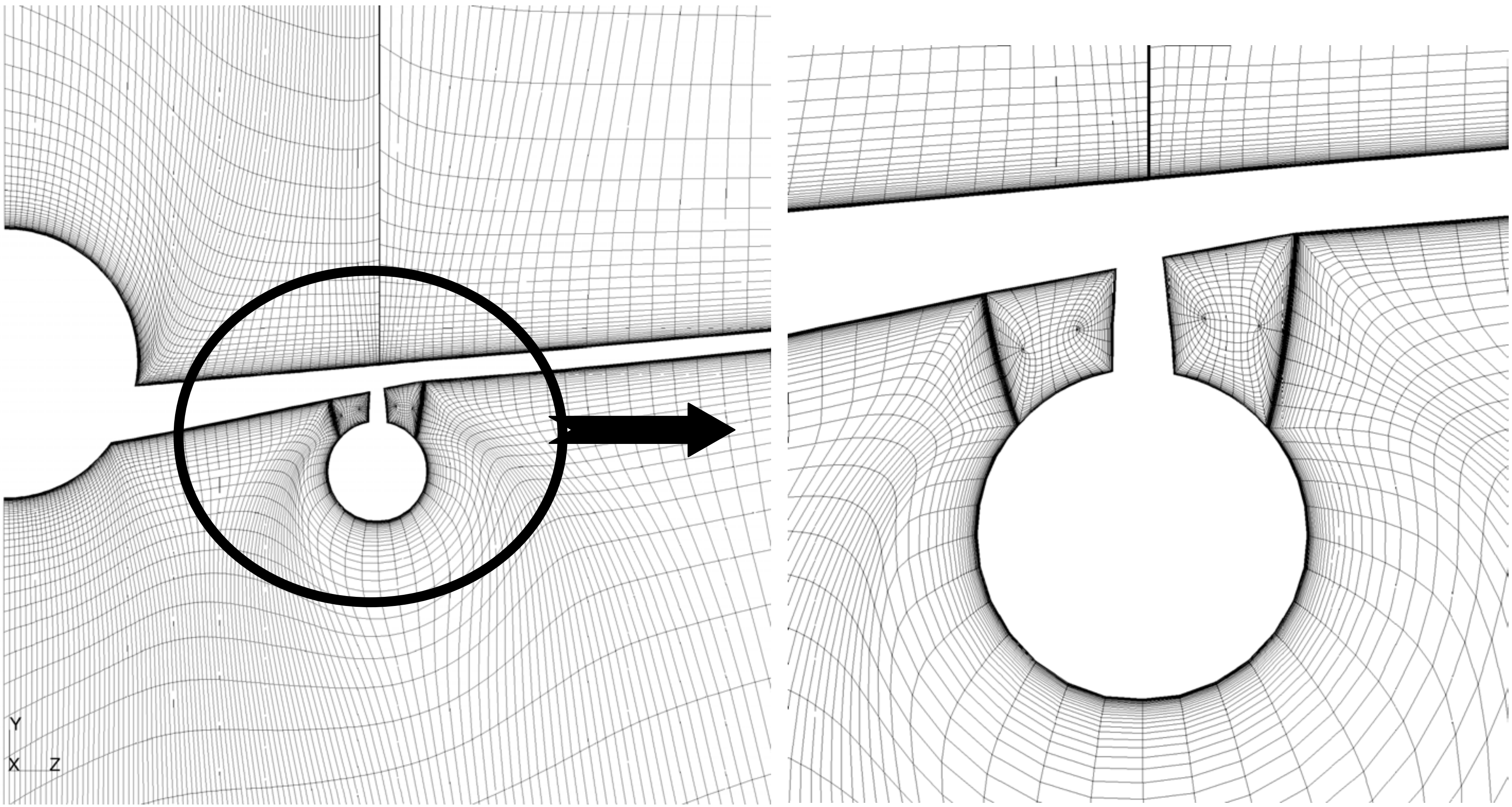
H-Grid

4 257x37 blocks

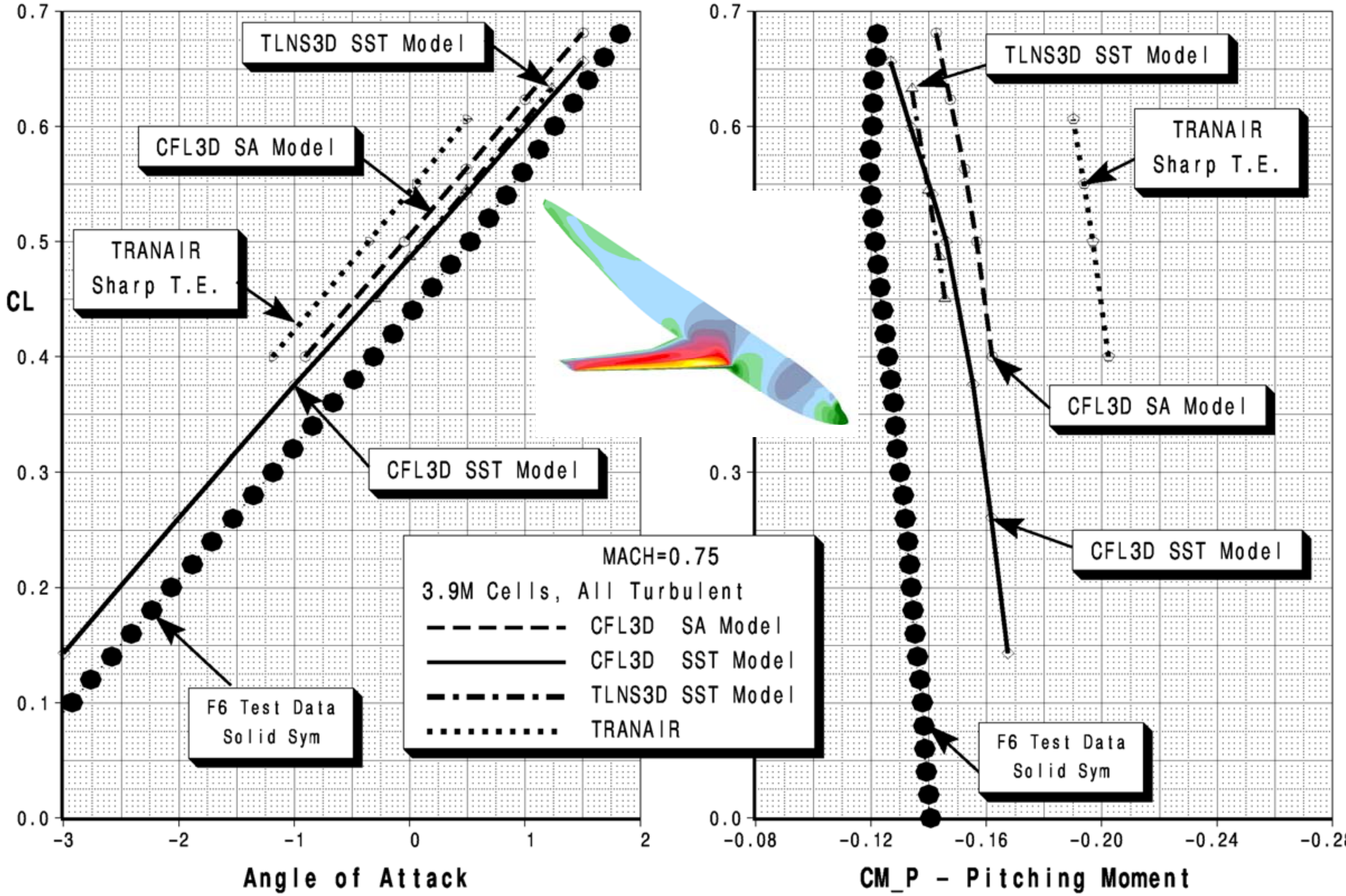
+ 1 65x41 block



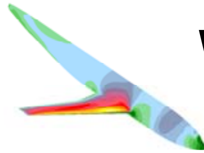
Typical Wing-Body-Nacelle-Pylon Grid – 6.2 Million Cells

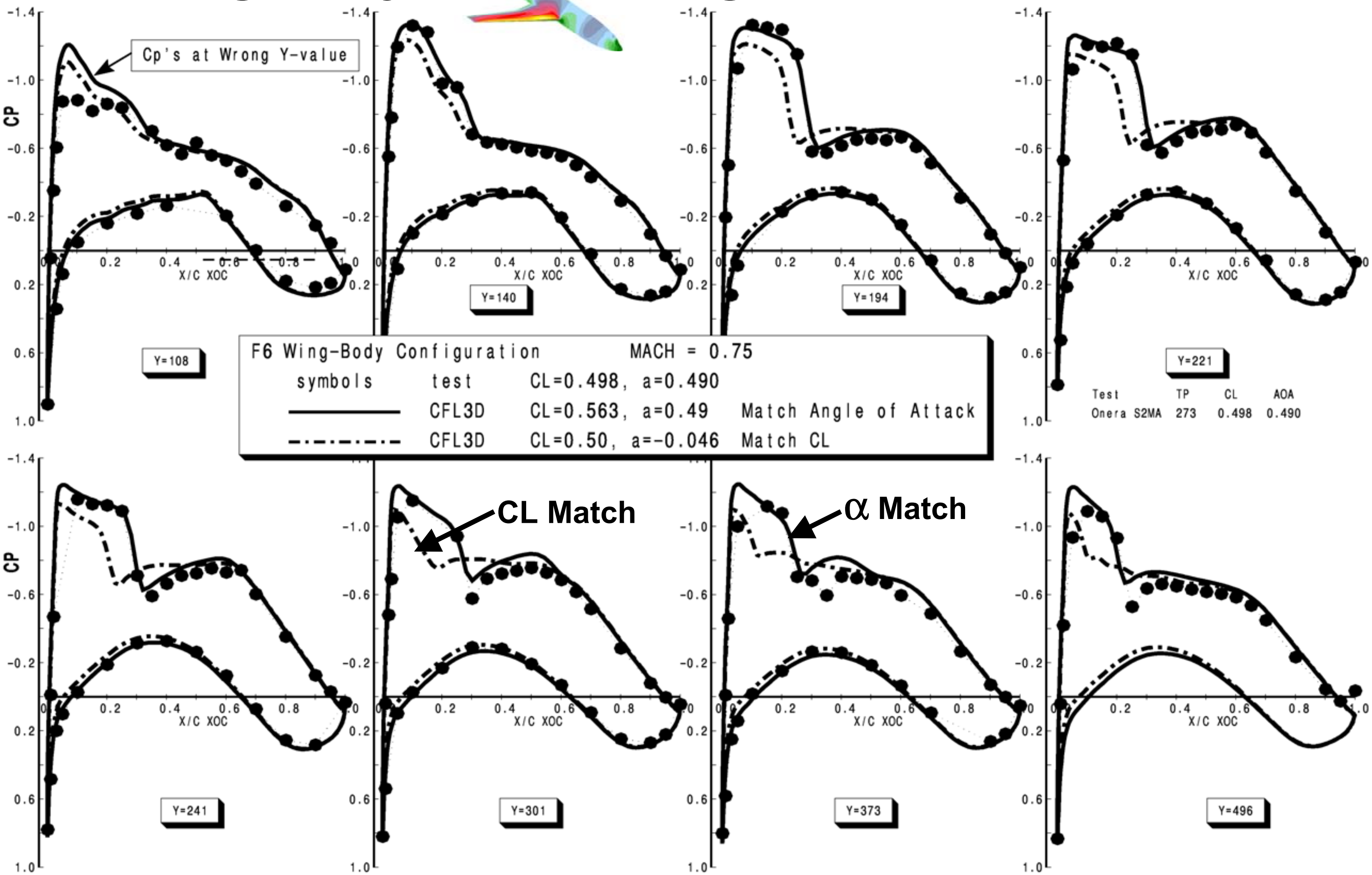


F6 Wing-Body Lift and Pitching Moment

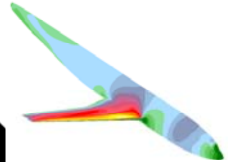


F6 Wing-Body Wing Cp's – Match α or CL?

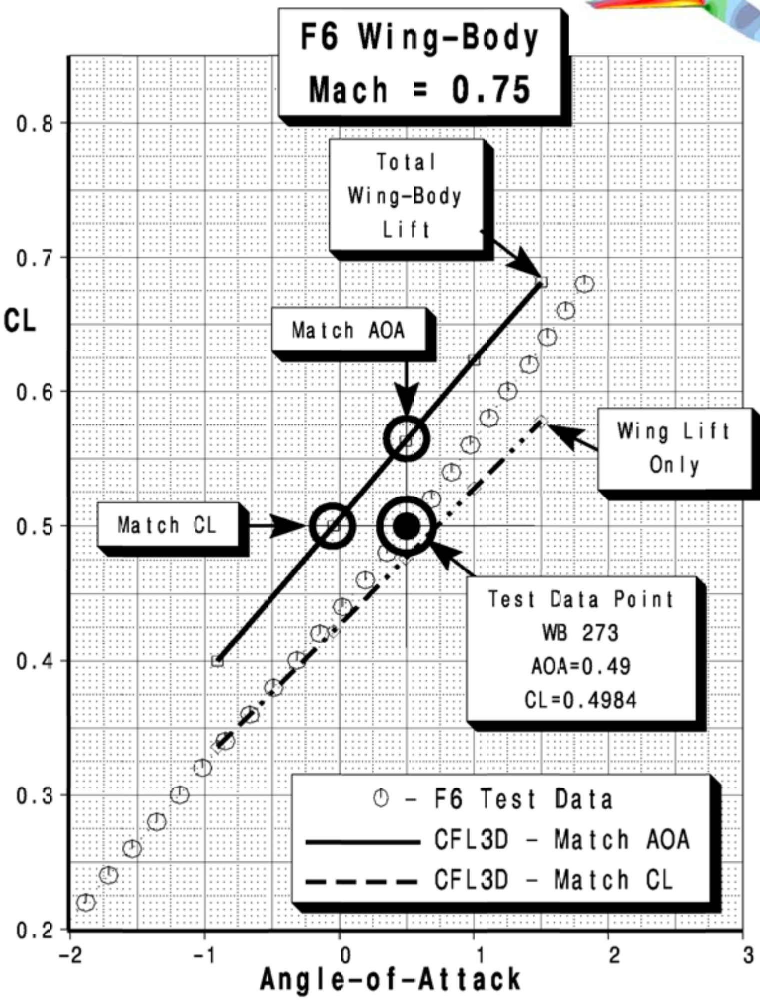


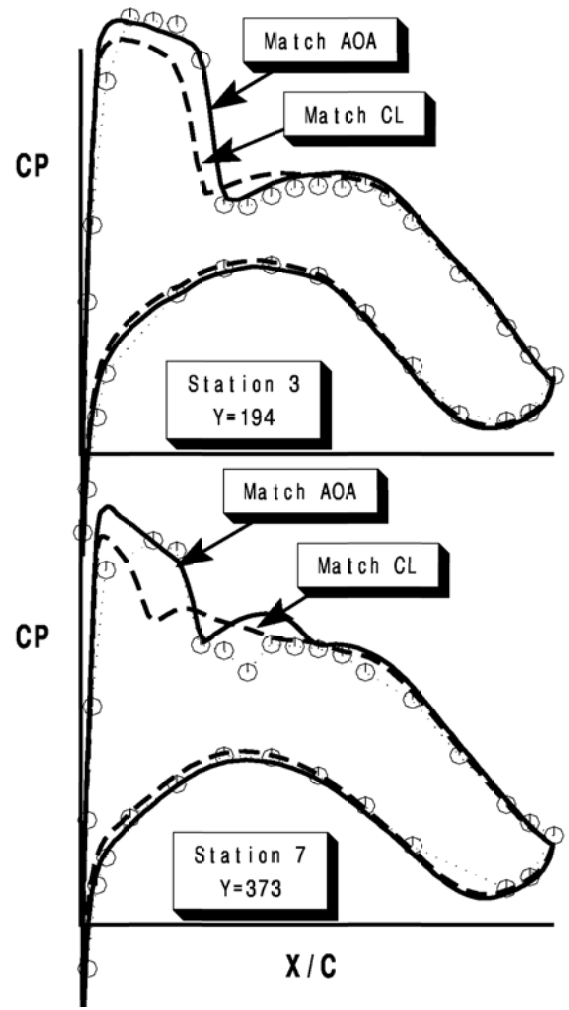


F6 Wing-Body



Wing Cp's – Match α or CL?





Wing pressure agreement raises question about lift force.

Agreement with wing pressures when AOA is matched tends to indicate that wing lift (~0.476) must be correctly predicted. The body lift must be greater than 5% of the total lift (10-12% is more typical) thereby implying that the total lift at that angle of attack cannot be ~0.50 but should be closer to the predicted amount!

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Wing-Body Grids

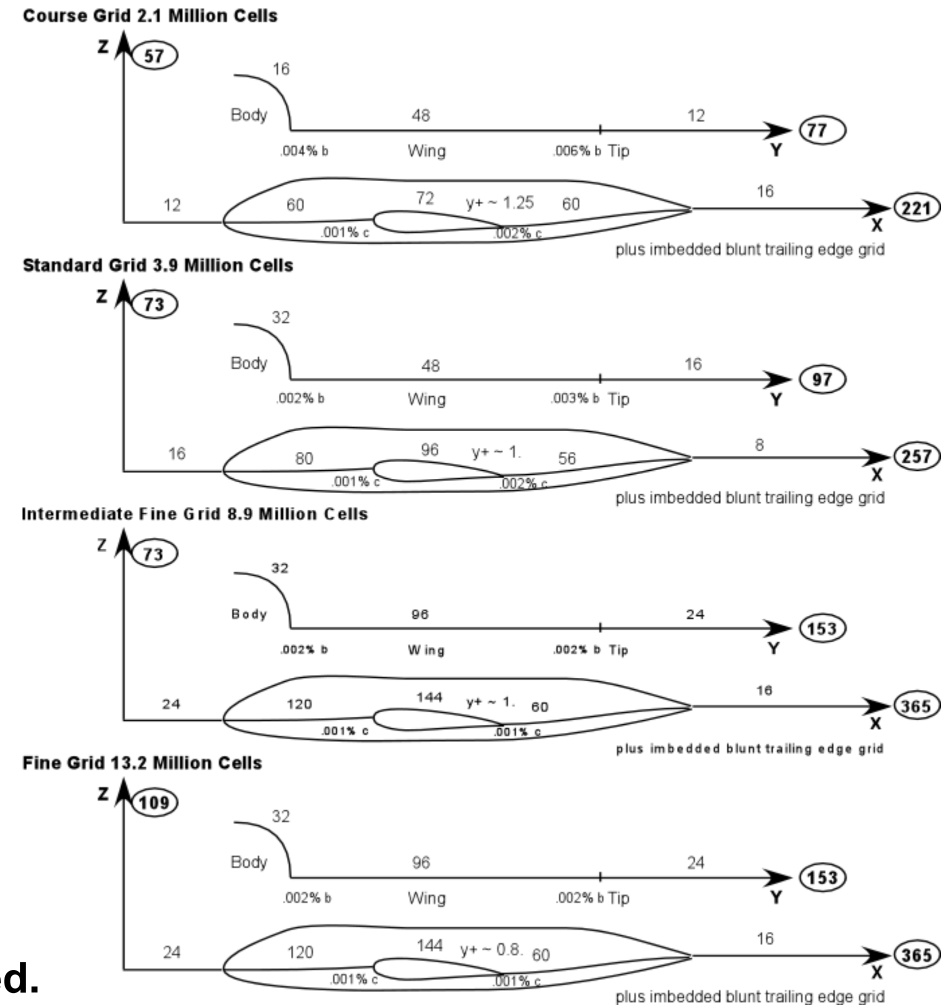
Course Grid 2.1 Million Cells
- 1st-cell size: y+ ~ 1.25
- BL Max-growth rate: 1.4 ~ 1.55
- BL Cells: 18

Medium Grid 3.9 Million Cells
- 1st-cell size: y+ ~ 1.0
- BL Max-growth rate: 1.17 ~ 1.24
- BL Cells: 36

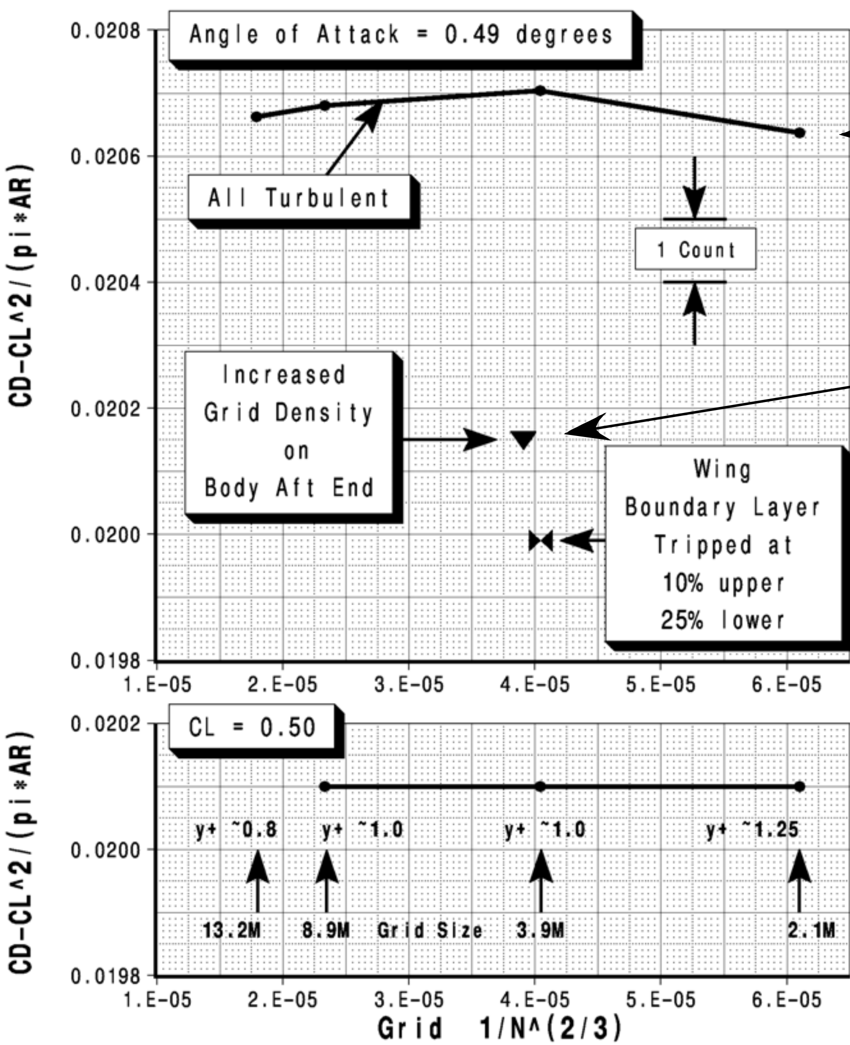
Fine Grid 8.9 Million Cells
- 1st-cell size: y+ ~ 1.0
- BL Max-growth rate: 1.17 ~ 1.24
- BL Cells: 36

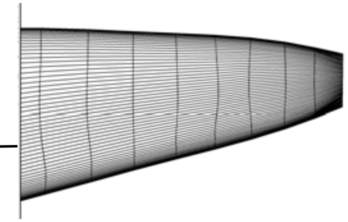
Finer Grid 13.2 Million Cells
- 1st-cell size: y+ ~ 0.8
- BL Max-growth rate: 1.17 ~ 1.24
- BL Cells: 36

- **Grids <u>are not</u> successively refined.**

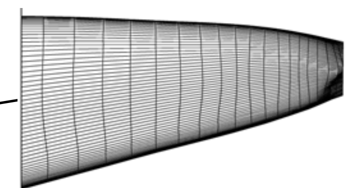


F6 Wing-Body – Grid Convergence Study

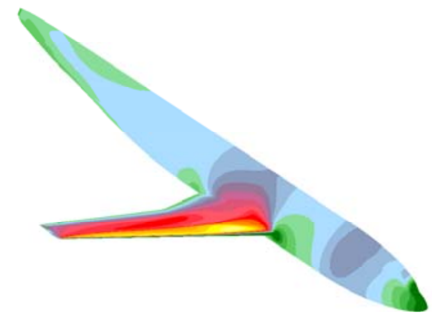




Standard grid on body

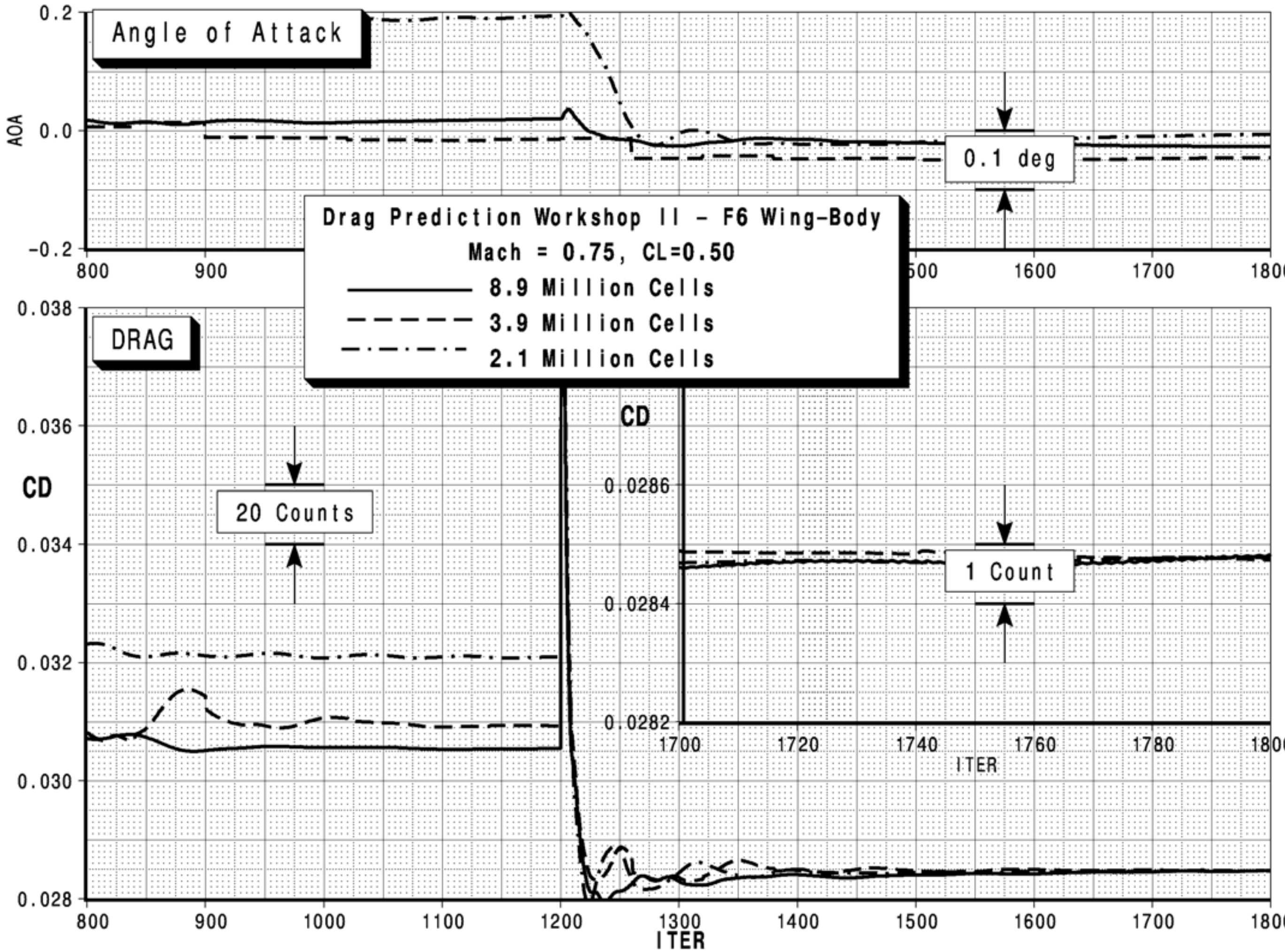


Enhanced body grid

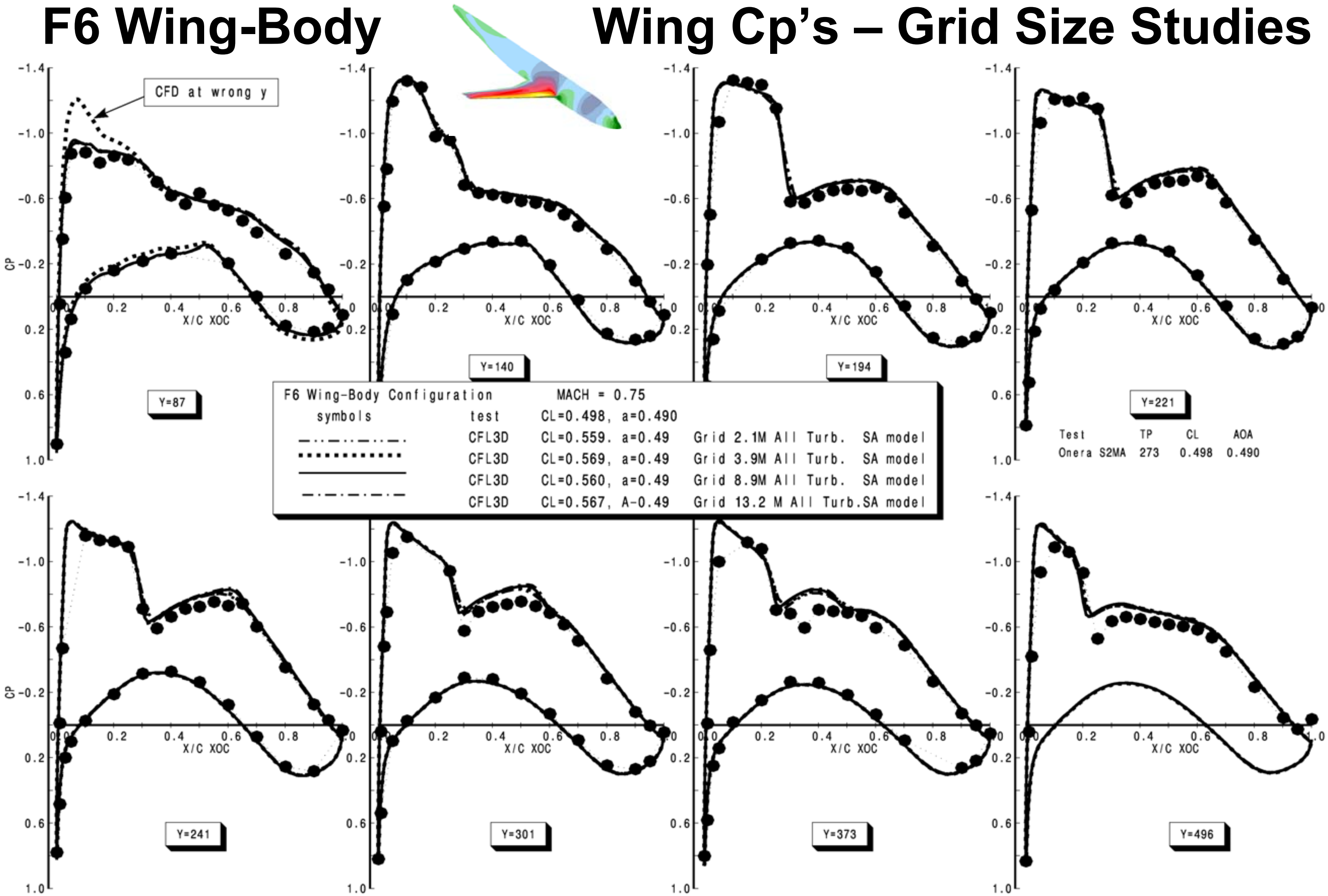


- **Mach = 0.75**
- **SA Turbulence Model – All Turbulent**
- **Grids <u>are not</u> successively refined.**
- **Each grid was independently generated to meet target size while maintaining emphasis on the wing.**

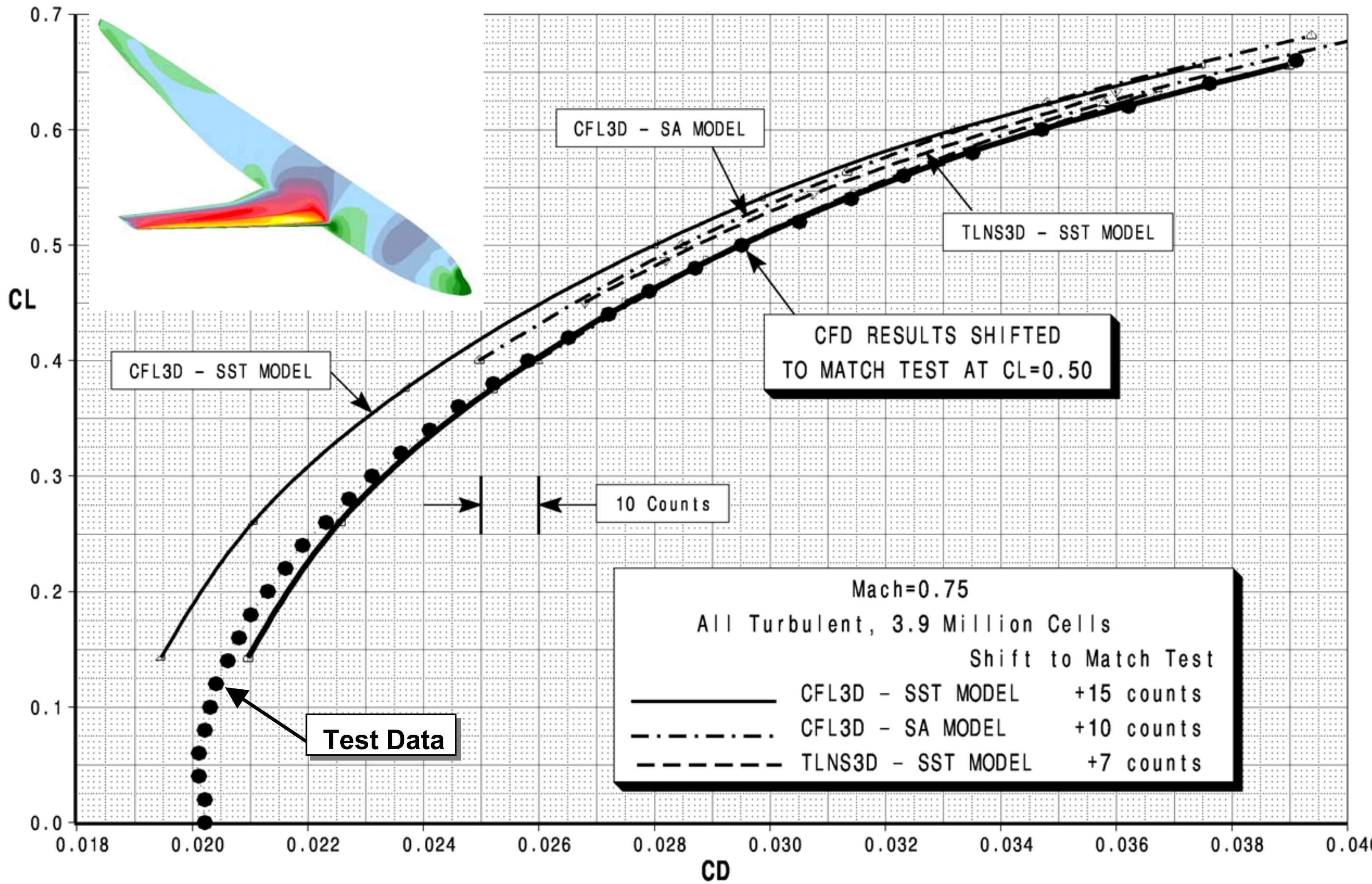
F6 Wing-Body – Convergence History



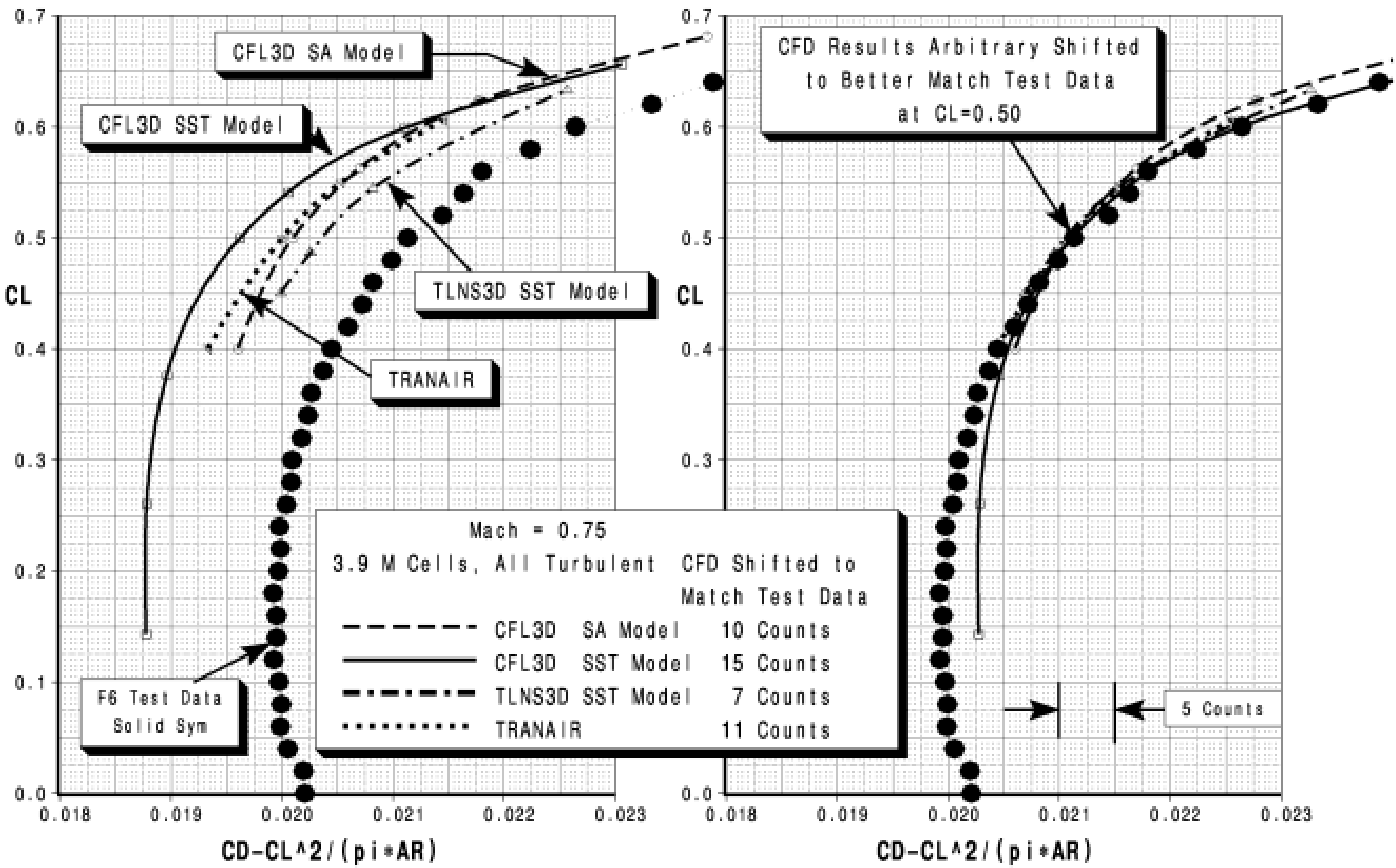
F6 Wing-Body Wing Cp's – Grid Size Studies



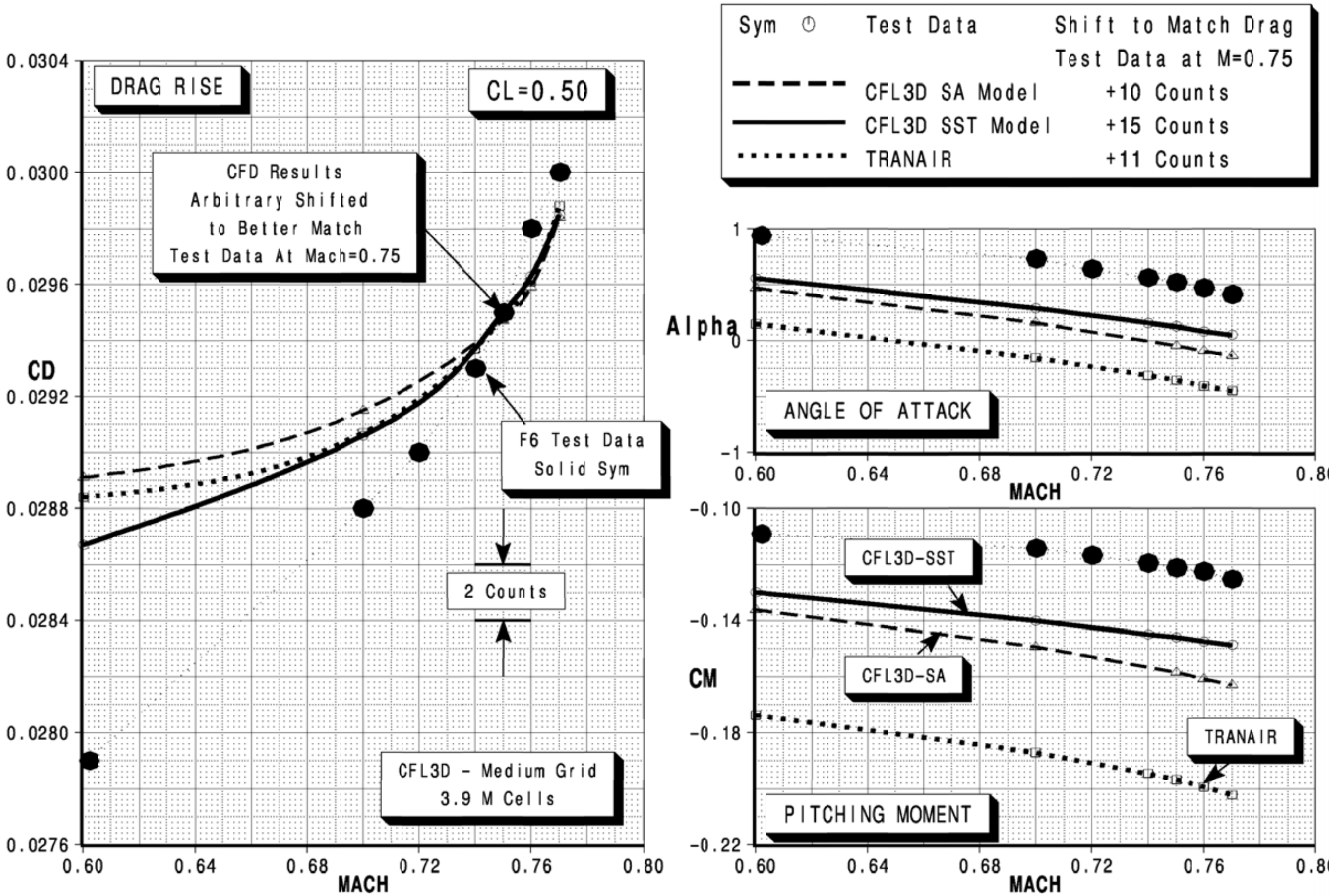
Wing-Body Drag Polar



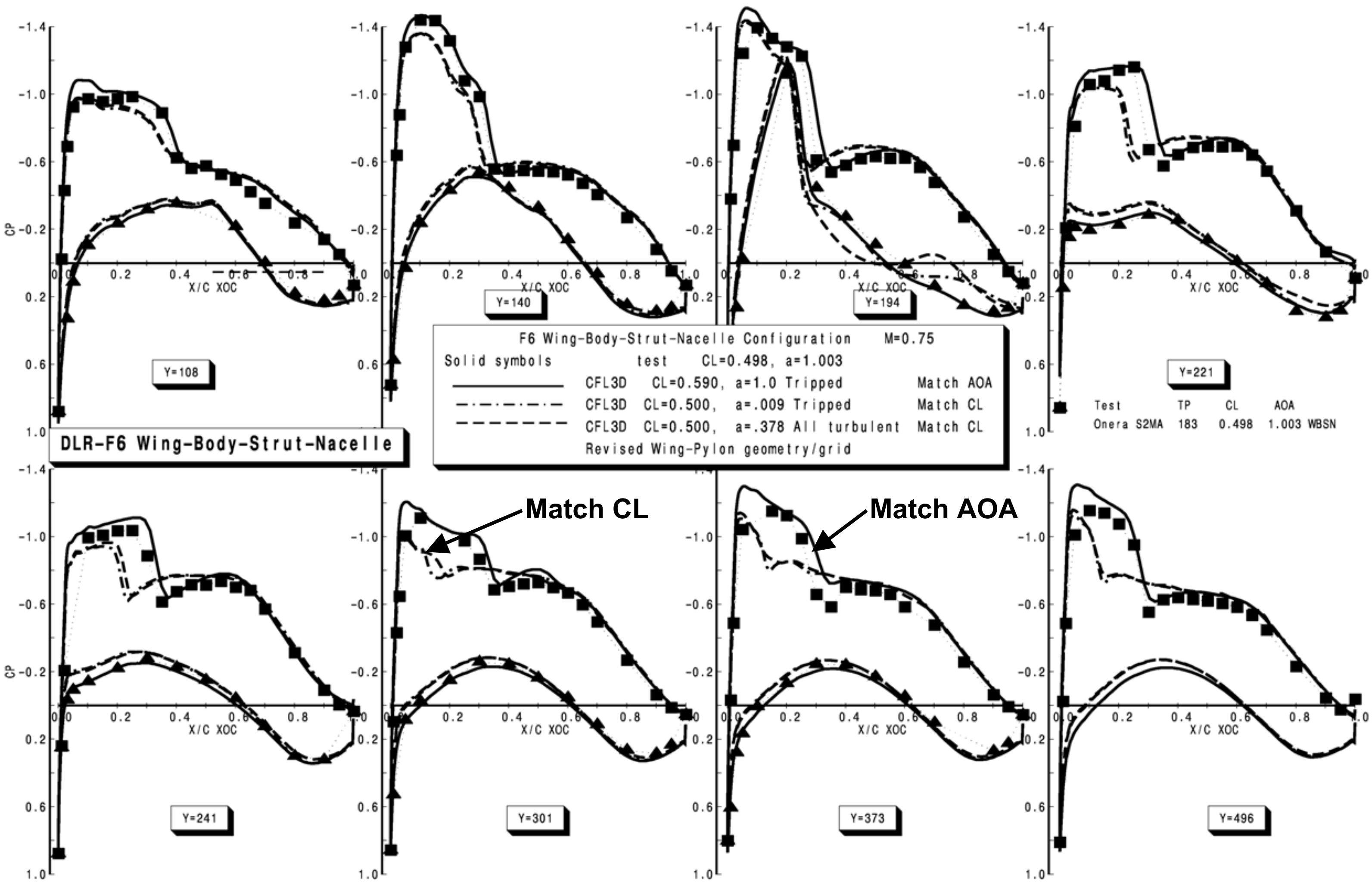
Wing-Body Polar Shape



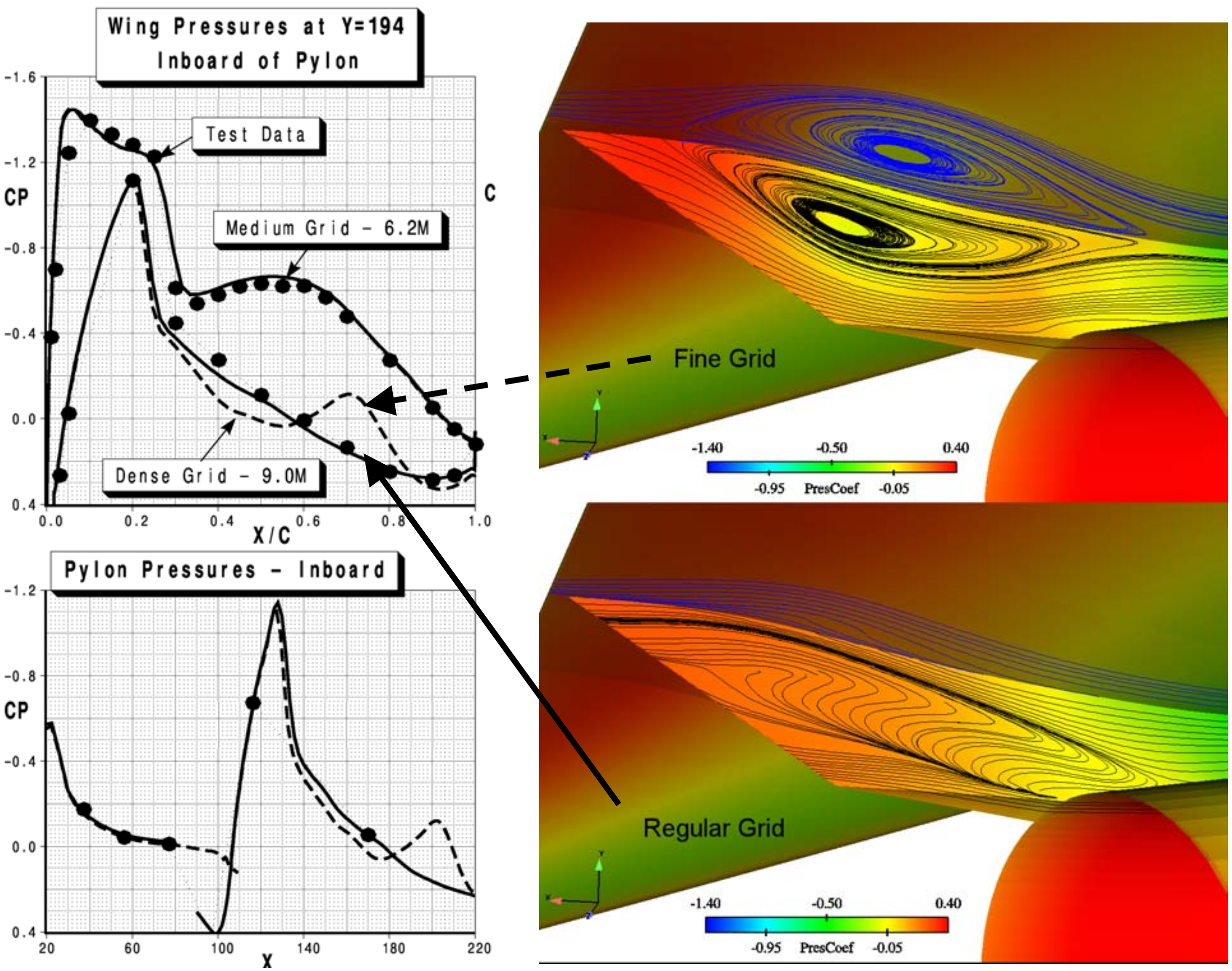
Wing-Body Drag Rise



Wing Pressure Distributions – Wing/Body/Nacelle/Pylon

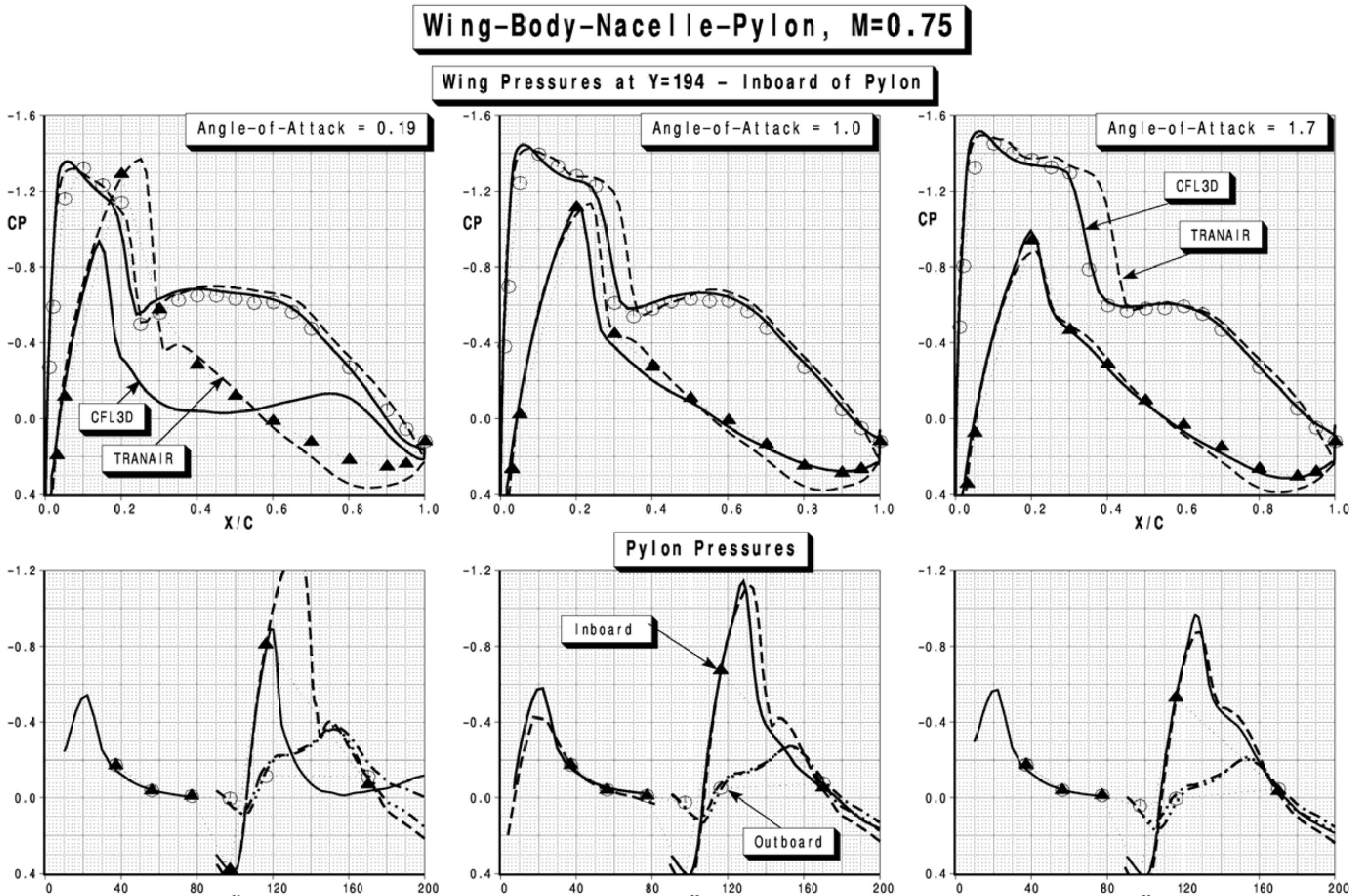


Why We Did Not Complete Grid Convergence Study for Wing-Body-Nacelle-Pylon

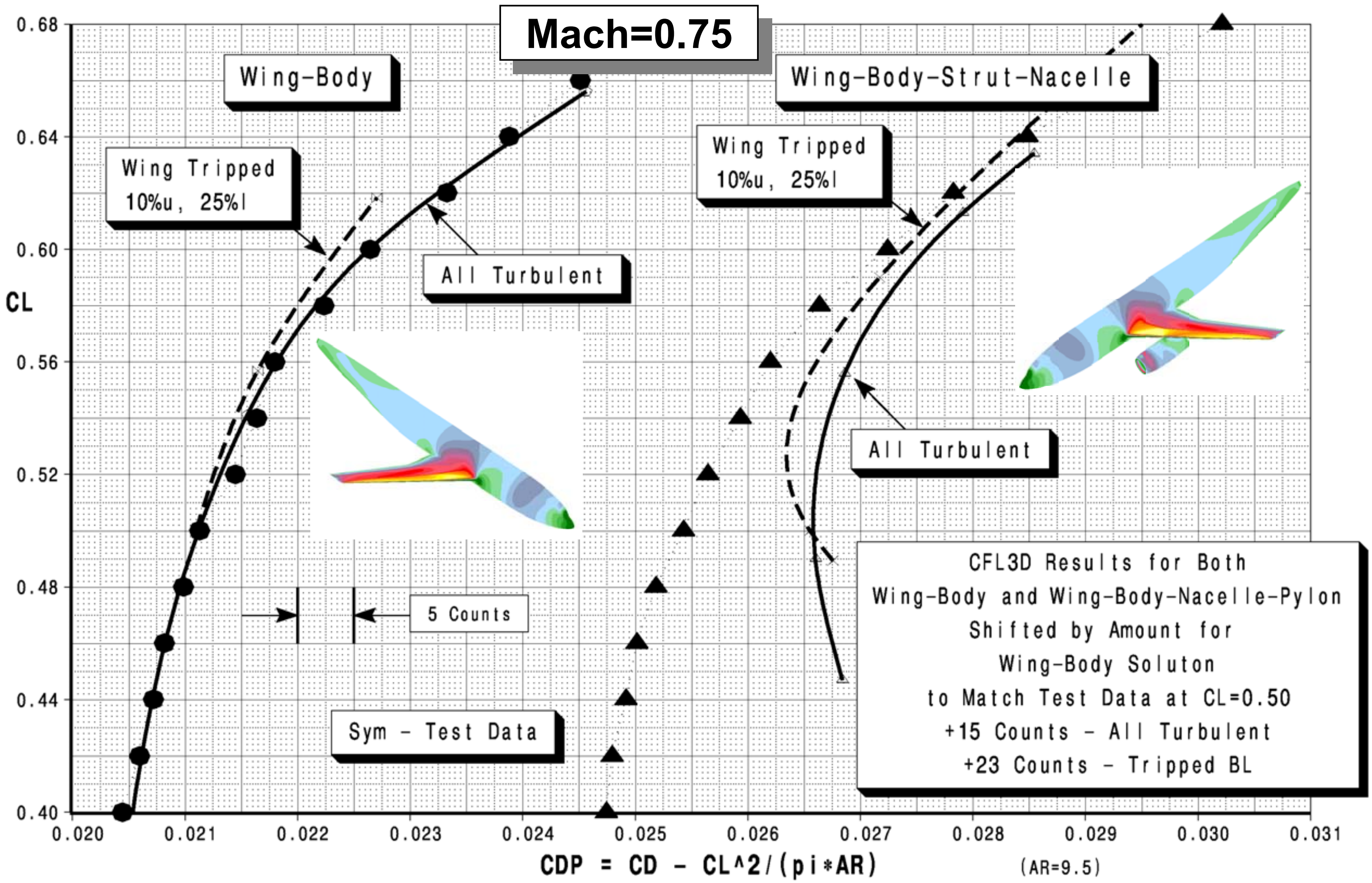


Increasing grid density resulted in excessive flow separation on the inboard side of the nacelle moving the CFD solution further away from the experimental data. Rather than converging on the "correct" solution with increasing grid density our solution was diverging. Grid convergence was meaningless for our code in this case.

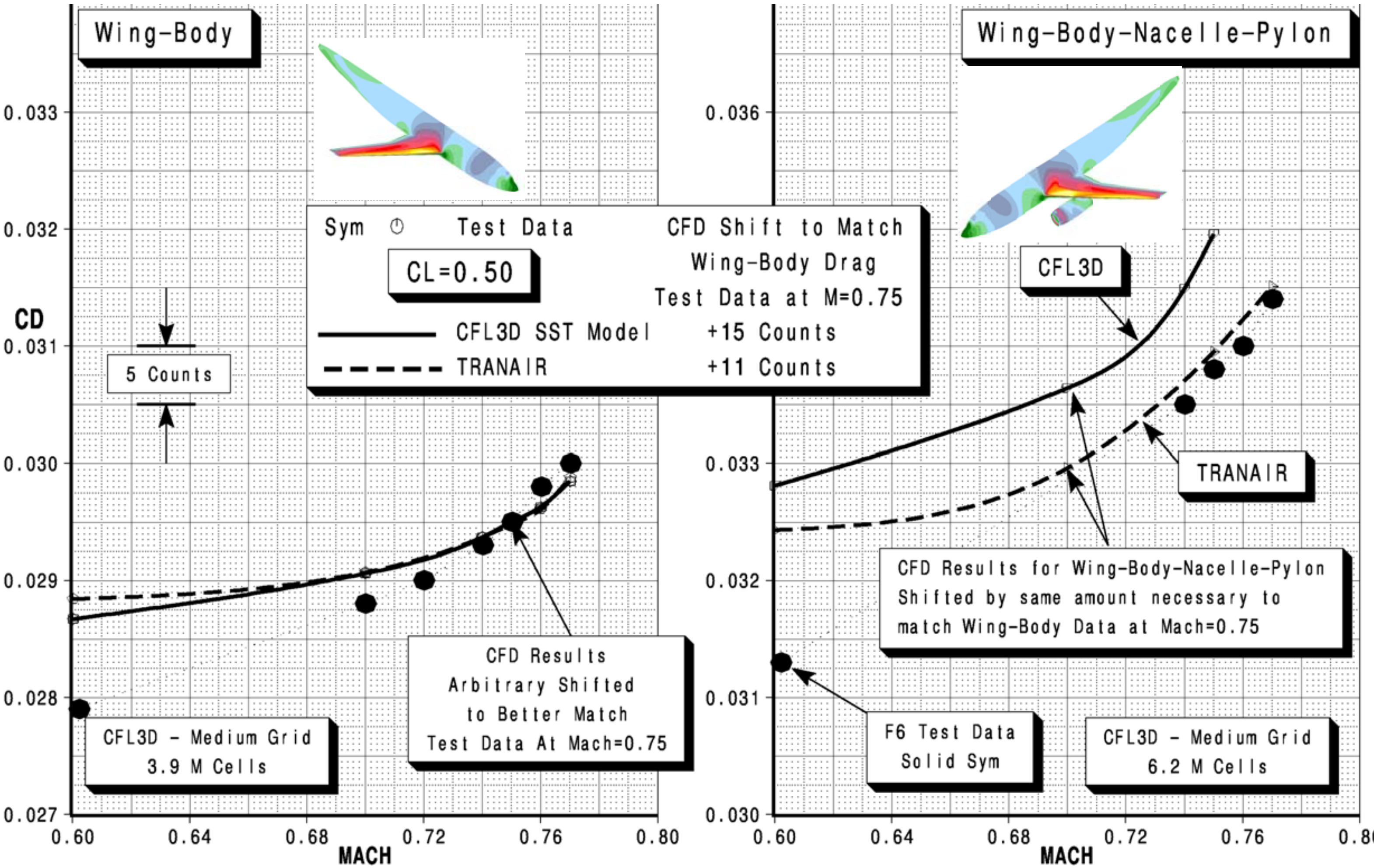
Wing and Pylon Pressures



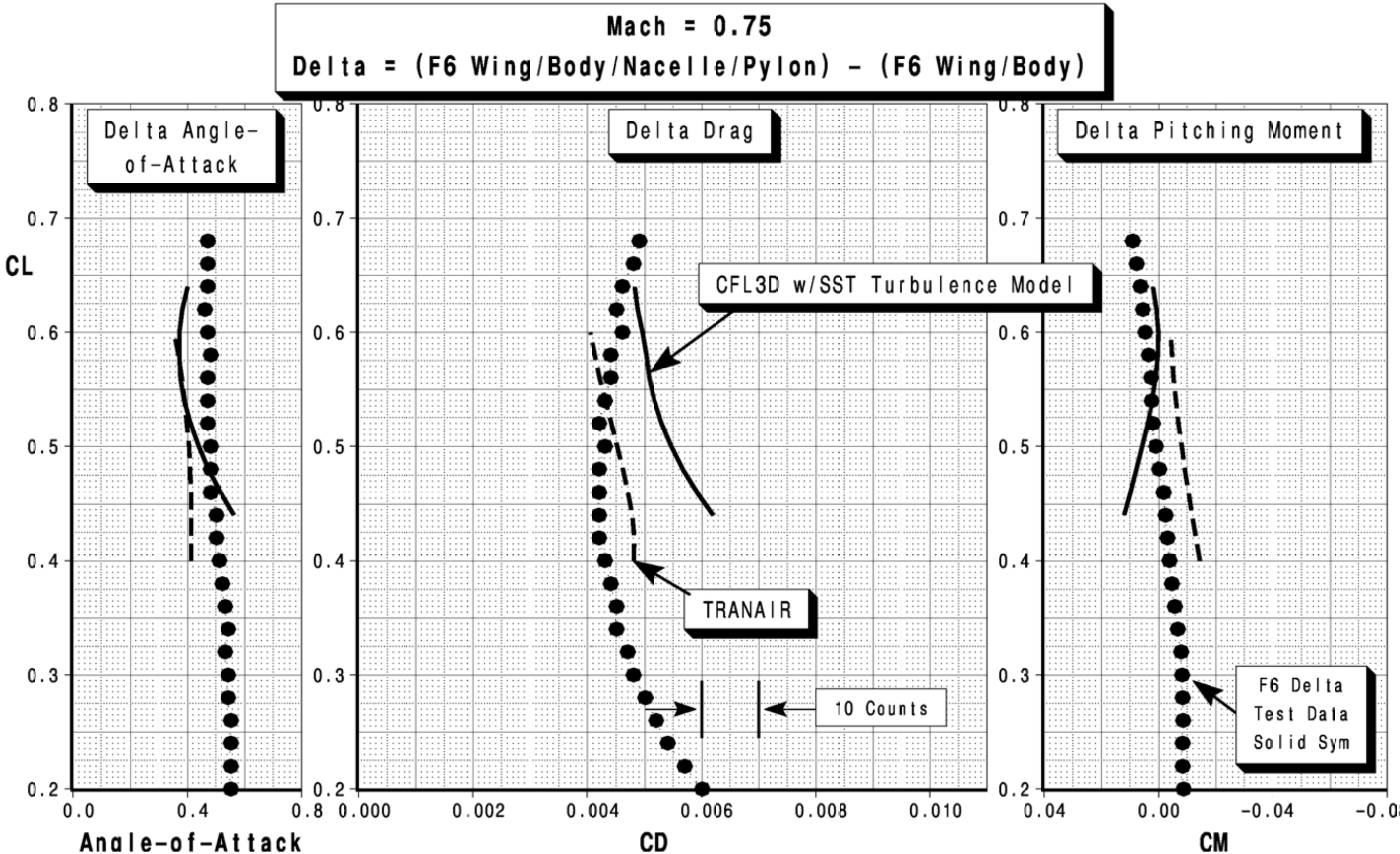
Drag Polar - Wing-Body vs Wing-Body-Nacelle-Pylon



Drag Rise - Wing-Body & Wing-Body-Nacelle-Pylon



Delta Drag Polar Sweep Increment due to Nacelle/Pylon



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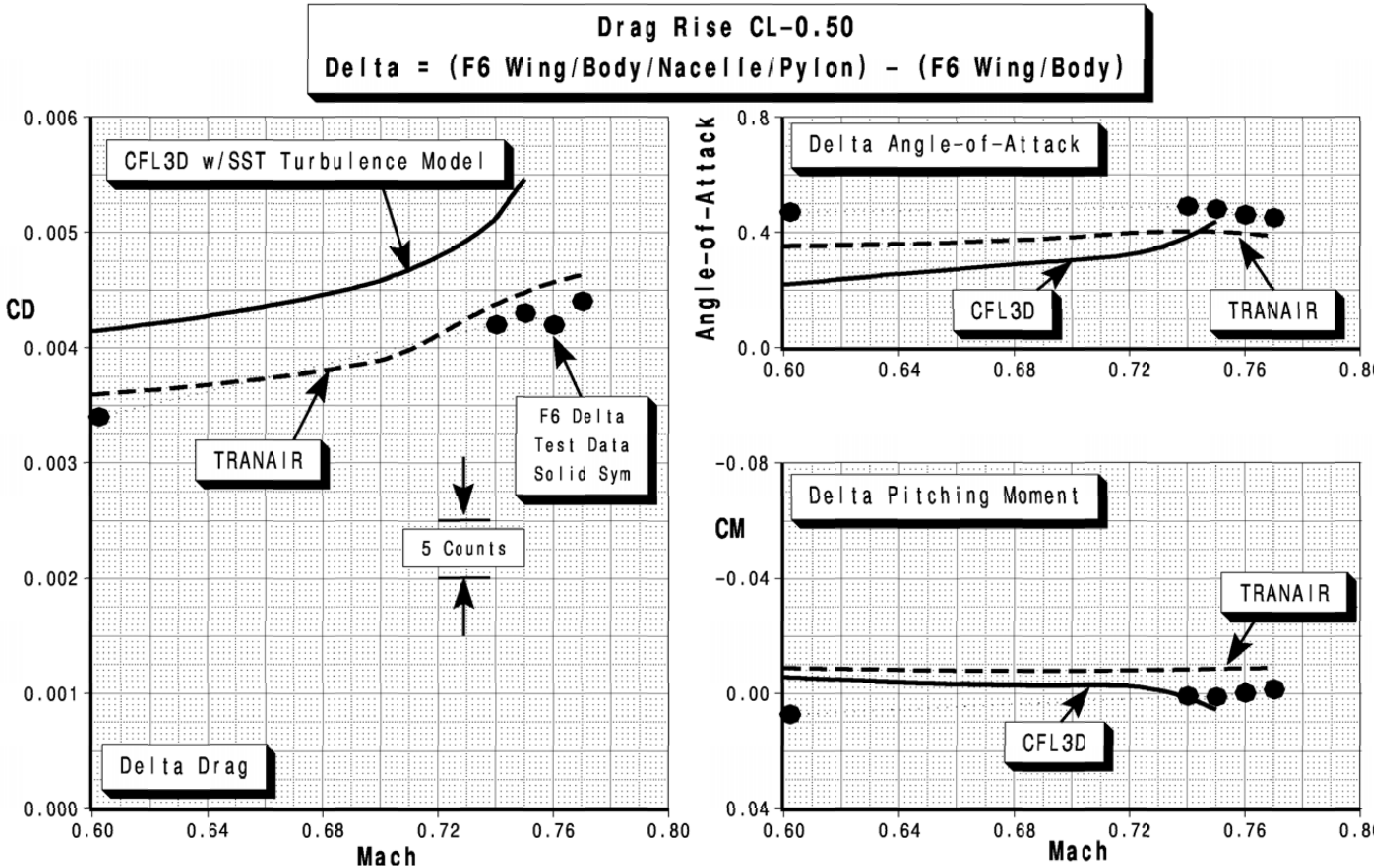
Delta Drag Rise Sweep Increment due to Nacelle/Pylon



Concluding Remarks

- A deceptively difficult case
  - Miss-match between wing pressure distributions and indicated lift
  - Flow separation pocket wing upper surface at side of body and on inboard side of pylon on Wing/Body/Nacelle/Pylon configuration
- Good results for the Wing/Body configuration
  - Minimal grid size sensitivity demonstrated
    - Resulted from consistent gridding strategy
    - Very important for drag increment prediction
- Disappointing results for Wing/Body/Nacelle/Pylon configuration
    - Excessive sensitivity of CFL3D to flow separation on inboard side of pylon
    - Better results with a lower order solver (TRANAIR)

    You can get the “right” answers for the wrong reasons!!

    - Did not complete grid convergence study
- Accurate prediction of difficult flow features is important not only for drag prediction but also for flight stability and control prediction issues
    - We still have a lot more work to do!