Case 1 F6 Fairing Drag Prediction for the 3rd CFD Drag Prediction Workshop

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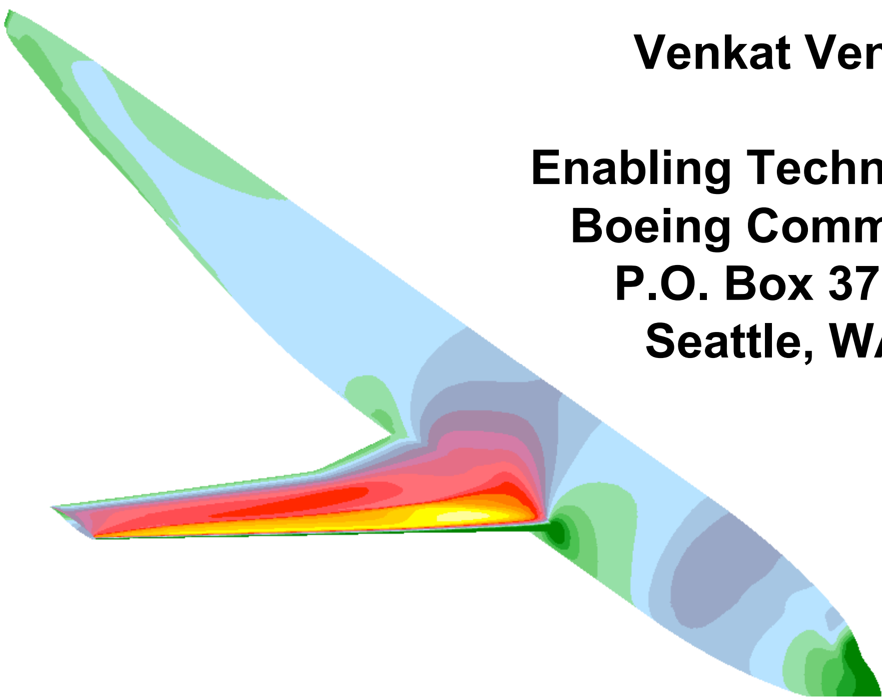
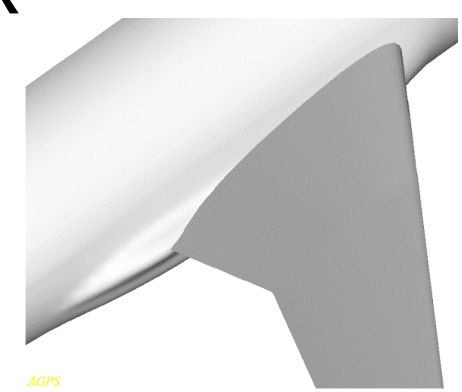




Objective

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

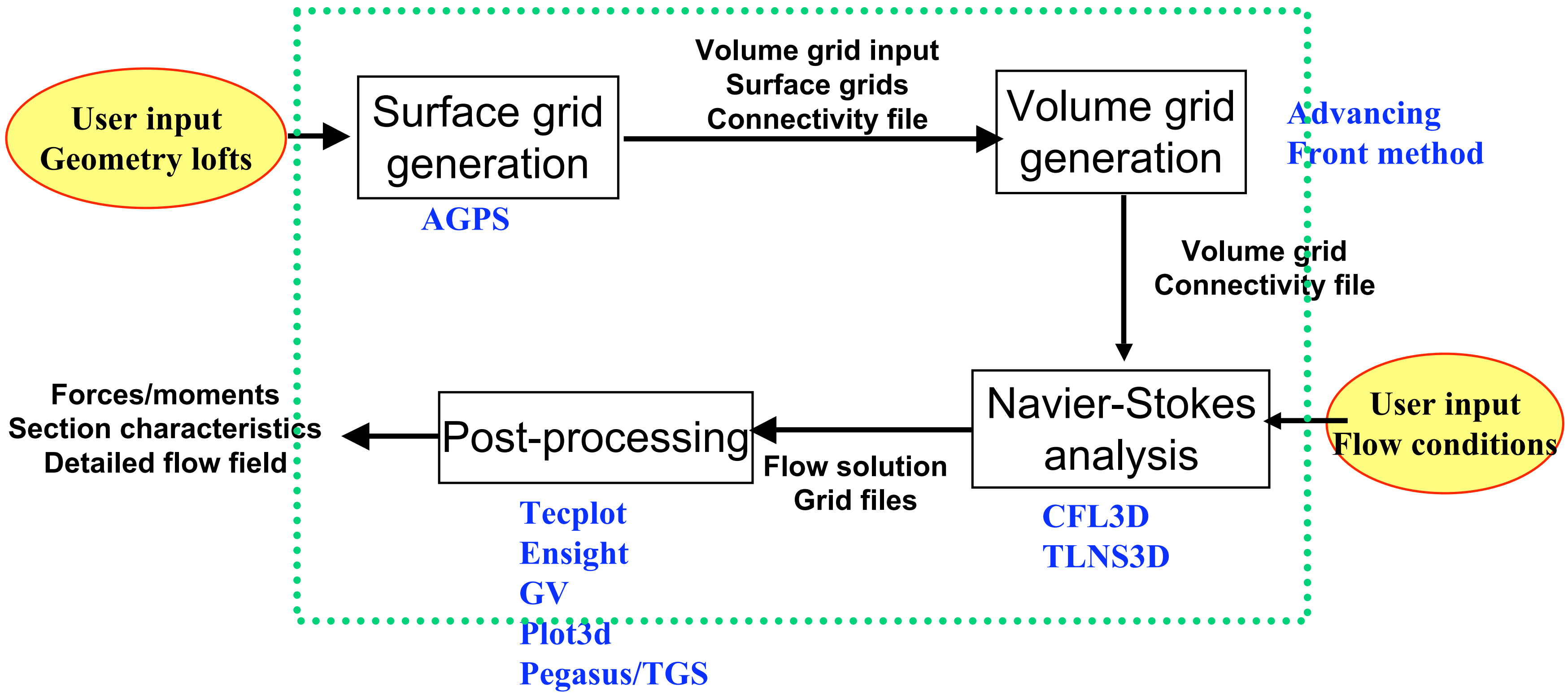
Senthan Swaminathan

Moeljo Hong

Emanuel R Setiawan

ZEUS/CFL3D

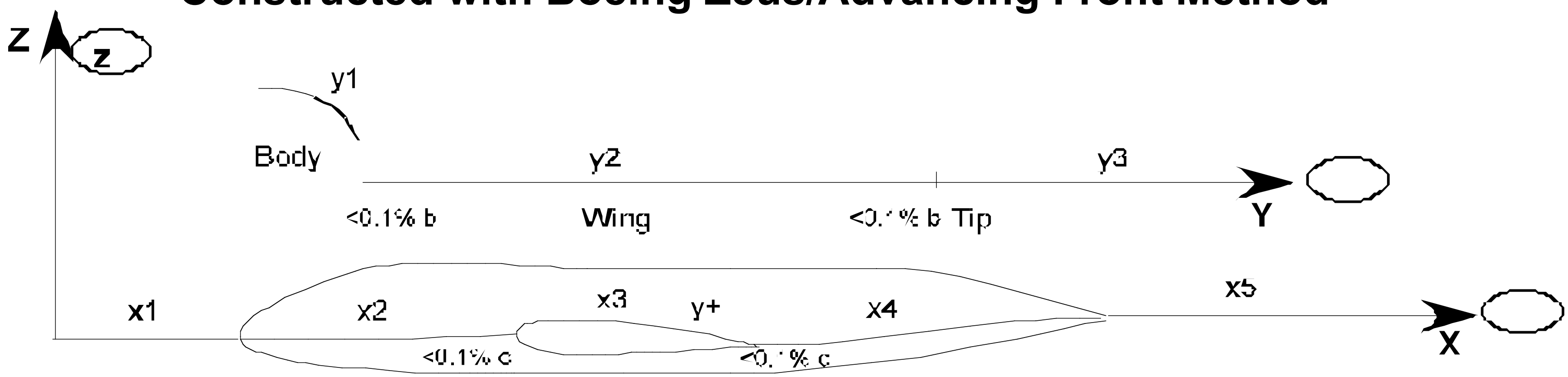
Driver for Surface Grid Generation, Volume Grid Generation, Navier-Stokes Analysis, and Post-processing



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

Structured Multi-Block Wing-Body Grids
Constructed with Boeing Zeus/Advancing Front Method



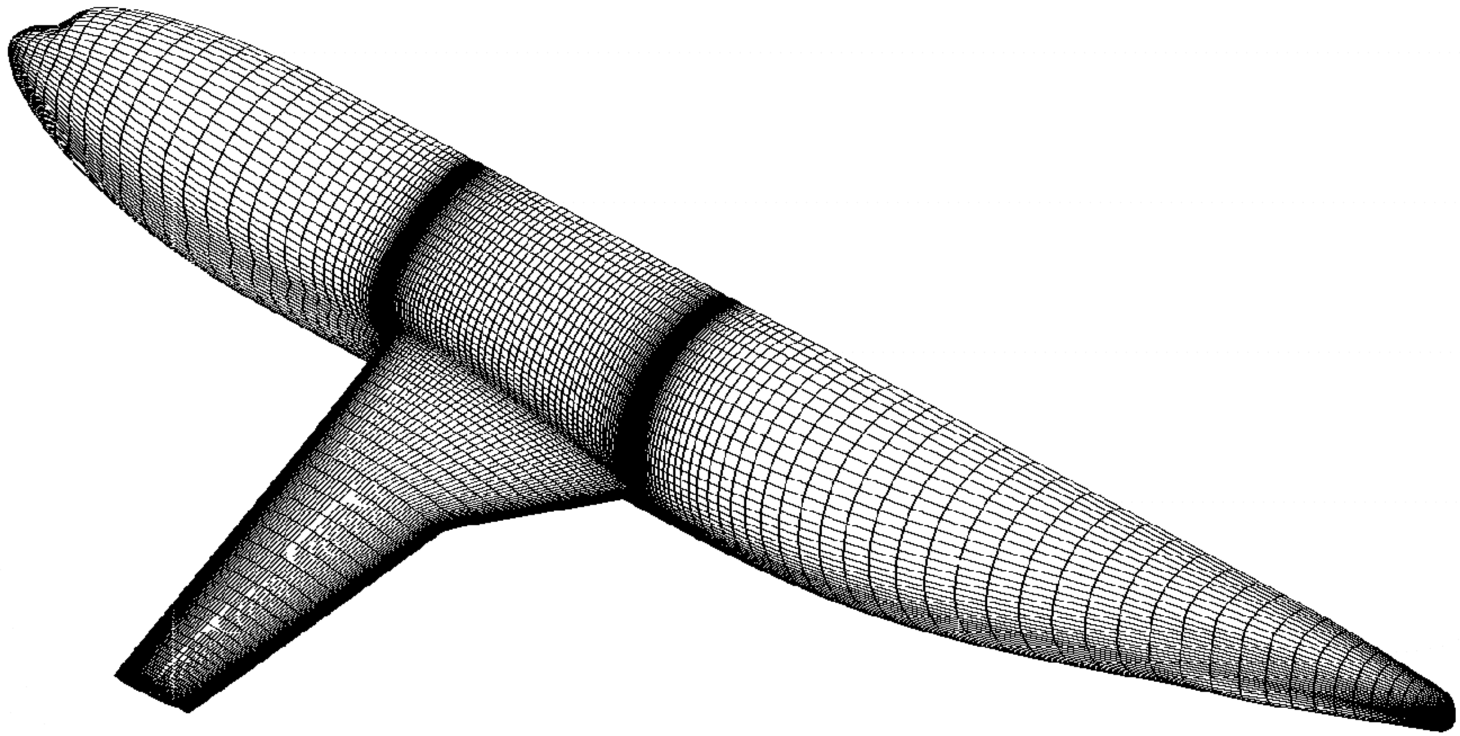
	x1	x2	x3	x4	x5	y1	y2	y3	z
Course	16	48	80	56	16	24	48	16	56
Med	24	72	120	88	24	32	72	24	84
Medfine	28	92	156	112	32	36	92	28	104
Fine	32	108	180	136	36	56	112	32	128

Blunt TE	z	y2
Course	32	48
Med	48	72
Medfine	60	92
Fine	72	112

Boundary Layer	# Cells	Ave y+
Course	24	0.82
Med	32	0.60
Medfine	40	0.50
Fine	48	0.40

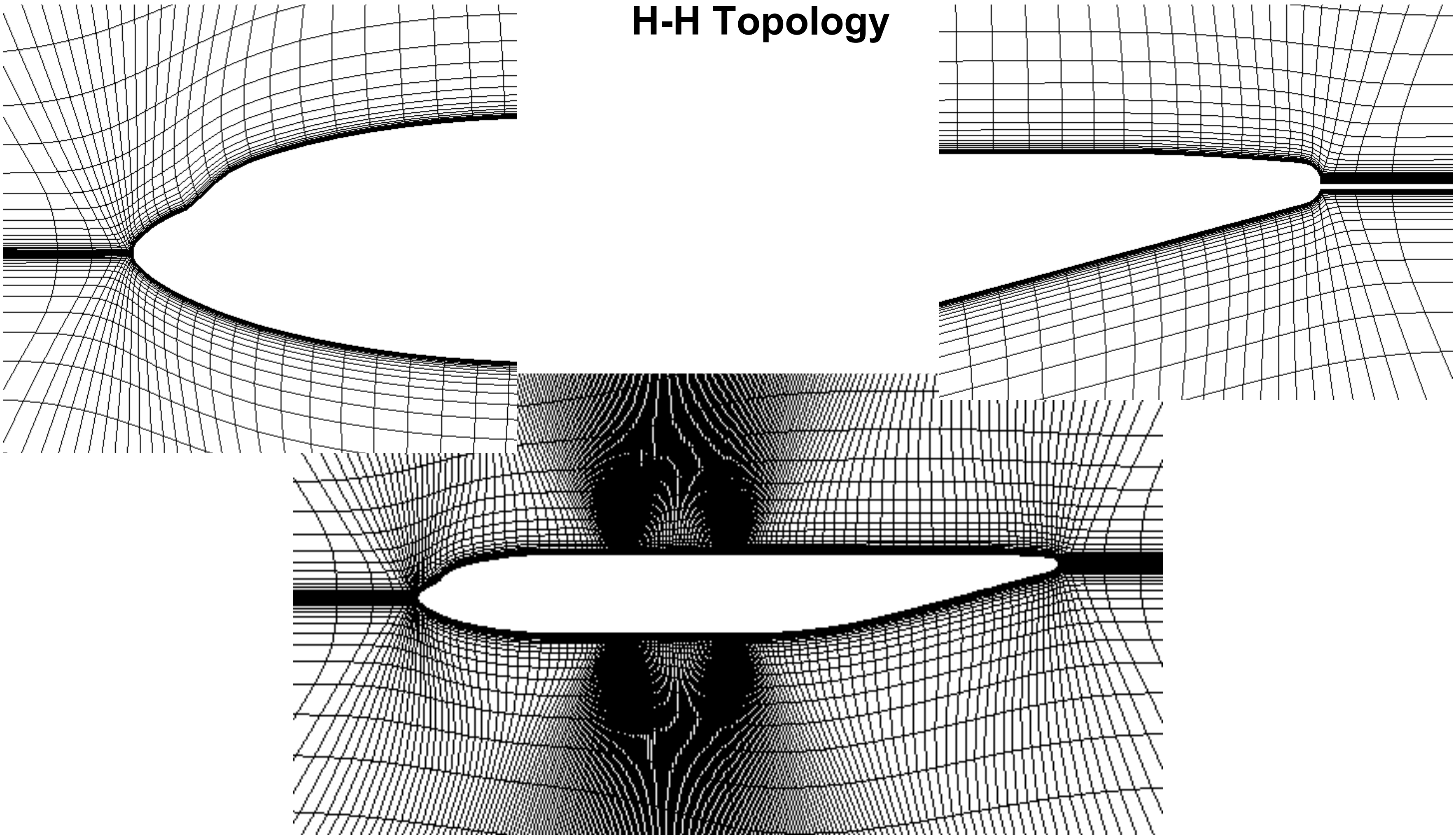
Total Grid Size
2.6E+06
9.2E+06
1.8E+07
3.1E+07

Structured Multi-Block Wing-Body Grids
Constructed with Boeing Zeus/Advancing Front Method

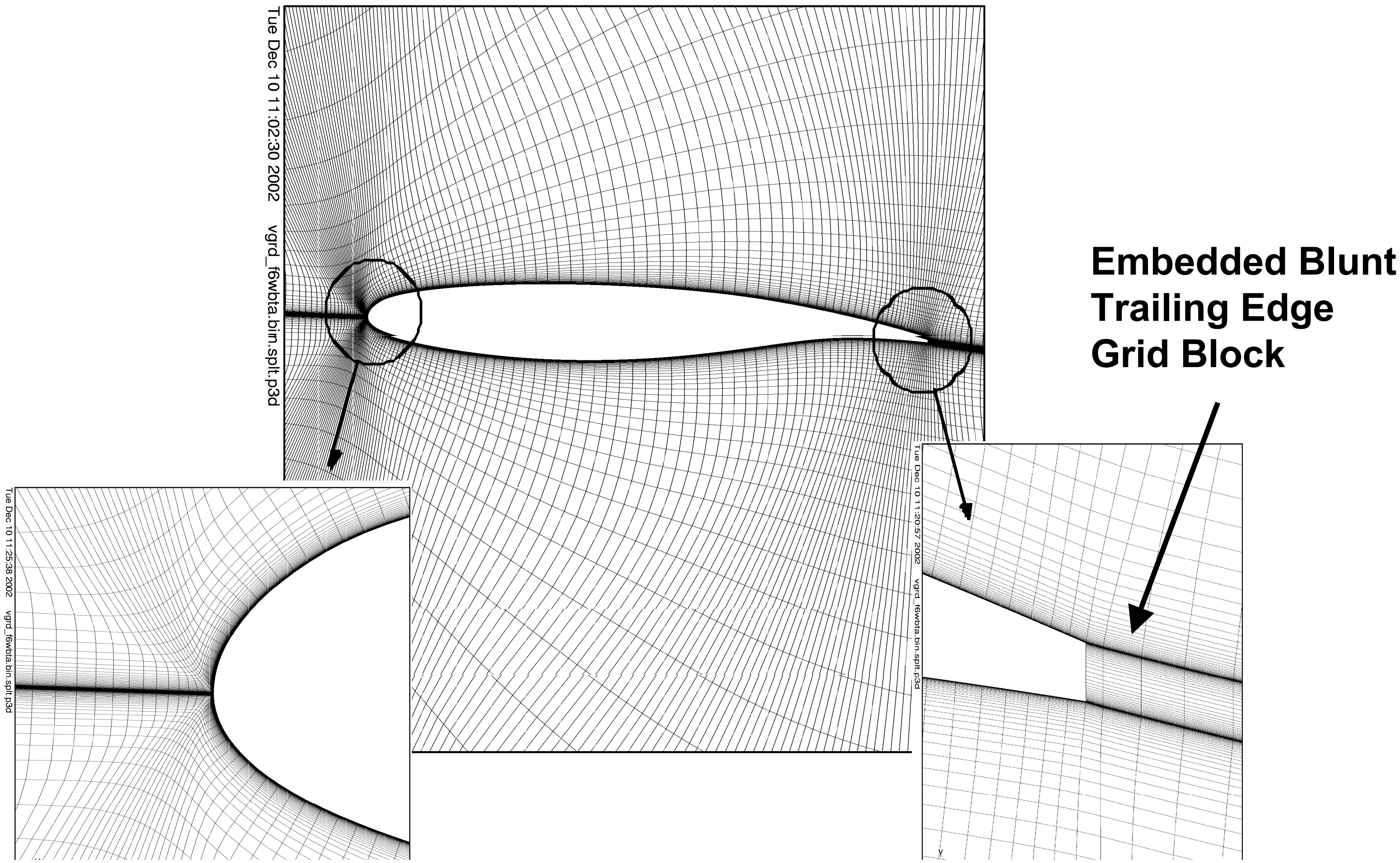


Typical Centerline Grid

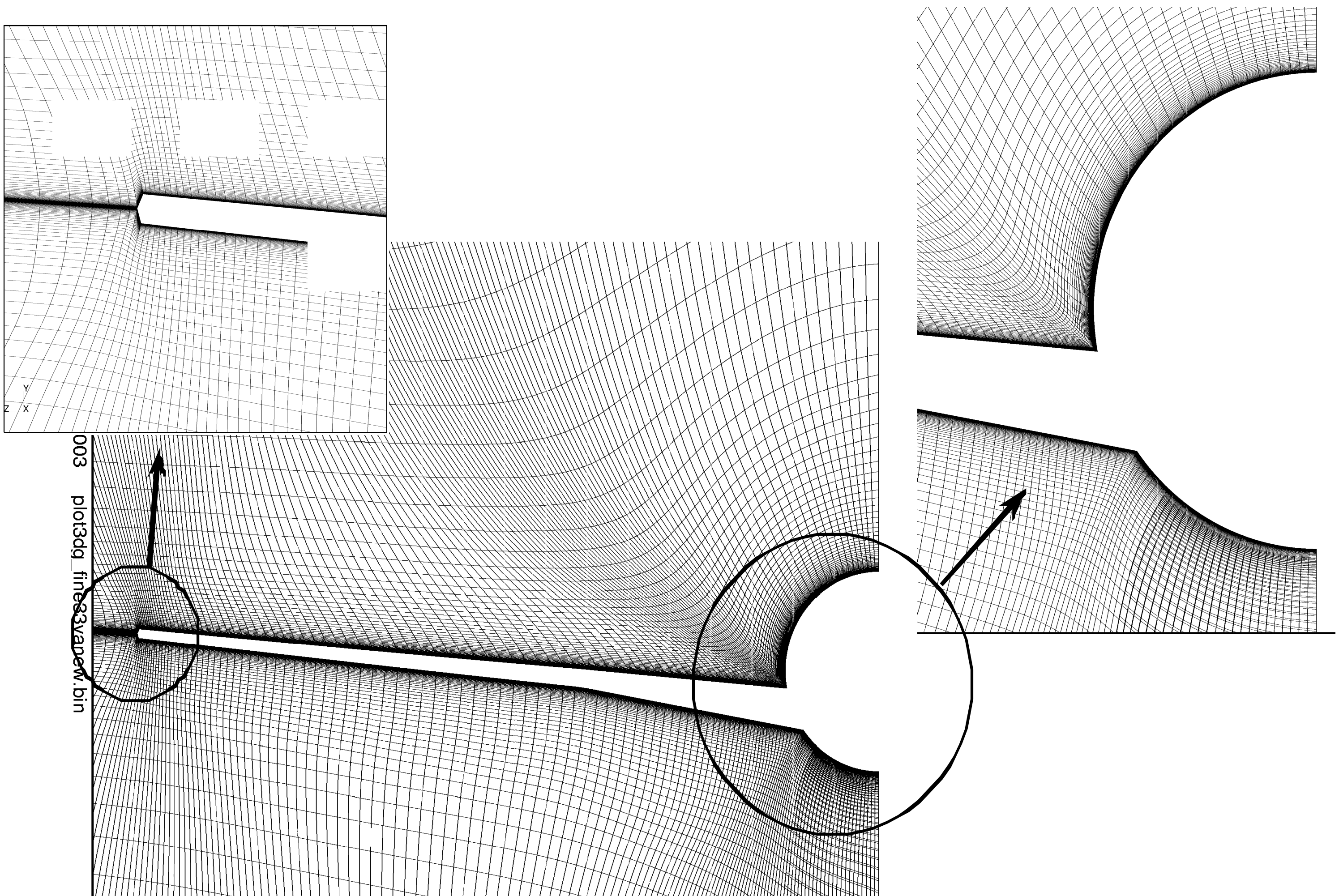
H-H Topology



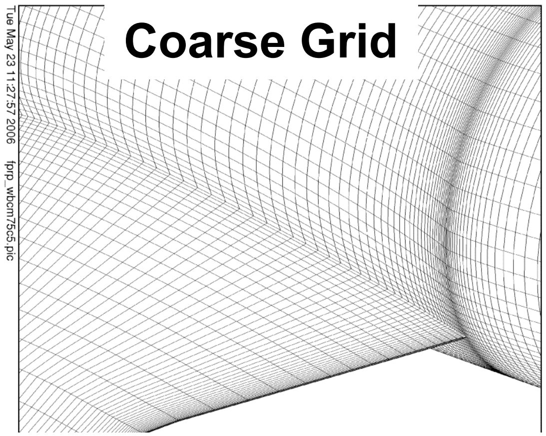
Typical Wing Grid
H-H Topology

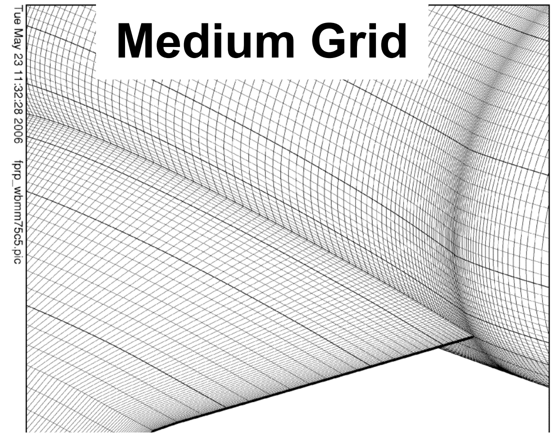


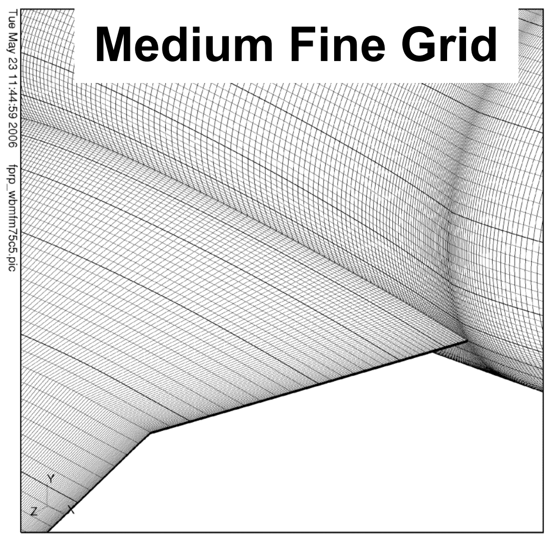
Typical I-plane Grid
H-Topology

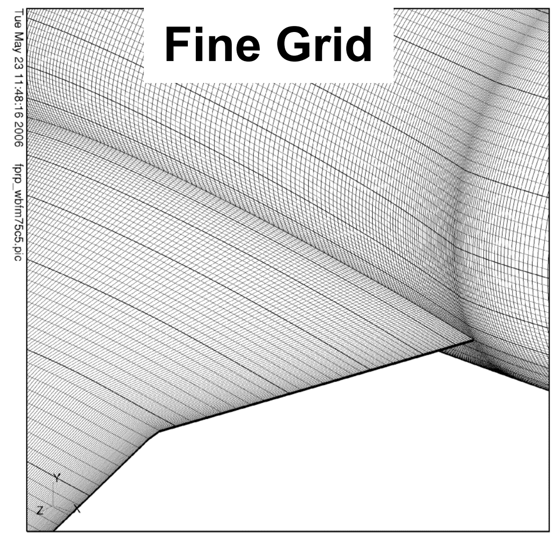


Grid Refinement – F6 Wing-Body

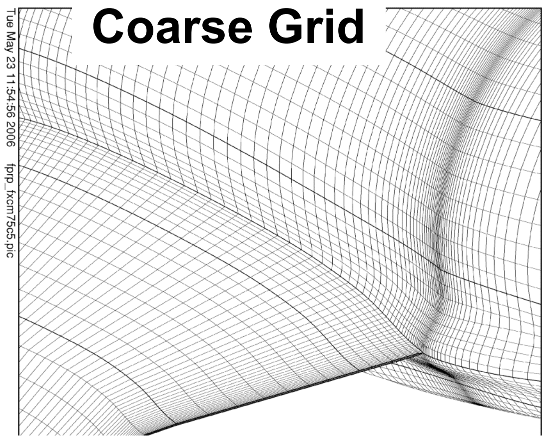


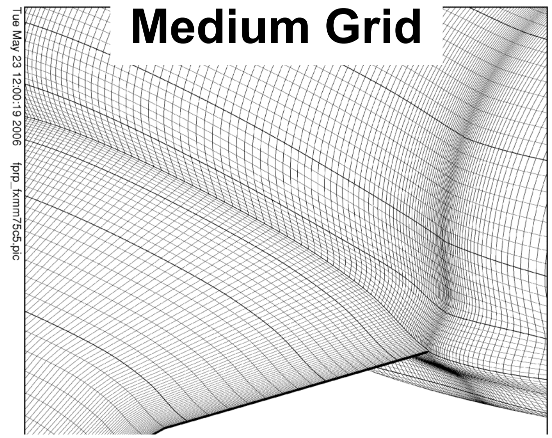


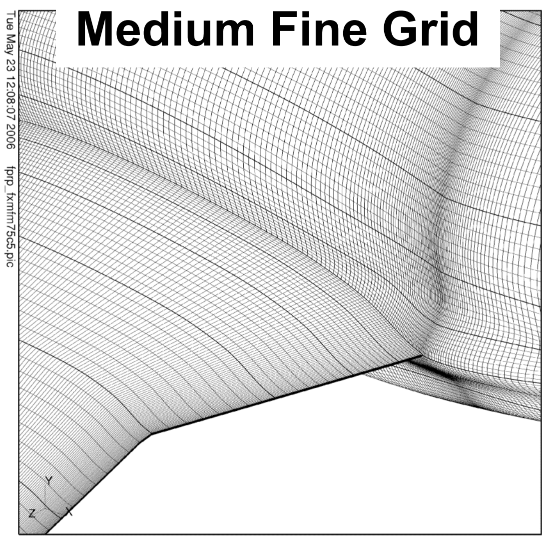


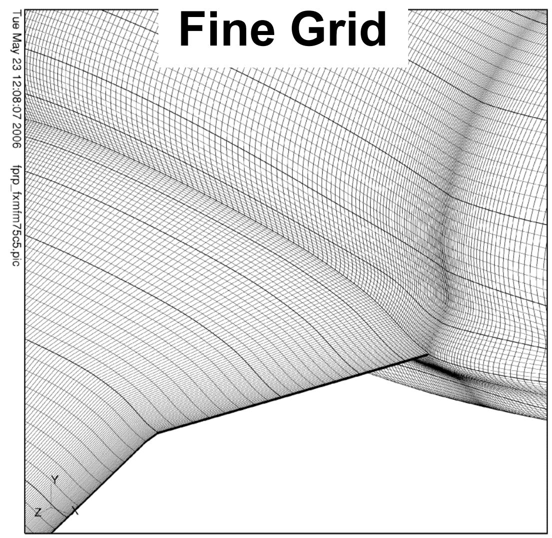


Grid Refinement – F6 Wing-Body w/FX2 Fairing



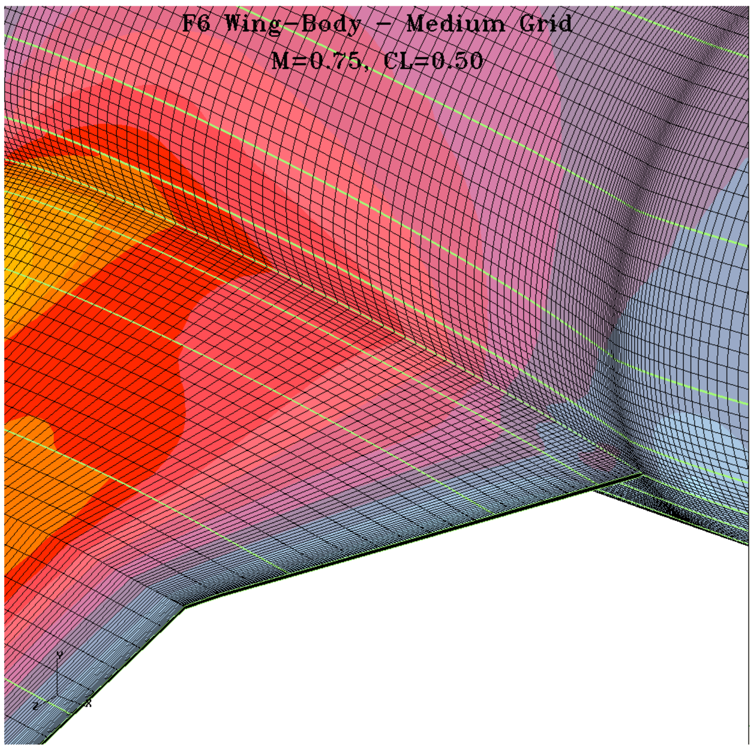




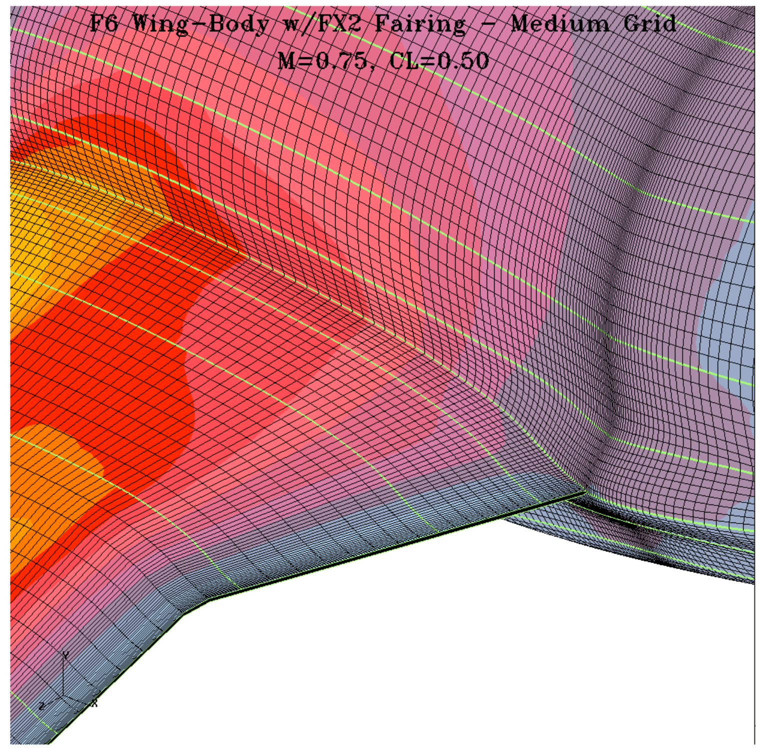


Medium Grid
F6 Wing-Body w/wo/FX2 Fairing

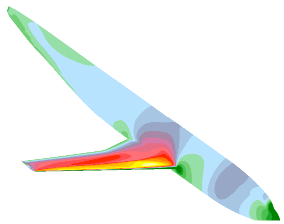
F6 Wing-Body

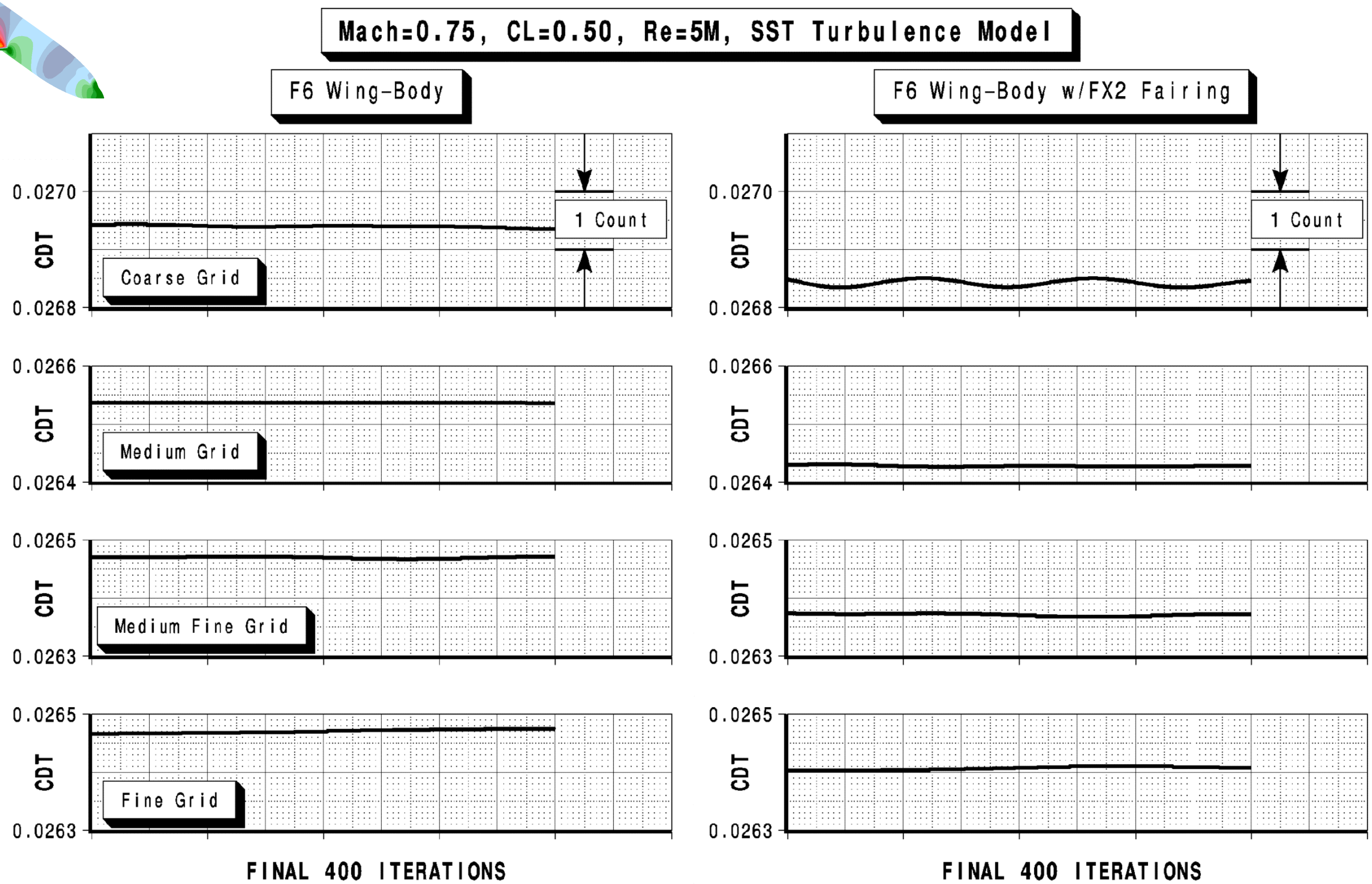


F6 Wing-Body w/FX2 Fairing

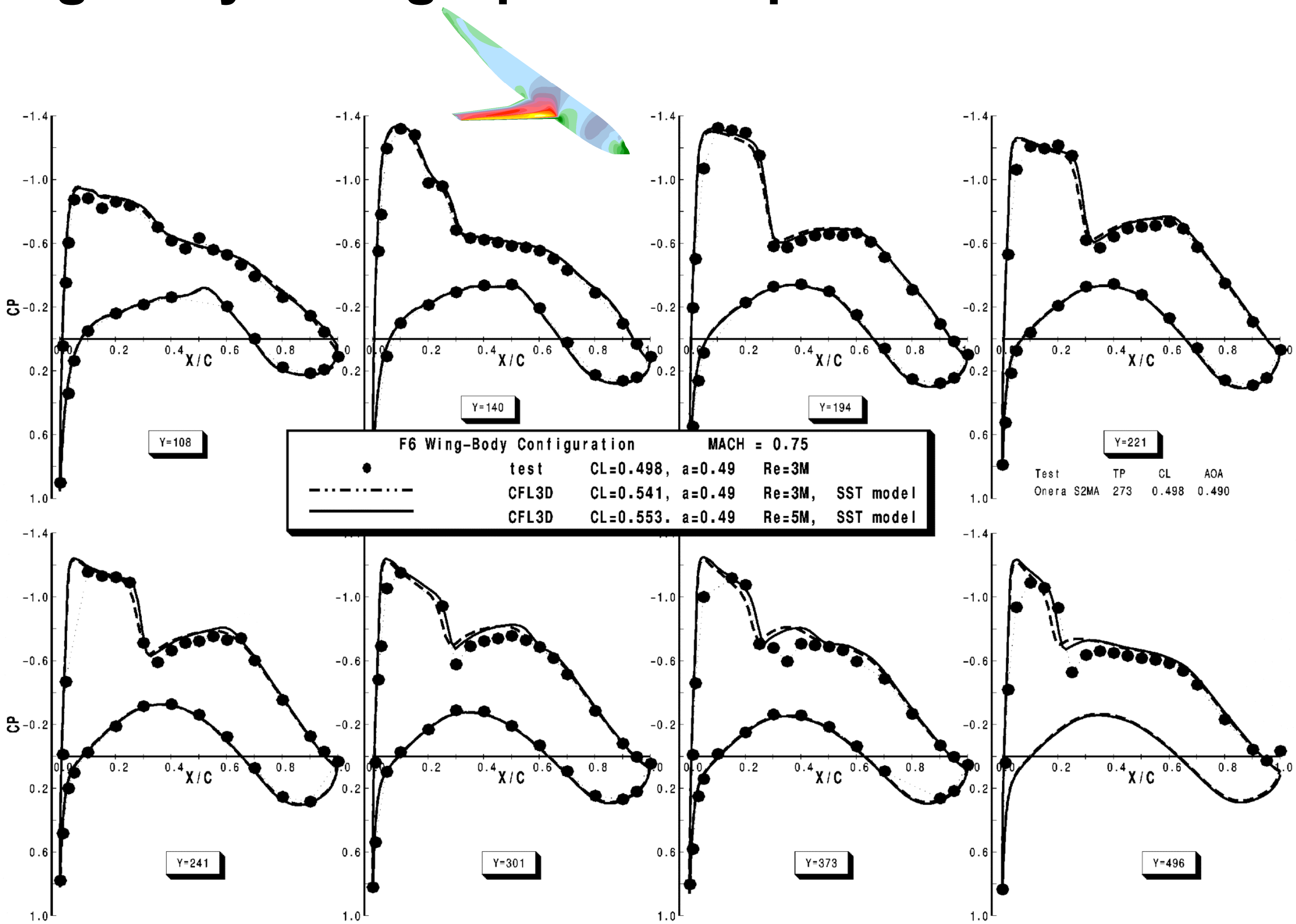


F6 WB w/wo FX2 – Drag Convergence

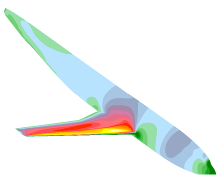


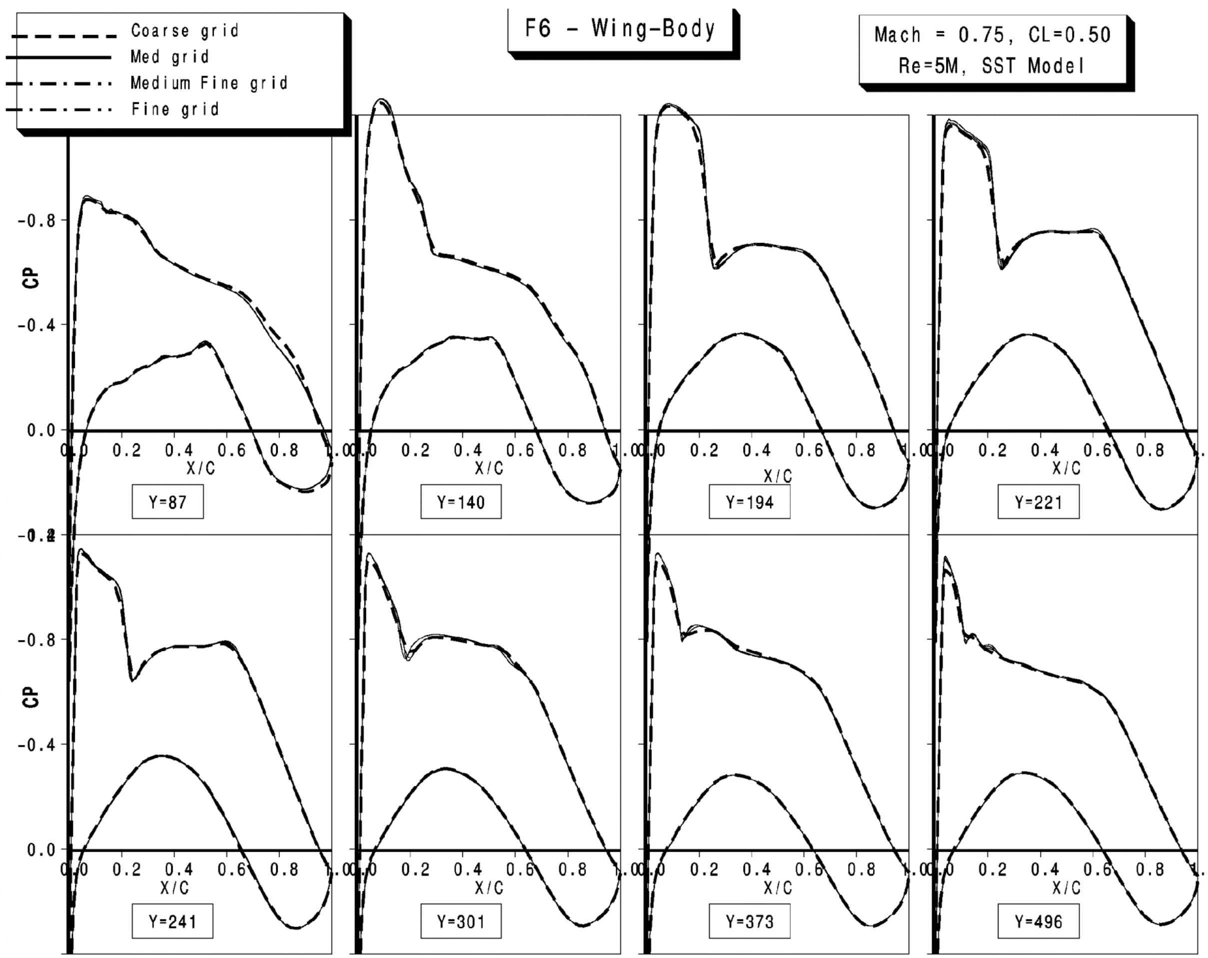


F6 Wing-Body - Wing Cp's – Comparison with Re=3M Test



F6 Wing-Body - Wing Cp's – Grid Convergence





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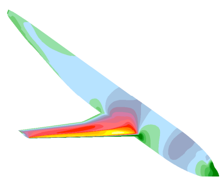
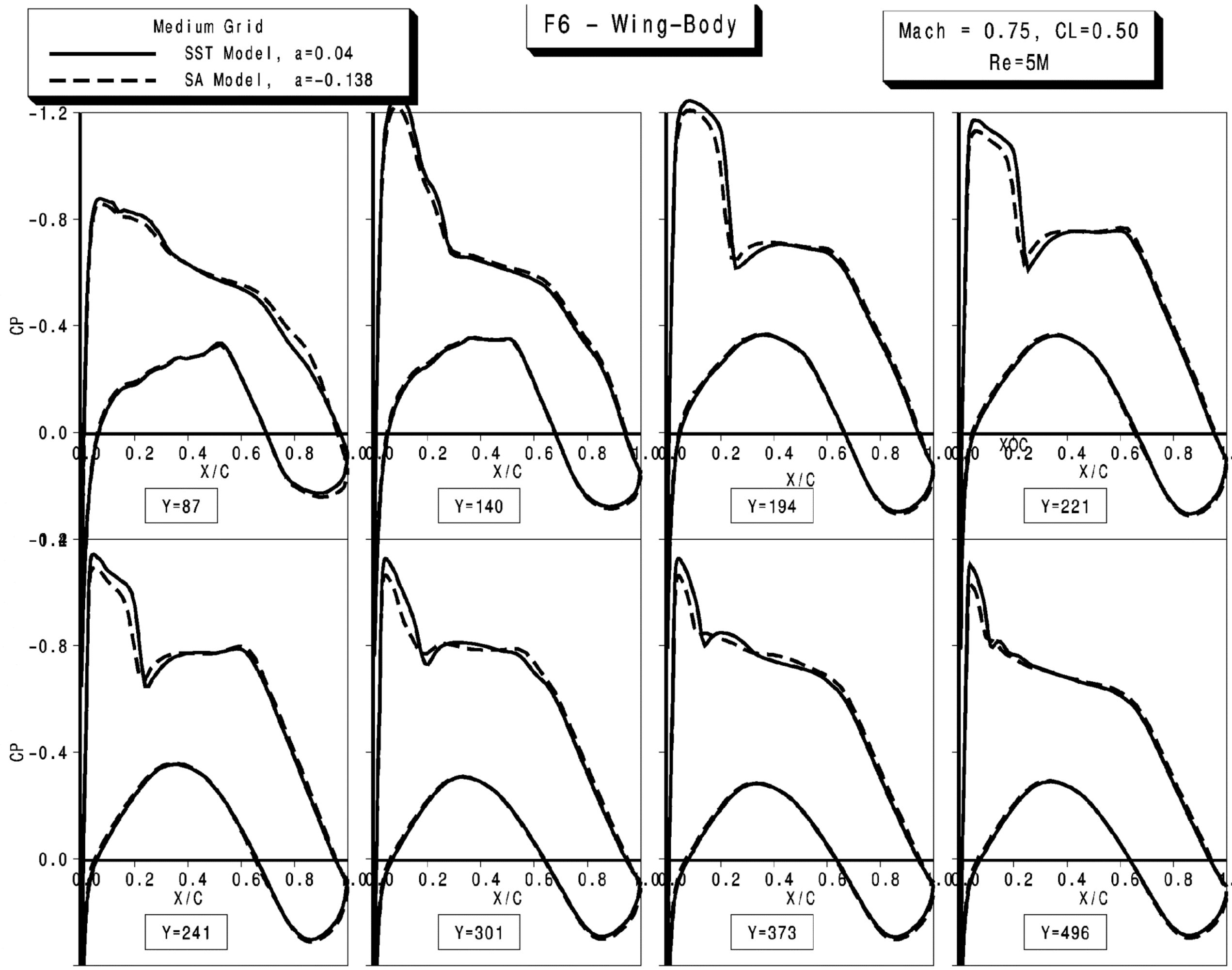
F6 Wing-Body - Wing Cp's – Turbulence Modeling Effects





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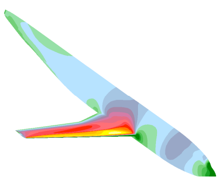
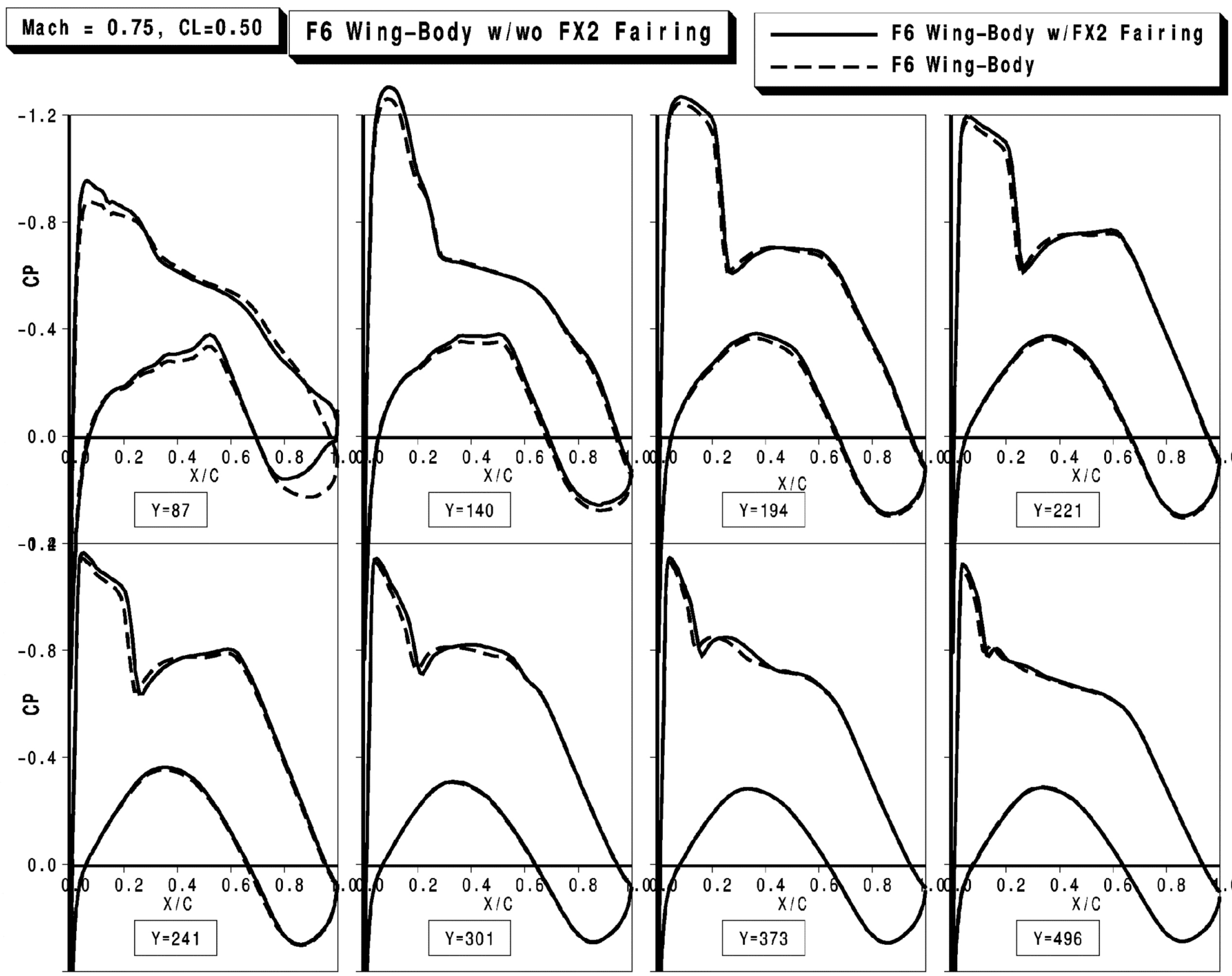
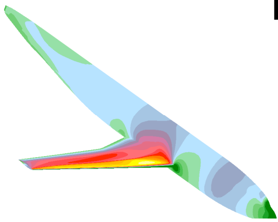
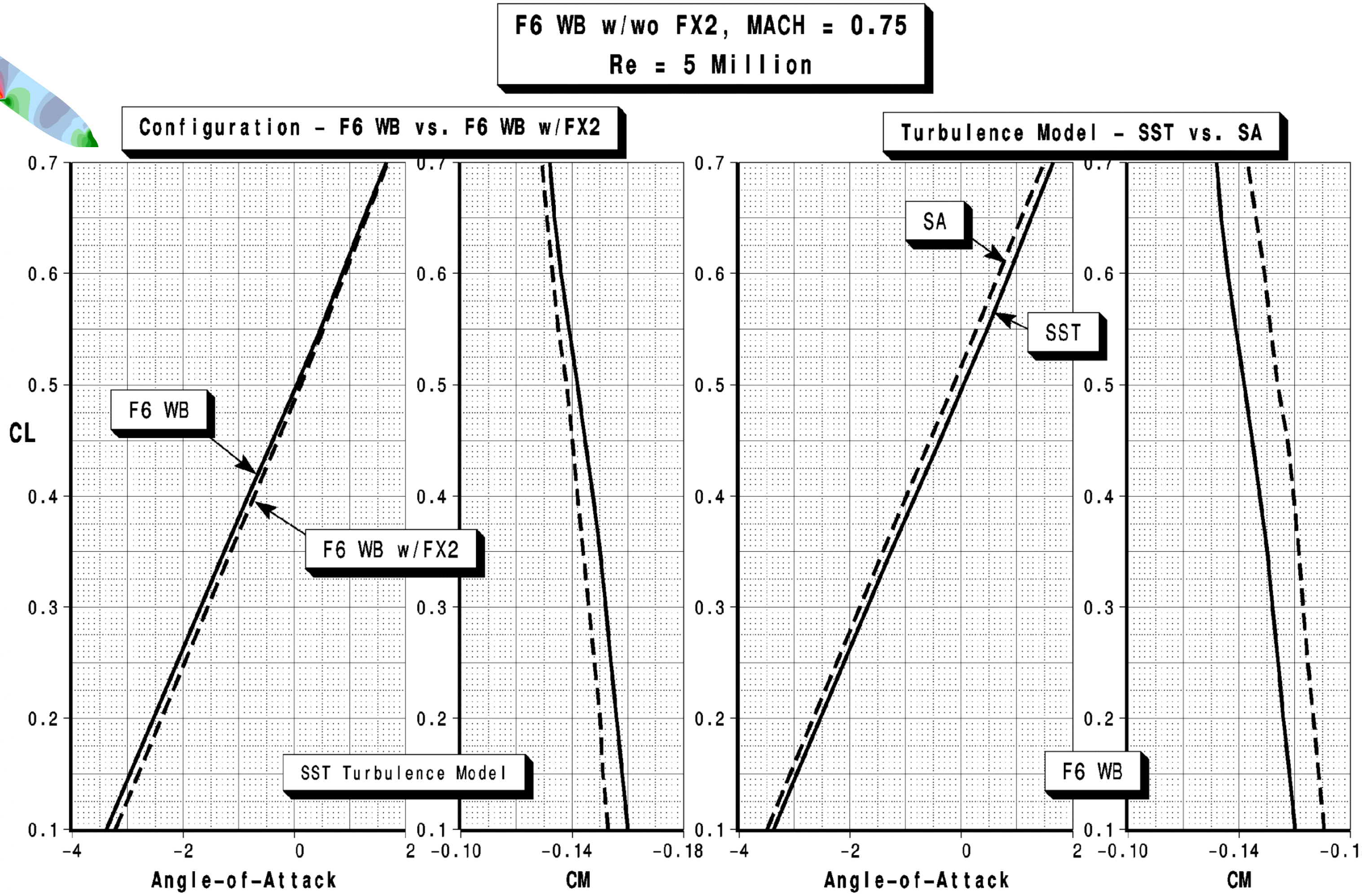
F6 Wing-Body - Wing Cp's – Effect of Fairing





F6 WB w/wo FX2 – Lift and Pitching Moment





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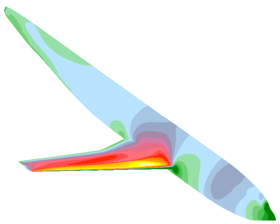
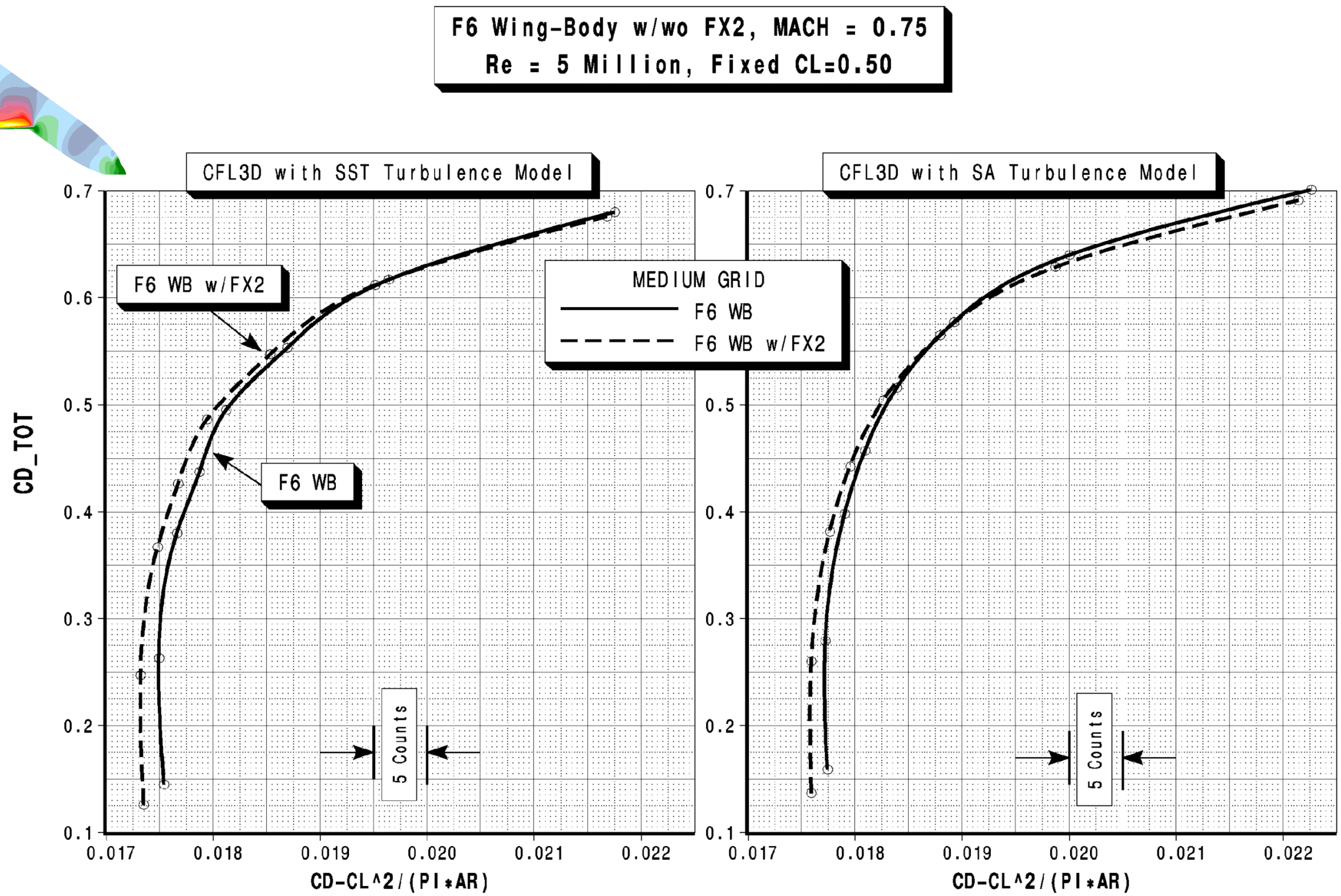
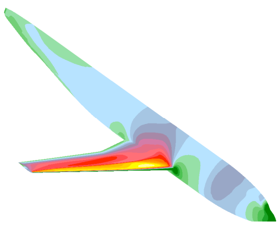
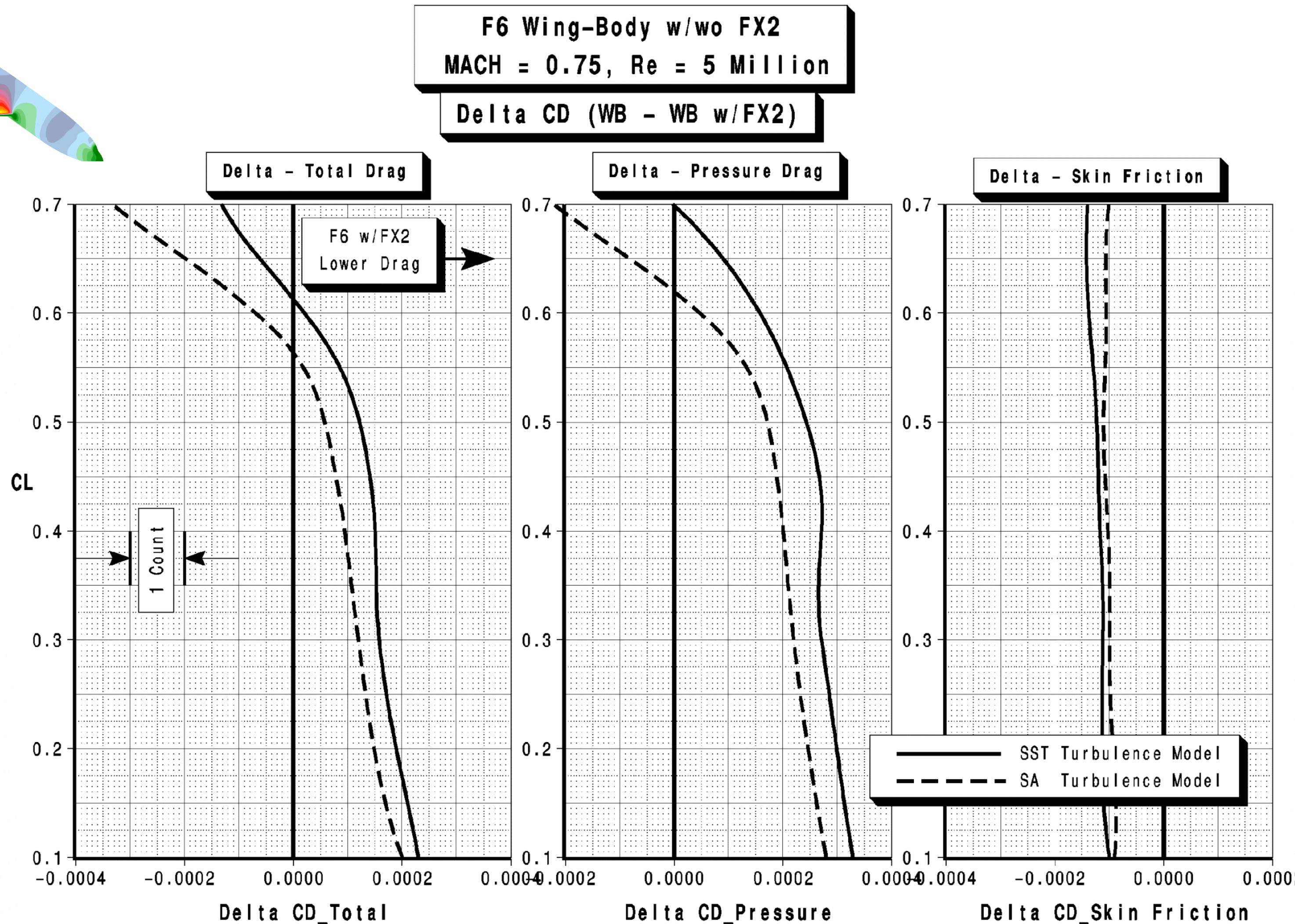
F6 WB w/wo FX2 - Polar Shape – Turbulence Modeling





F6 WB w/wo FX2 – Drag Polar Increments





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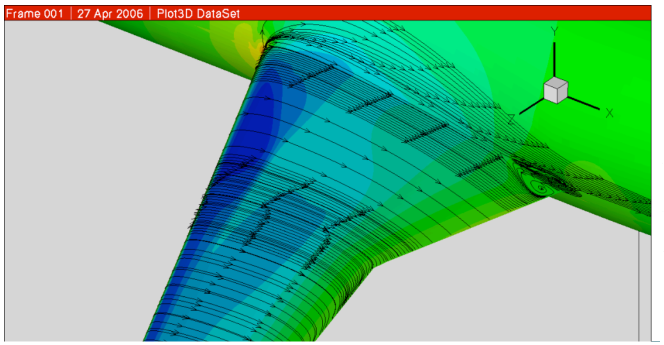
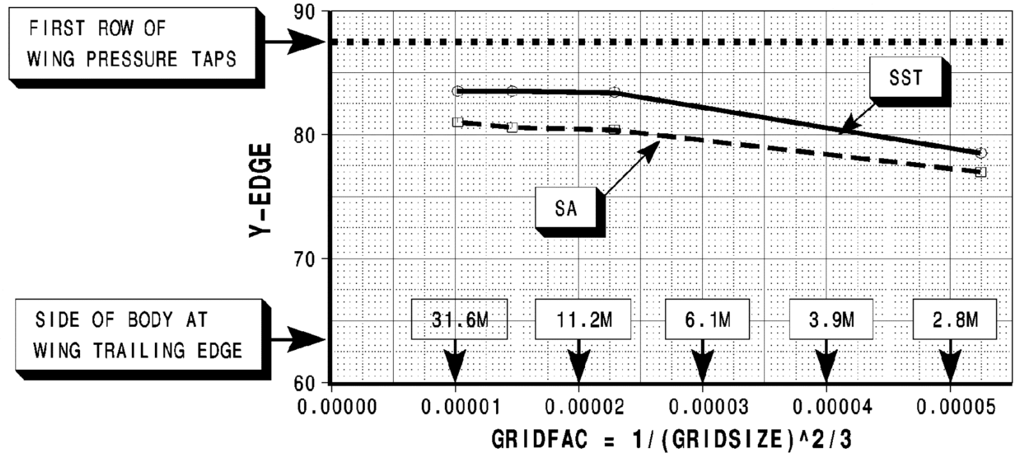
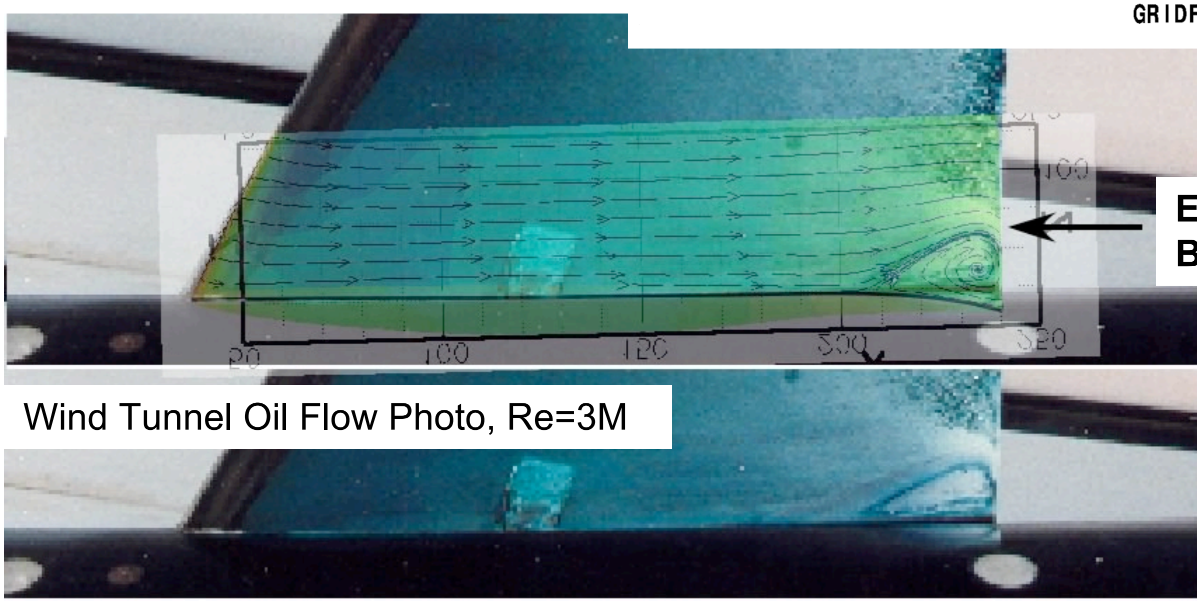
F6 WB Separation Bubble on Wing – Turbulence Modeling



Overlay of Computed Streamlines, SST Turbulence Model, Re=5M

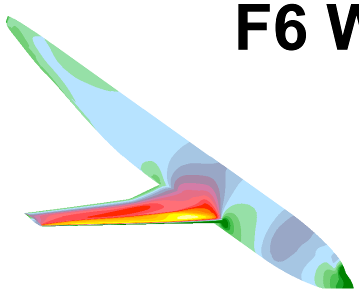


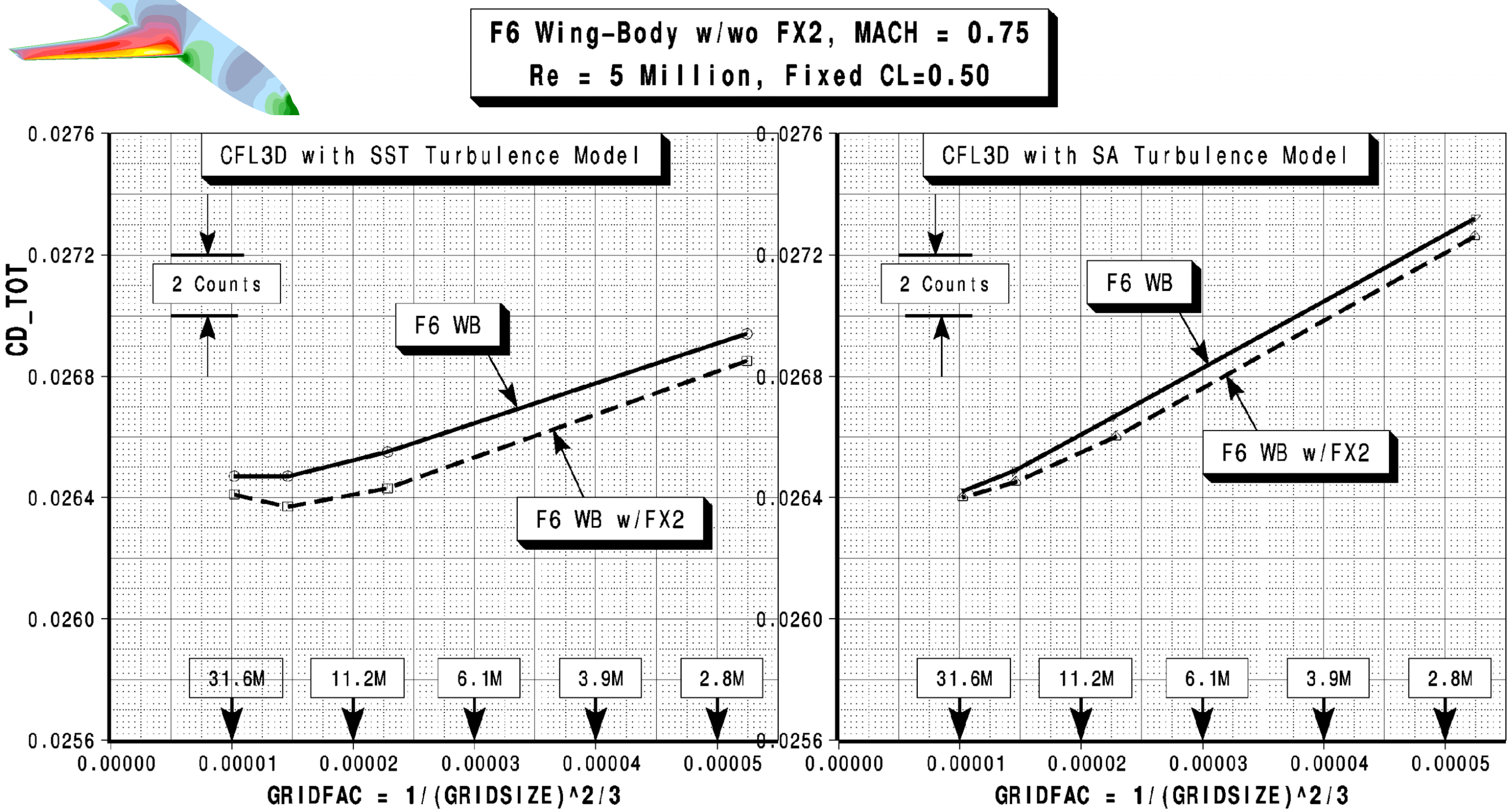


Edge of Separation Bubble on Wing

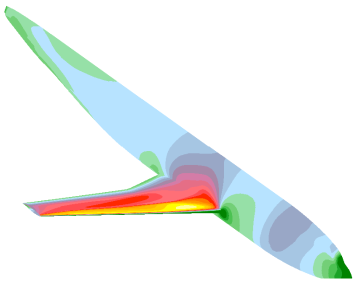
Wind Tunnel Oil Flow Photo, Re=3M

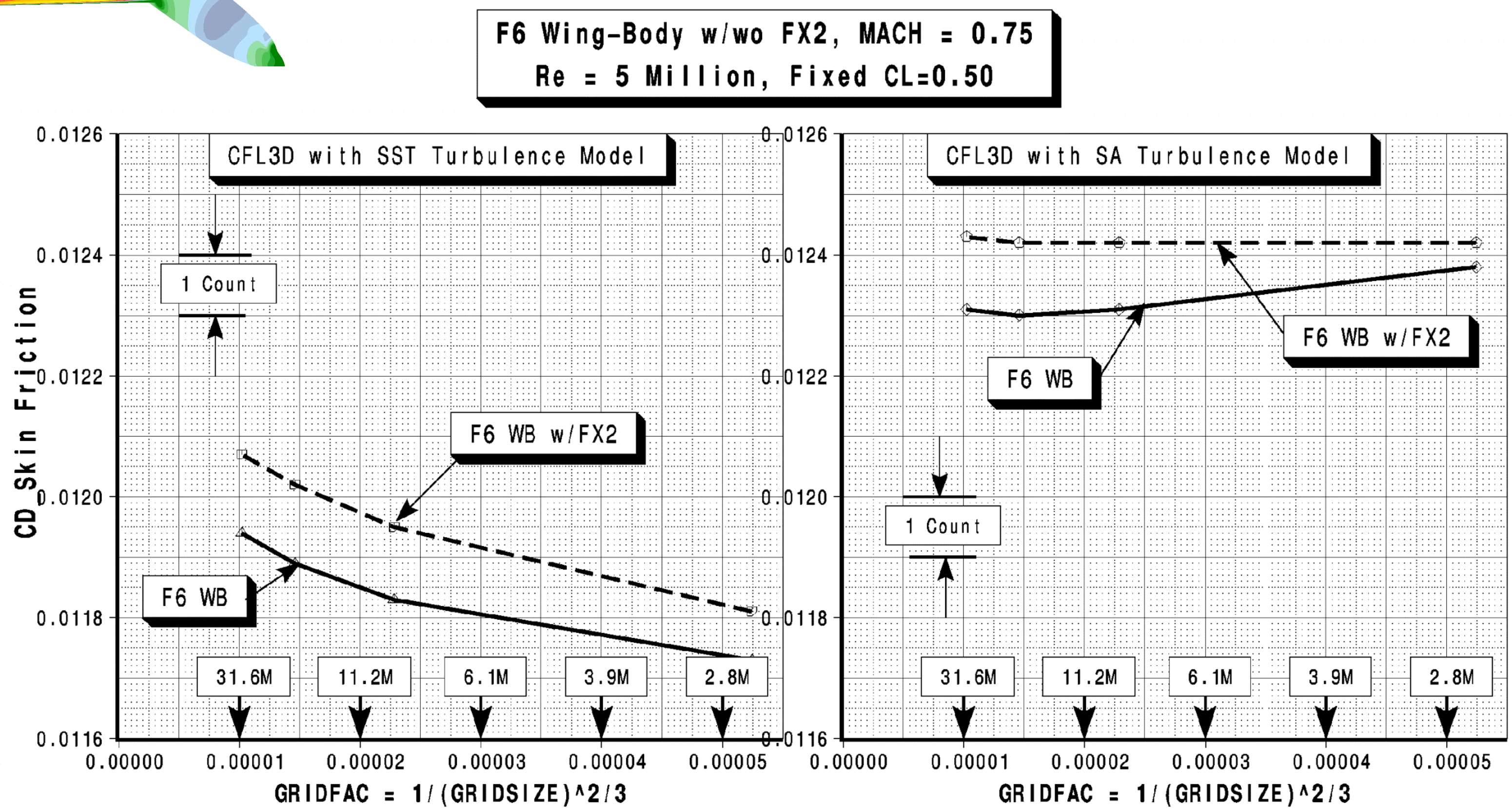
F6 WB w/wo FX2 – Total Drag Convergence





F6 WB w/wo FX2 – Skin Friction Drag Convergence





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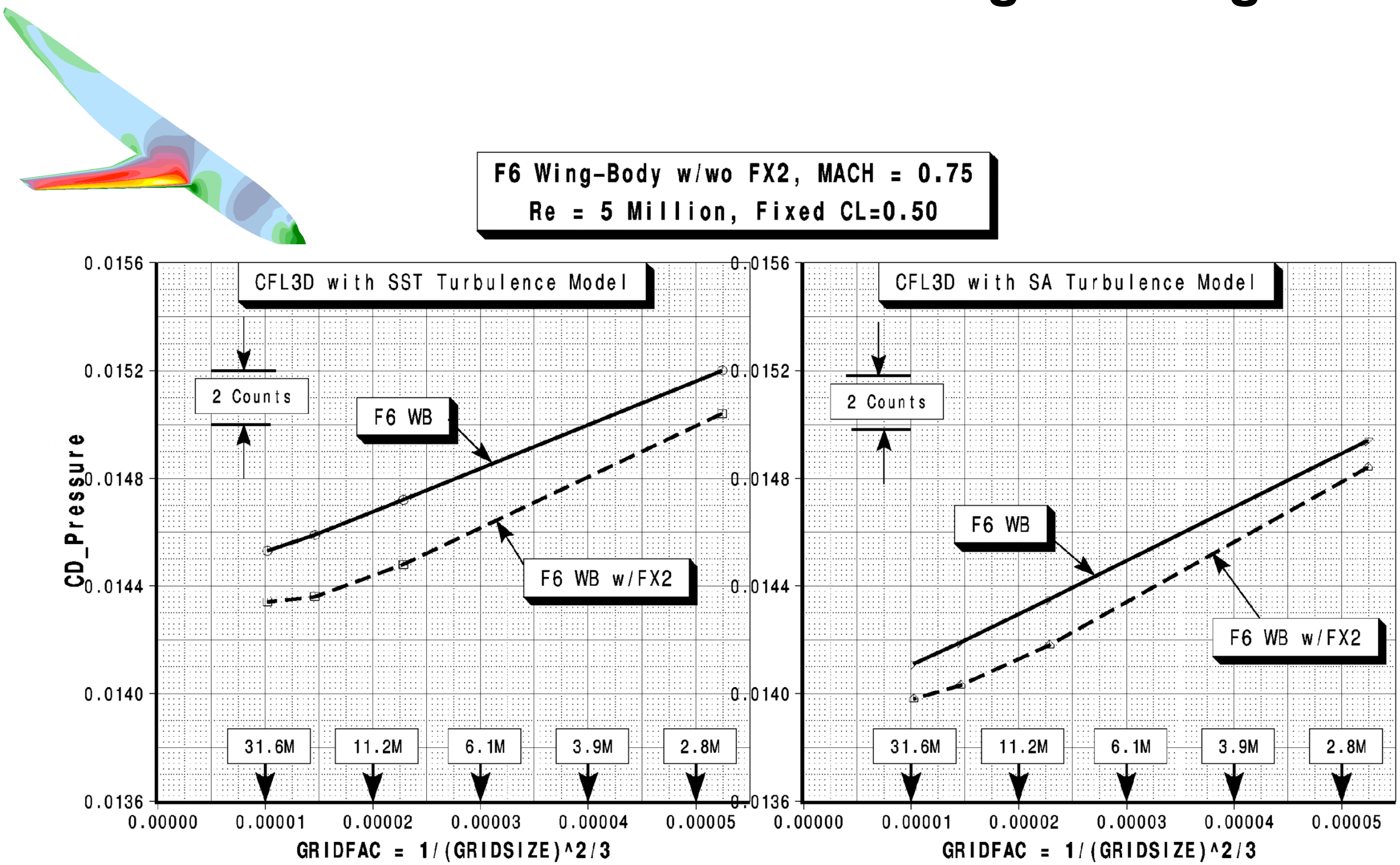
F6 WB w/wo FX2 – Pressure Drag Convergence



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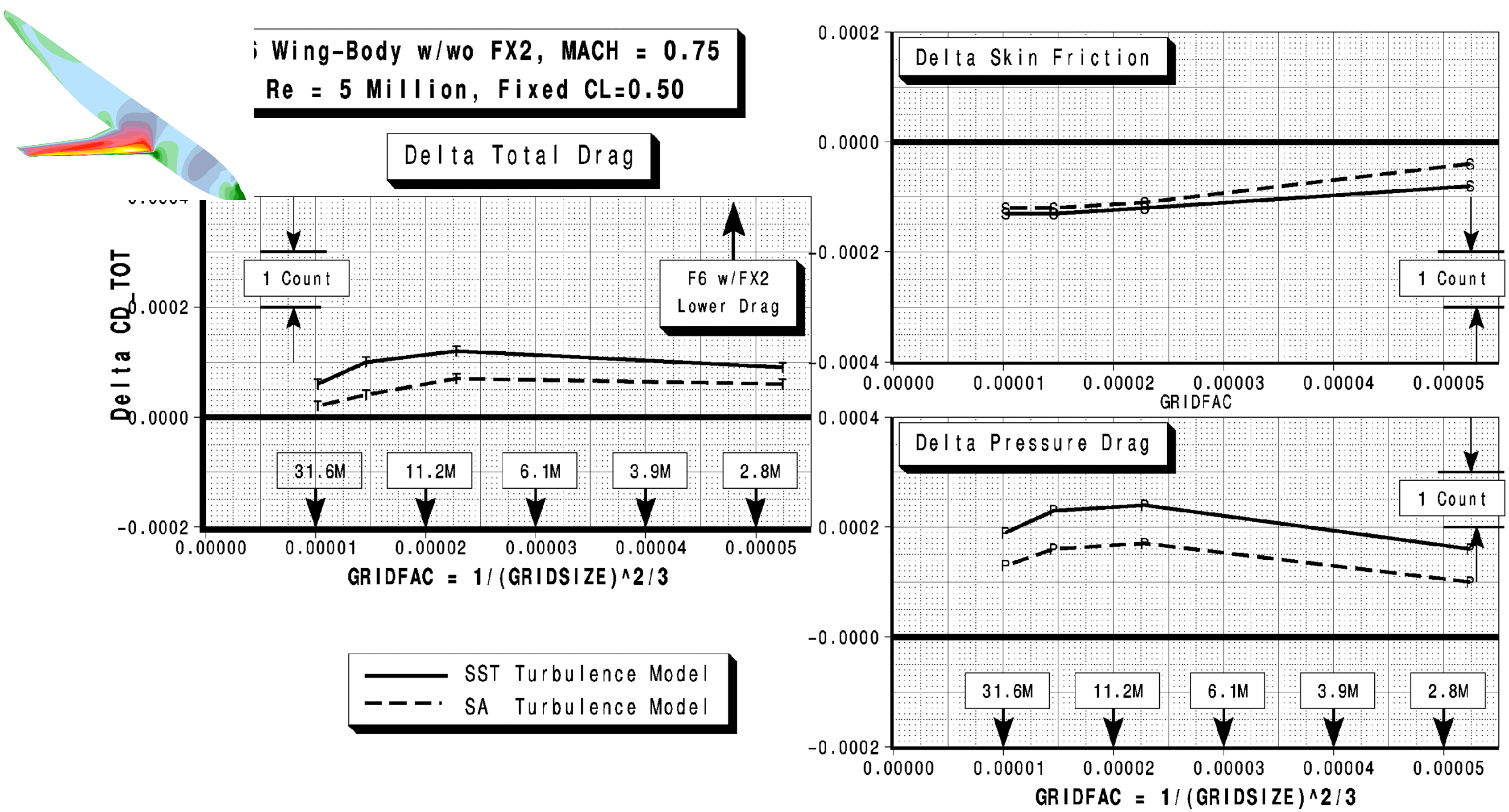
F6 WB w/wo FX2 – Drag Increment Grid Convergnece

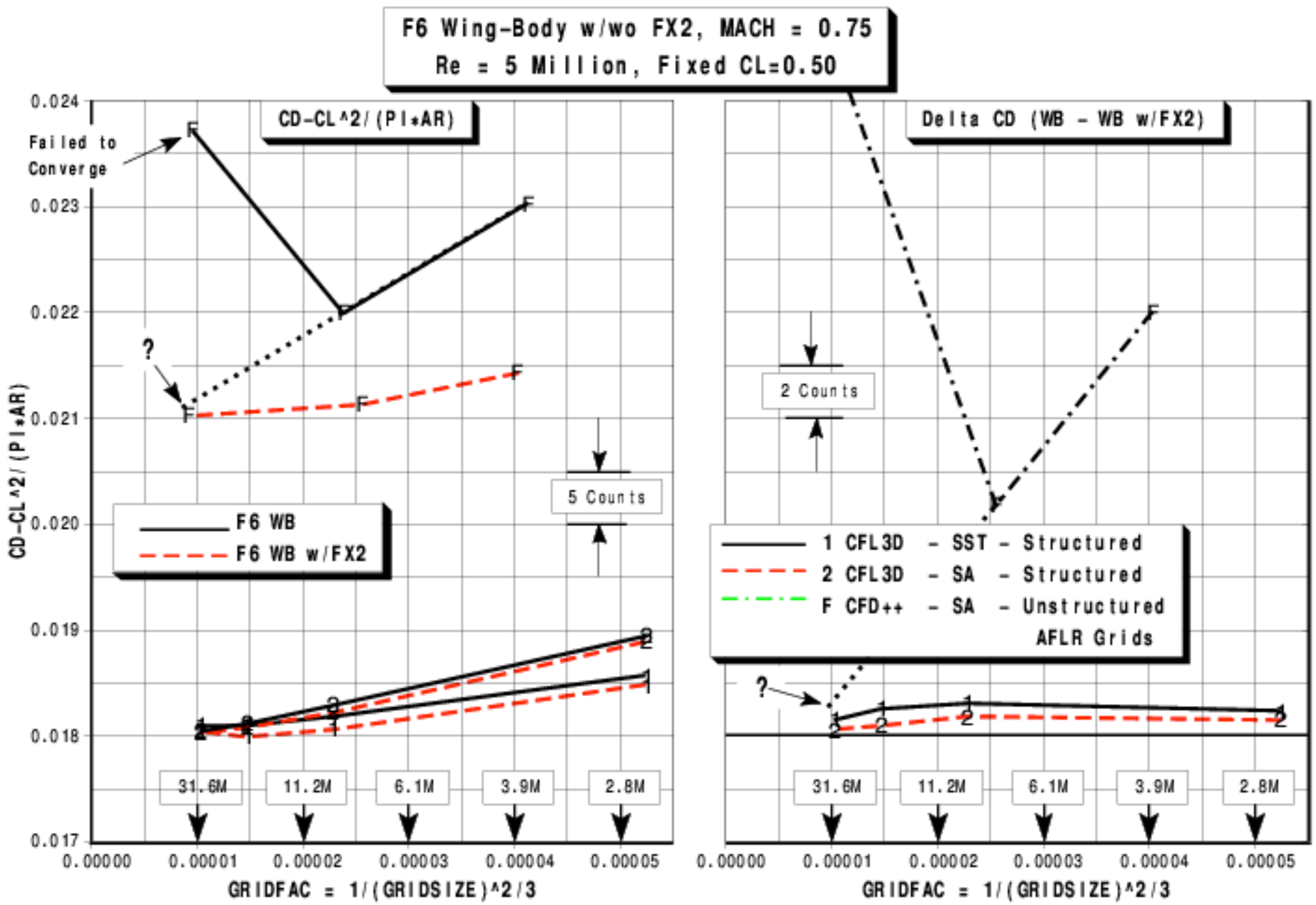
Delta = (F6 WB) - (F6 WB w/FX2)



CFD++ – Unstructured Grid Navier-Stokes Code

- Developed by Metacomp Technogies
- Unified grid, unified physics and advanced numerical discretization and solution framework.
- Finite volume
- Upwind biased
- Multigrid for acceleration
- Arbitrary elements and has overset capabilities.
- Choice of turbulence models
  - Spalart-Almaras SA Model
  - k-ε-Rt Model
- Time accurate with dual-time stepping
- Runs efficiently on parallel machines through MPI

CFD++ – Unstructured Grid Navier-Stokes Code
Grid Convergence



Concluding Remarks

Zeus/CFL3D – Structured Grids

- Zeus/CFL3D exhibited reasonable grid convergence characteristics for both SA and SST turbulence models.
  - Good sequence of grids
  - Good solution convergence
  - Concern with trend at finest grids
- Separation bubble size little affected by grid size, some difference with turbulence model
- Pressure distributions essentially invariant with grid

CFD++ - Unstructured Grids

- F6 Wing-Body: Good temporal convergence on coarse and medium St. Louis mixed-element grids; non-convergence observed on fine St. Louis grid because of large, spurious side of body separation.
- F6 Wing-Body with FX2 Fairing: Very good temporal convergence on all St. Louis mixed-element grids. Divergence observed with Langley grids, generated using VGRID.