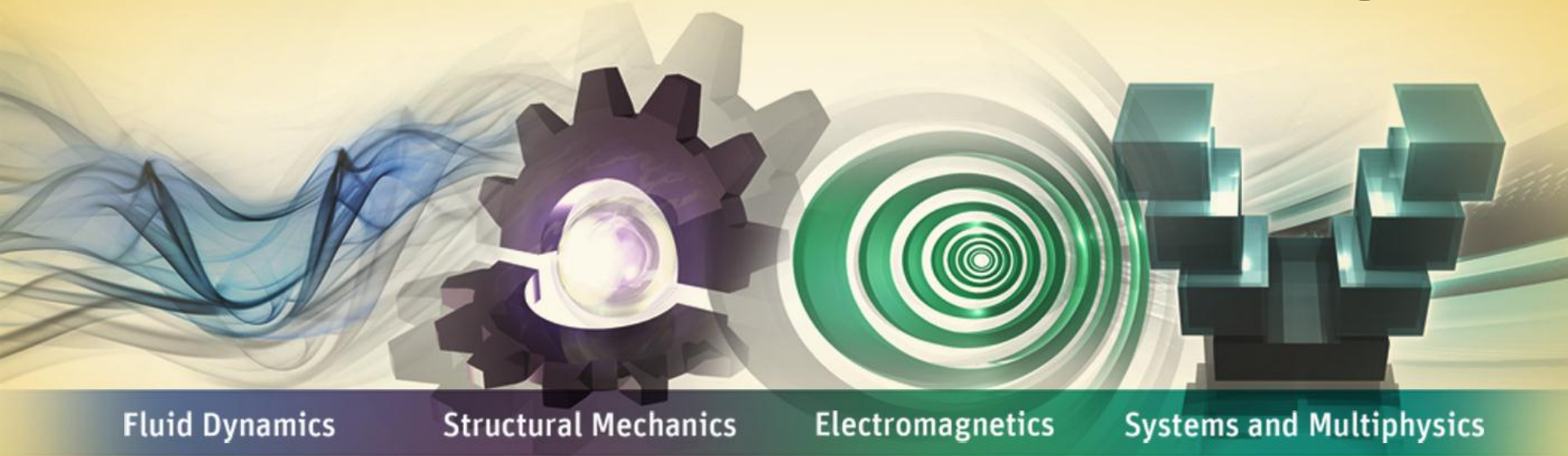


Rectangular Supercritical Wing



Fluid Dynamics

Structural Mechanics

Electromagnetics

Systems and Multiphysics

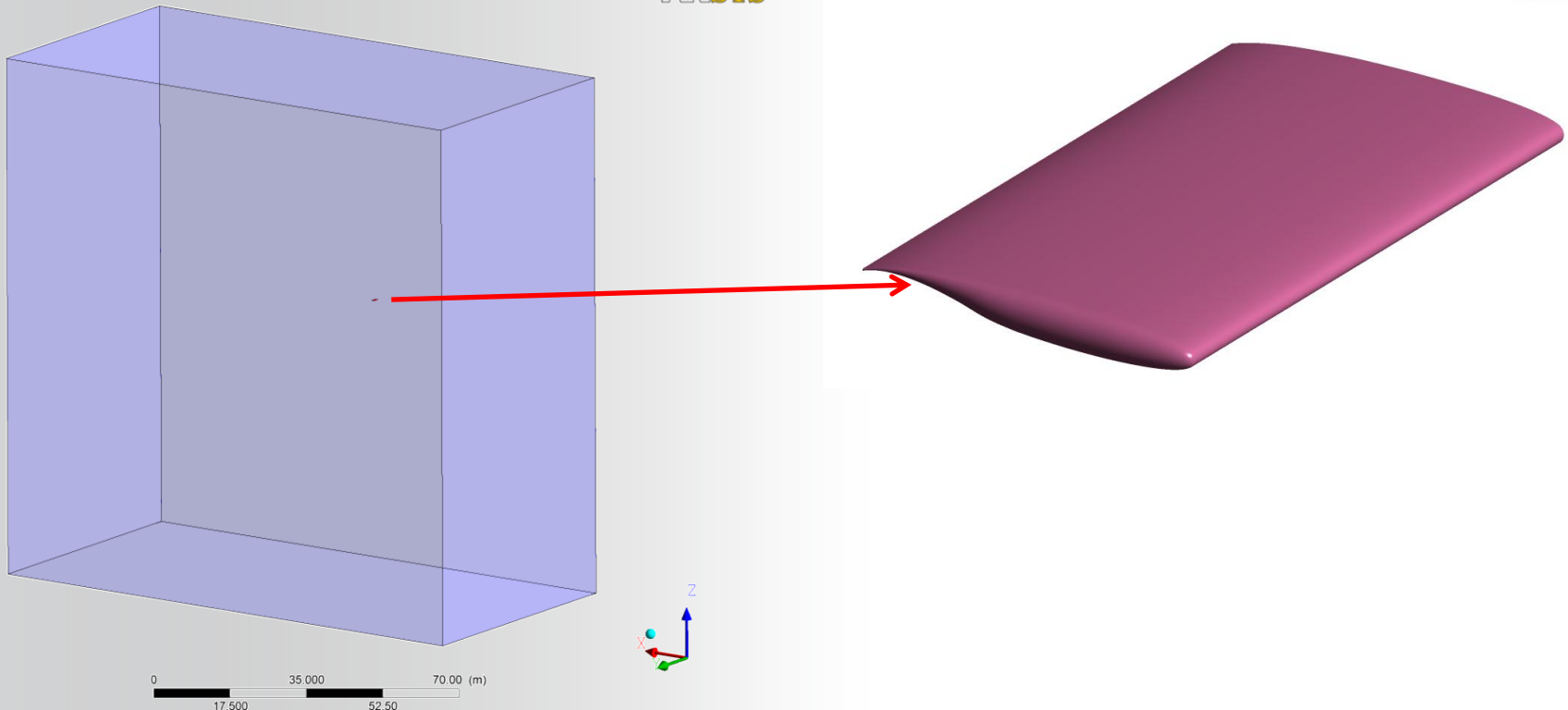
Angela Lestari, Thorsten Hansen
ANSYS

Computational Domain

- **Cref = 24.0 inches (609.6 mm)**
- **Span = 48 inch**
- **100 * Cref in all directions**

ANSYS

ANSYS

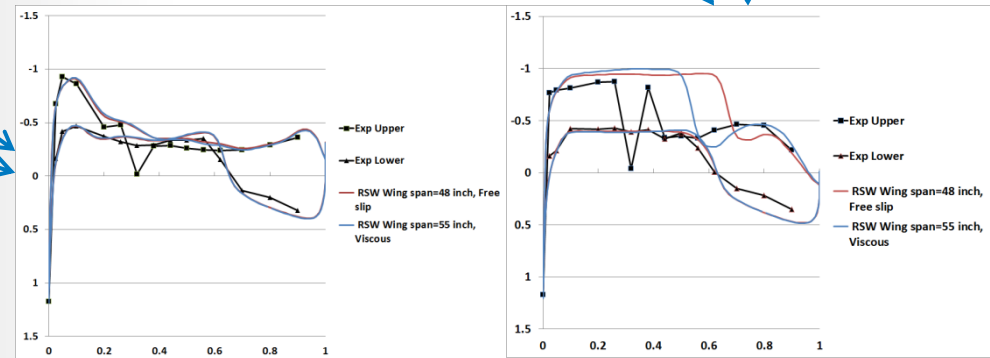
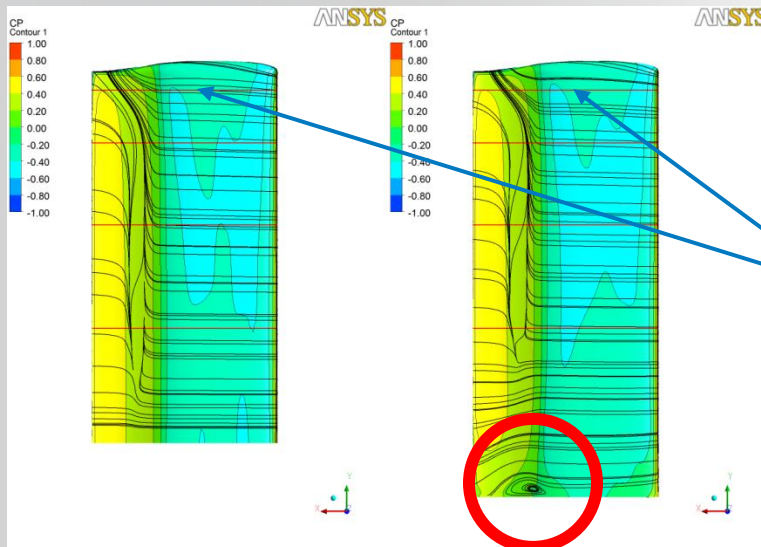
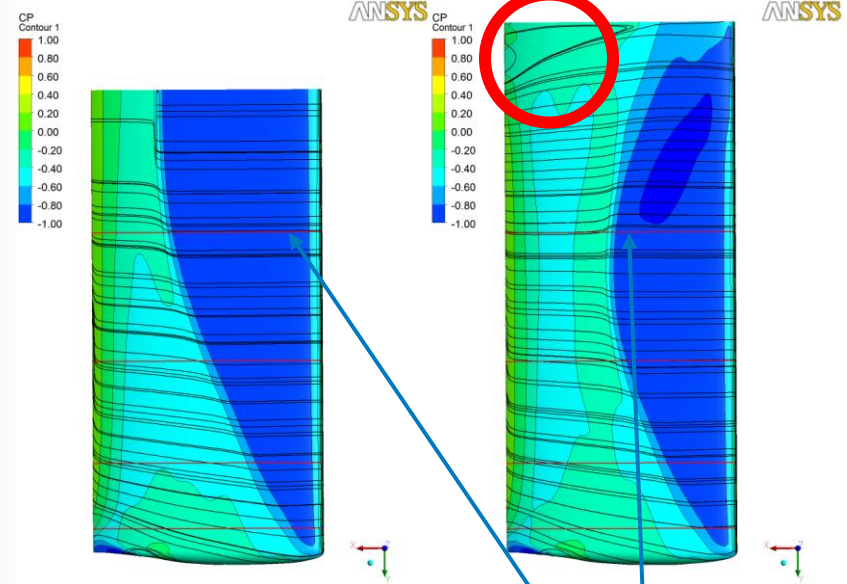


Splitter Plate

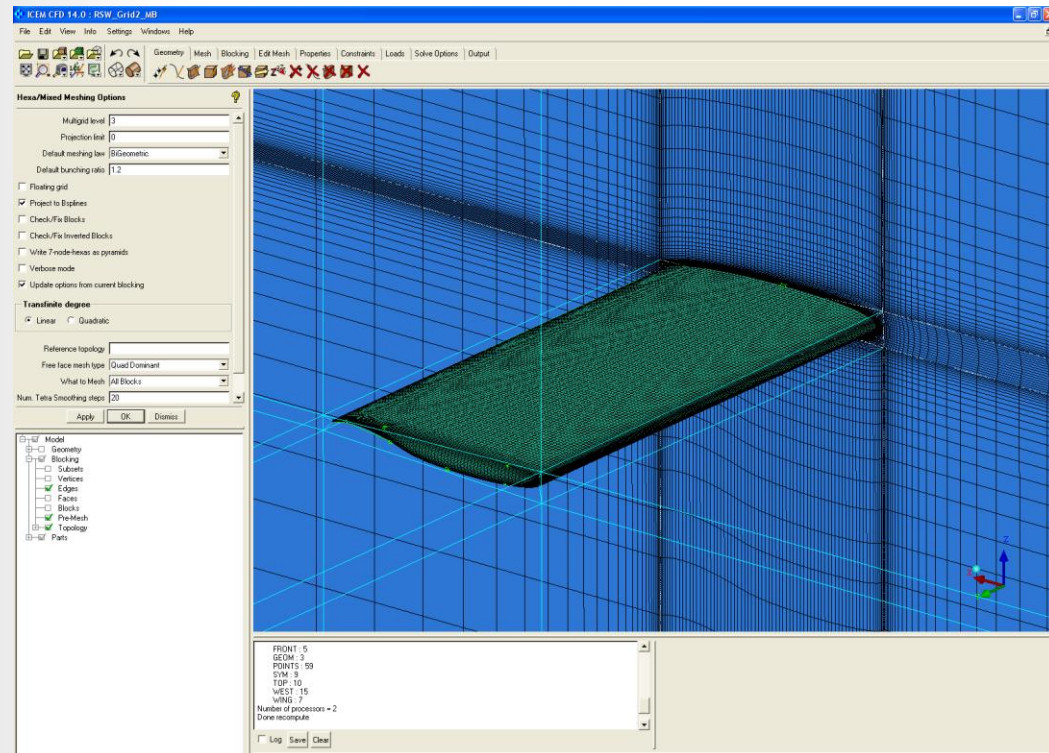
- Original span = 48 inch
 - Free-Slip wall @ tunnel wall
- Extended span = 55 inch
 - Viscous wall @ tunnel wall

Original

Extended



- ANSYS ICEM CFD
- Hexahedral elements
- Scalable grids
 - Consistent mesh quality upon grid refinement
- Multigrid
 - levels = 3

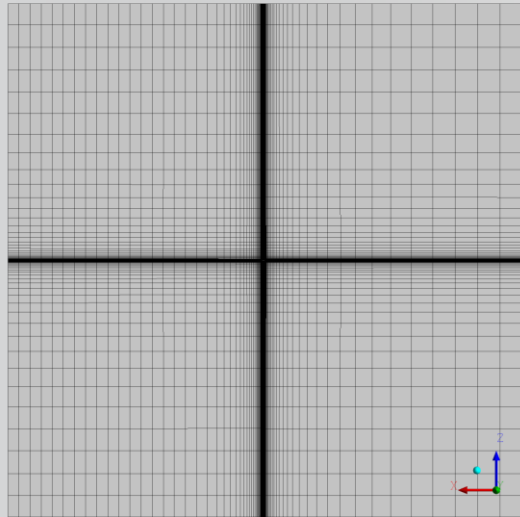


Grid Information

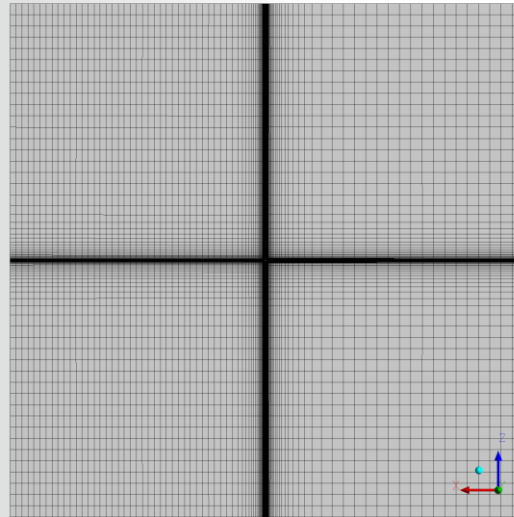
	Grid 1	Grid 2	Grid 3
Number of nodes	1,911,235	5,892,737	15,427,625
Number of elements	1,863,680	5,792,768	15,238,656
Minimum grid angle	32.66°	32.37°	28.71°
Maximum aspect ratio	12,931	13,123	12,945
First grid node @ Wall, inch	0.000158'' ($y^+=0.6$)	0.000105'' ($y^+\sim 0.41$)	0.000070'' ($y^+\sim 0.26$)

Grid Information

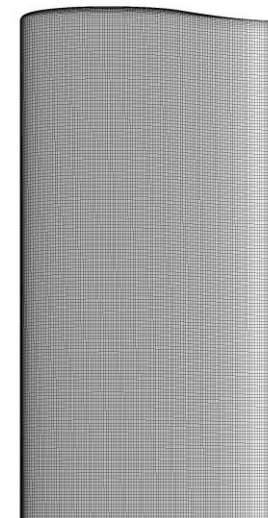
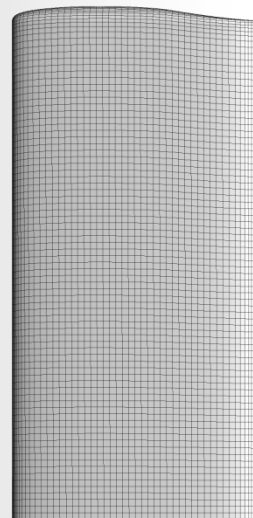
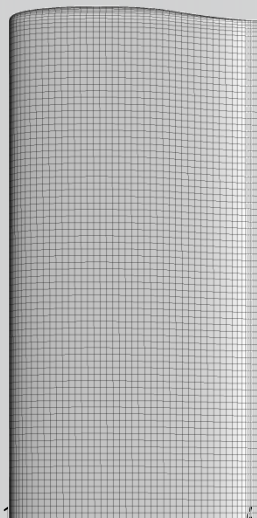
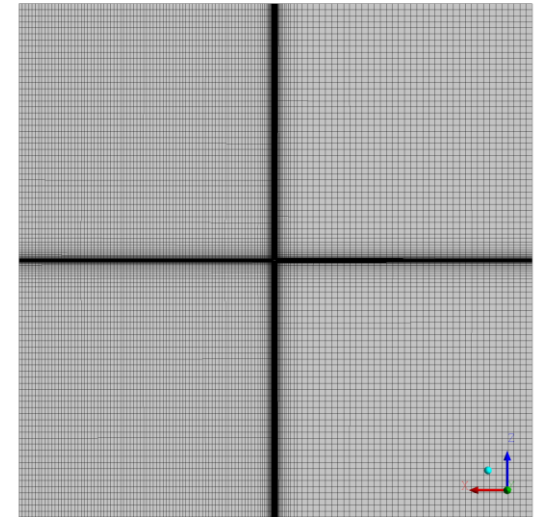
Grid 1



Grid 2

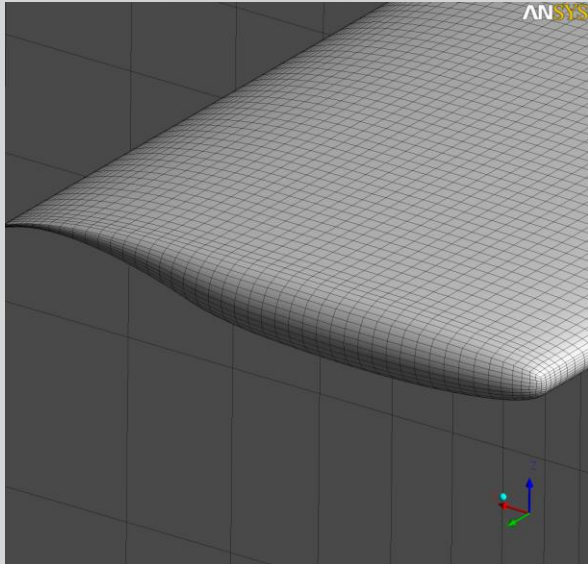
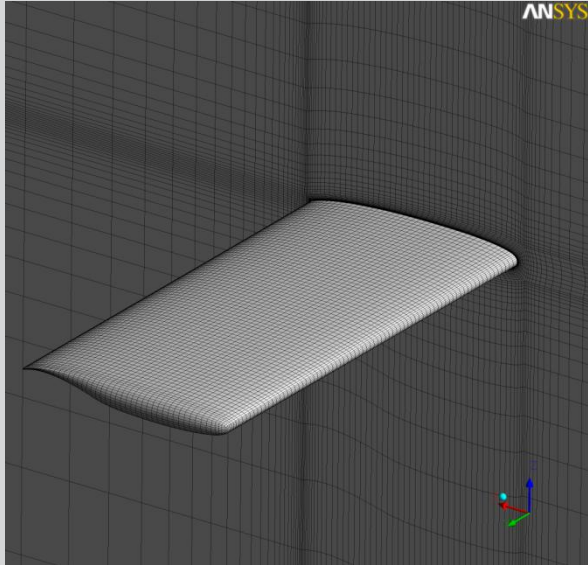


Grid 3

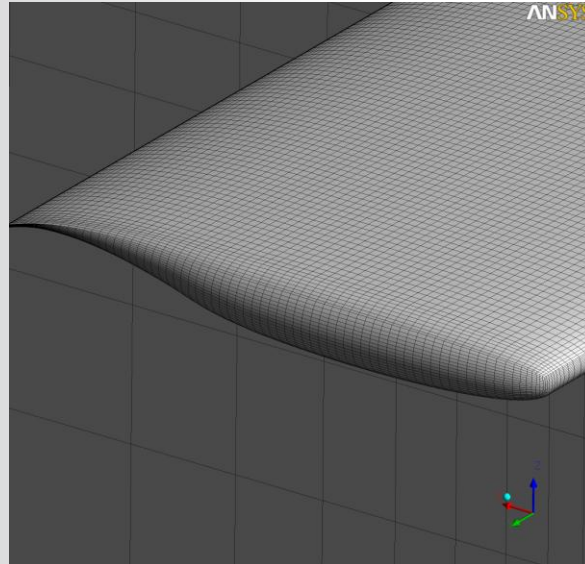
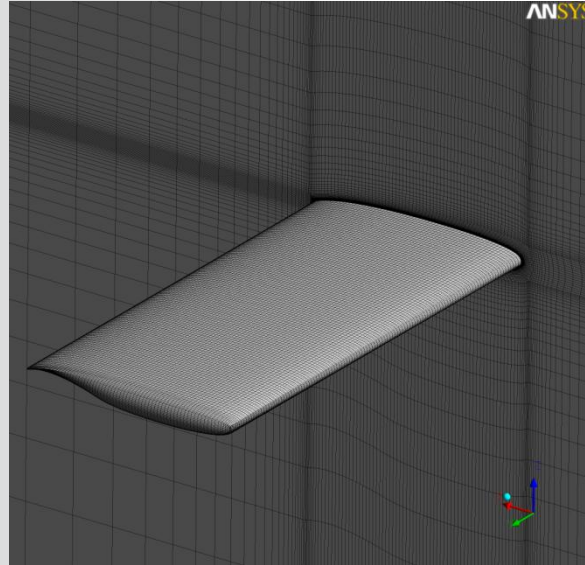


Grid Information

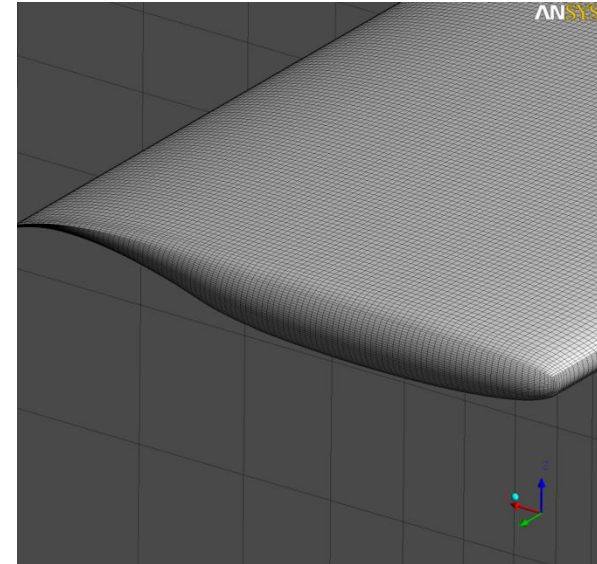
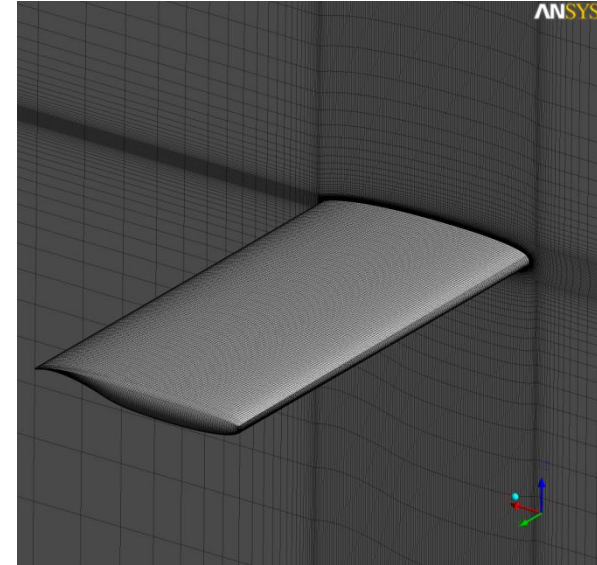
Grid 1



Grid 2

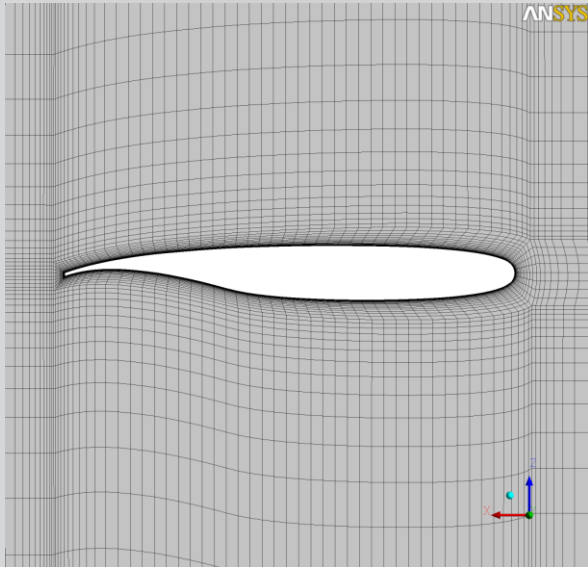


Grid 3

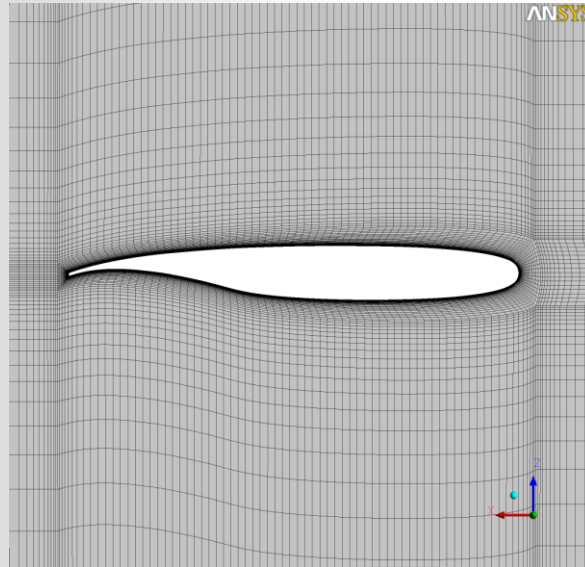


Grid Information

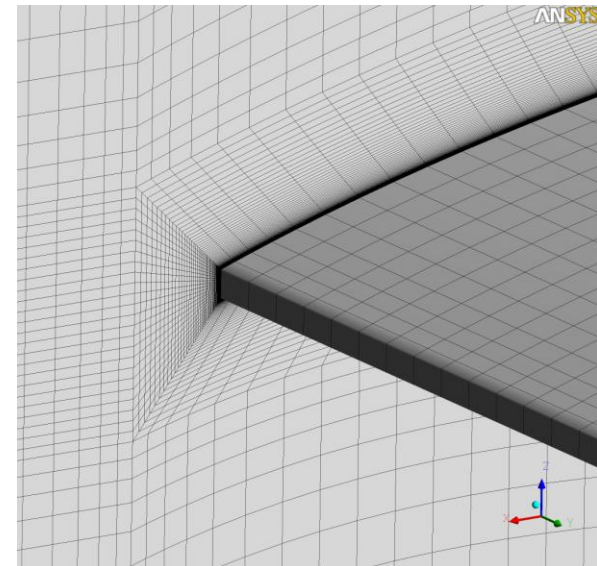
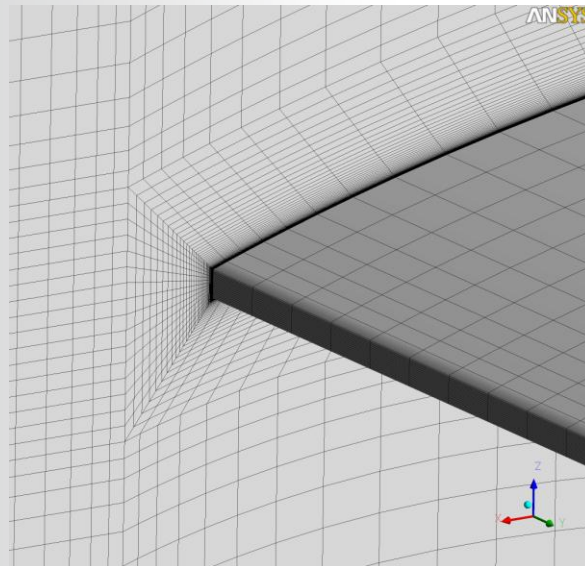
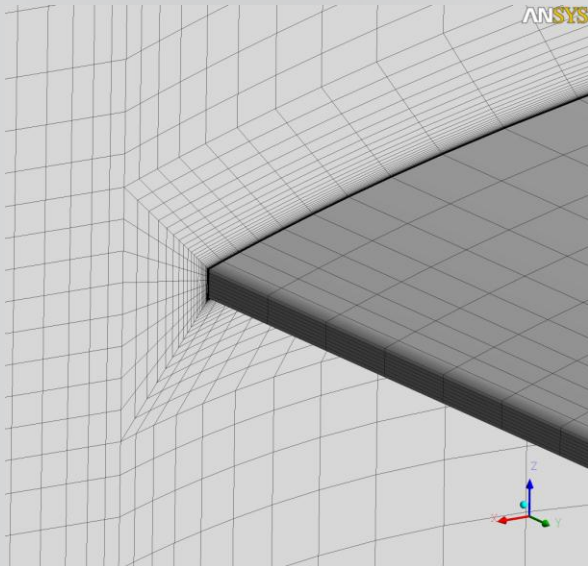
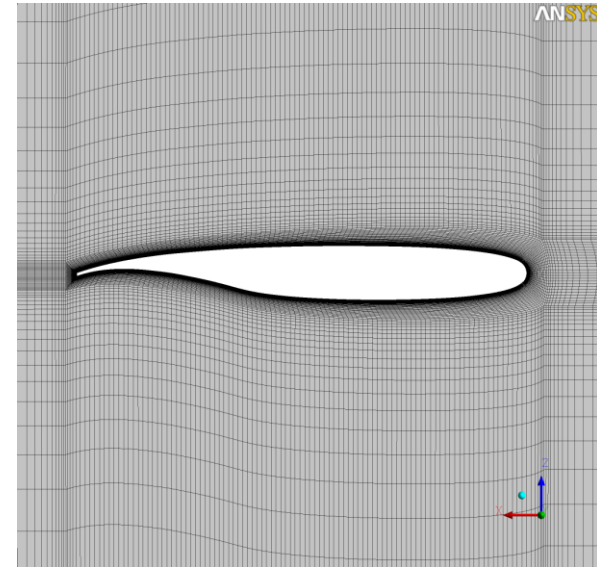
Grid 1



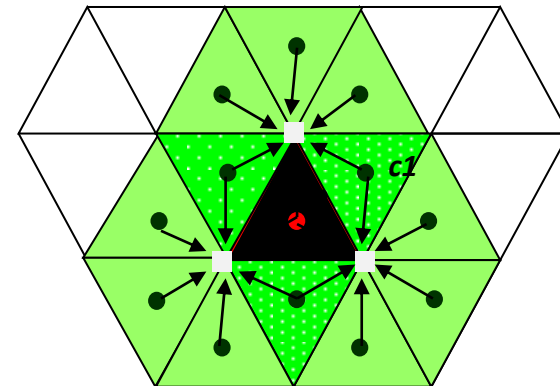
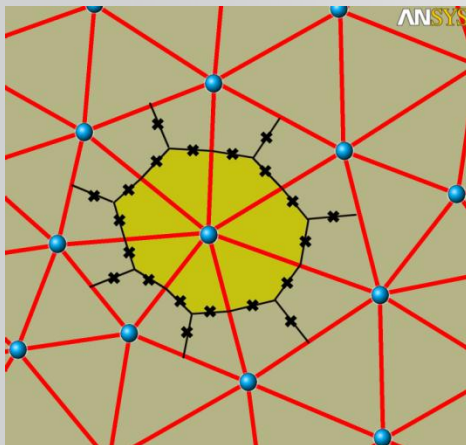
Grid 2



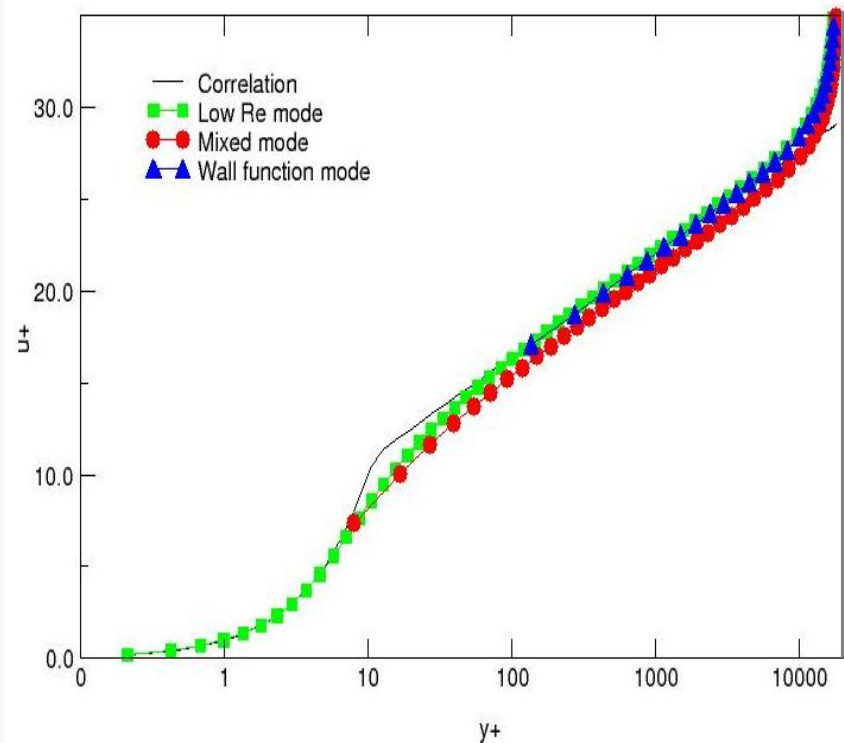
Grid 3



- ANSYS CFX 14
 - Coupled (U,V,W,P) solver
 - Pressure based
 - Convective discretization
 - High-resolution scheme
 - Algebraic multigrid
 - Vertex centred
- ANSYS FLUENT 14
 - Coupled (U,V,W,P) solver
 - Pressure based
 - Convective discretization
 - 2nd order upwind
 - Algebraic multigrid
 - Cell centred

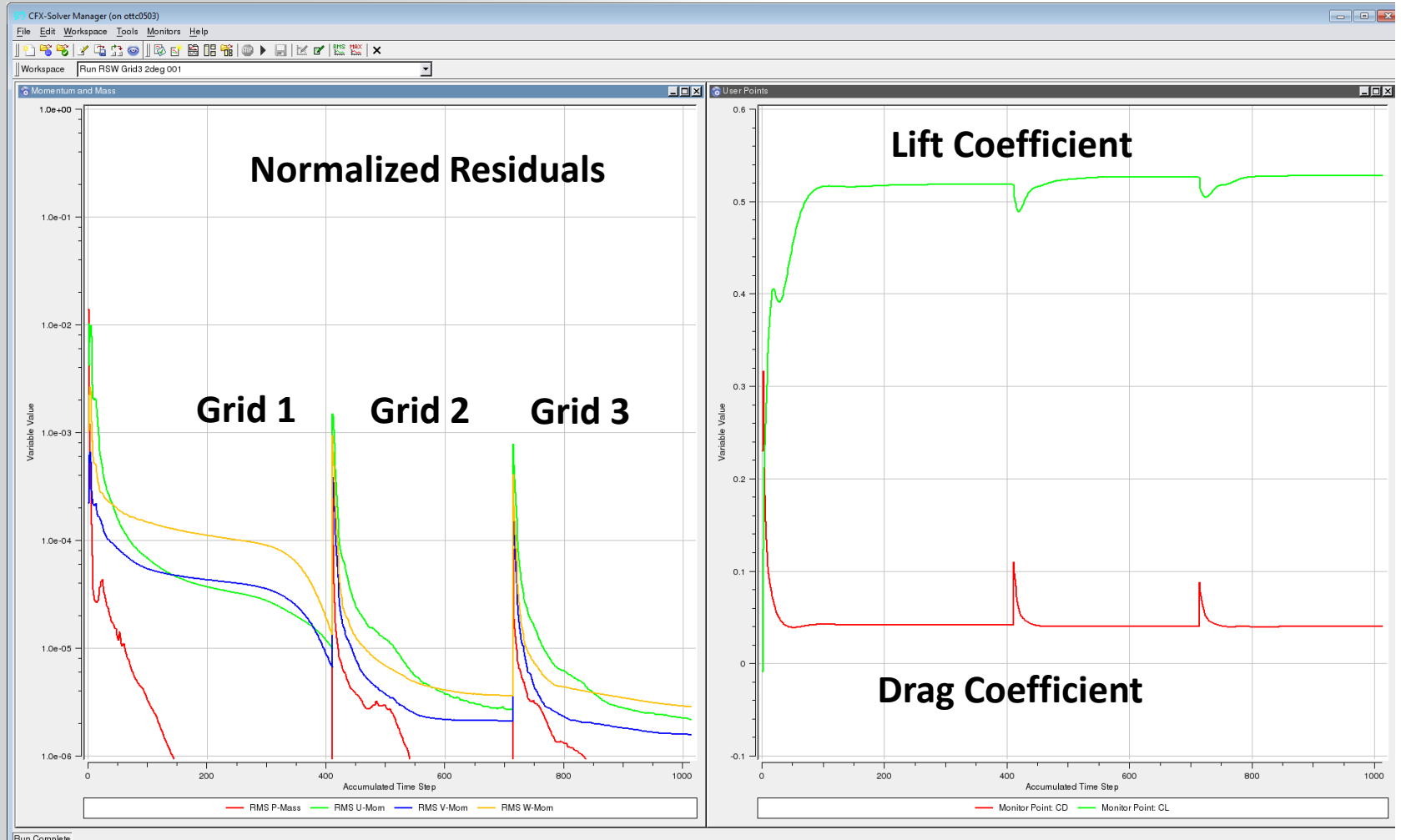


- Ensemble-averaged mass, momentum and energy conservation equations
- Turbulence model
 - SST (Menter, 1994)
- Automatic choice of linear/logarithmic near wall profiles

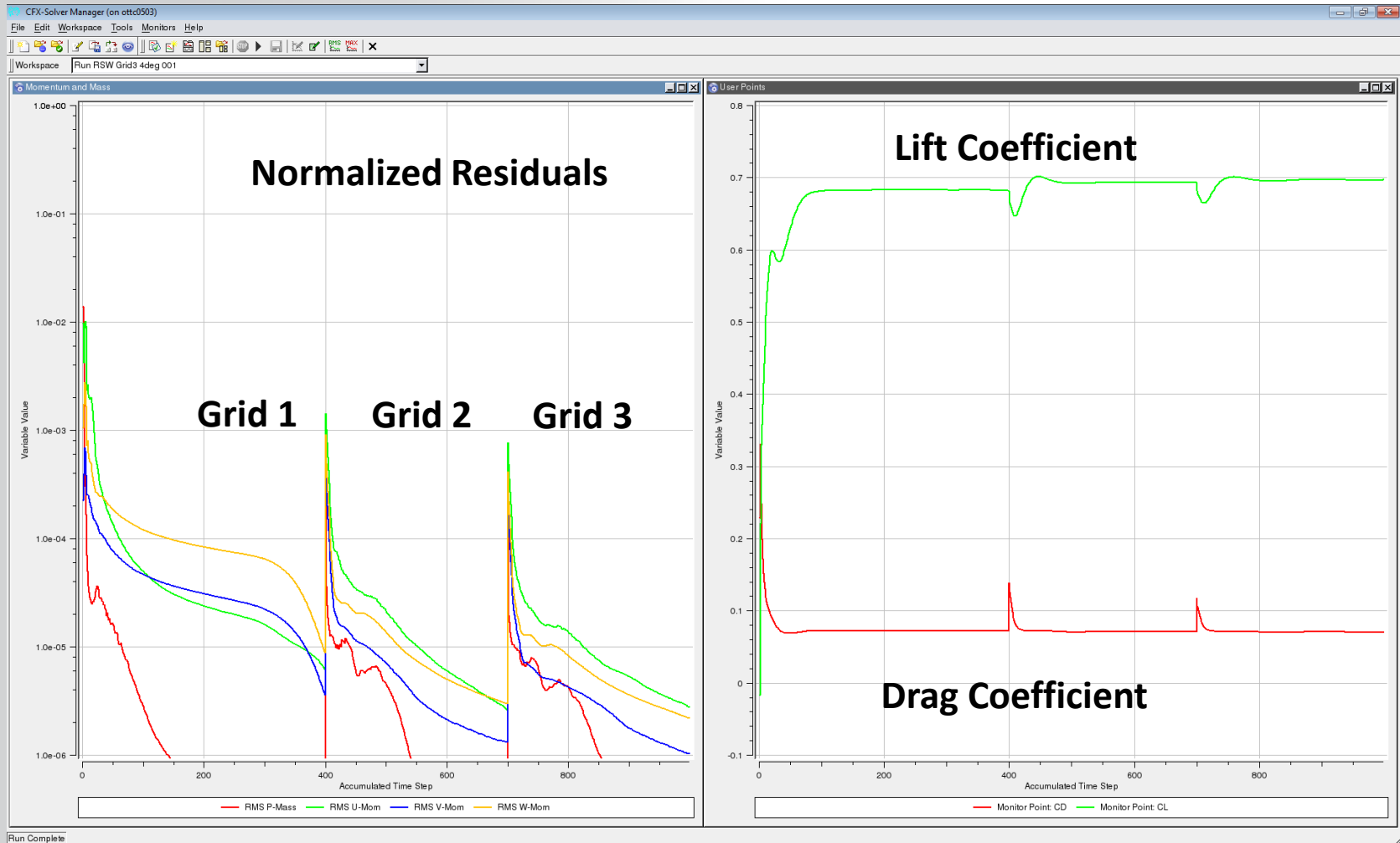


Automatic Wall Treatment

CFX Solver, $\alpha = 2^\circ$



CFX Solver, $\alpha = 4^\circ$

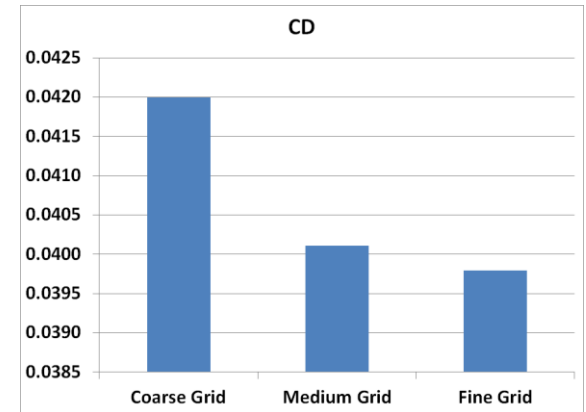
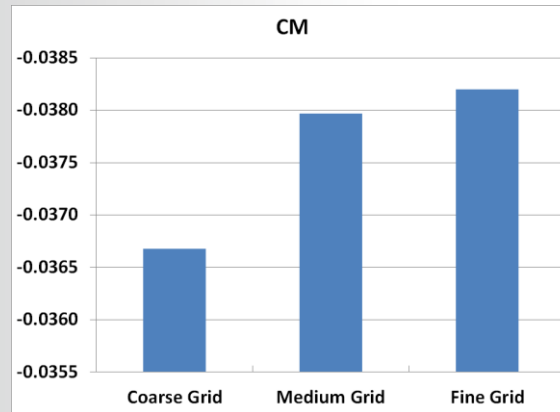
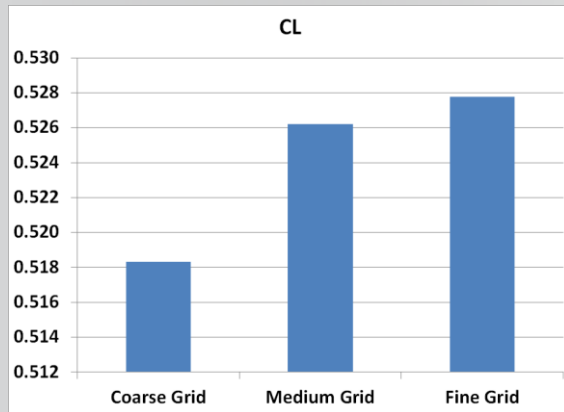


CFX Solver Information, Steady-State

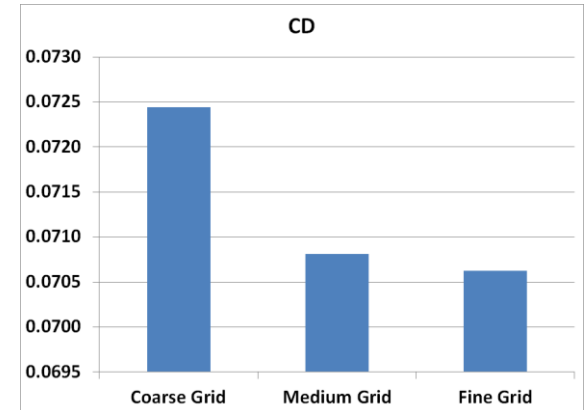
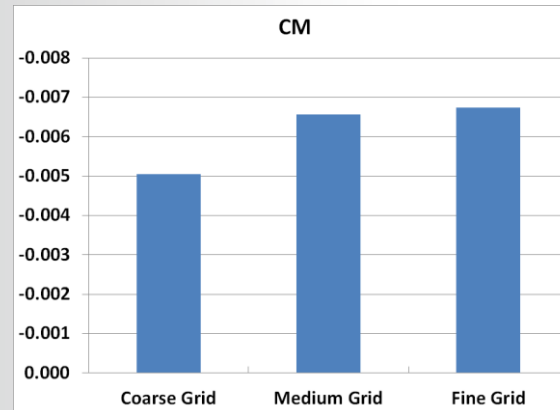
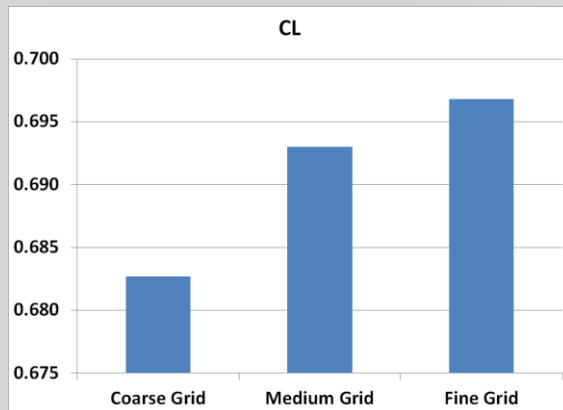
	# of elements, mio	# of iterations	# of CPUs	Total Wall Clock Time	Memory, Gbyte
Grid 1	1,86	411	12	1 h 56 min	2.85
Grid 2	5.79	300	36	1 h 45 min	8.85
Grid 3	15,24	300	108	1 h 43 min	23.48

CFX Discretization Error, Steady-State

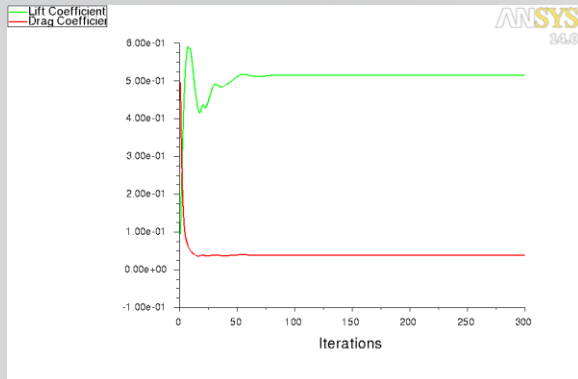
RSW, AoA = 2°



RSW, AoA = 4°

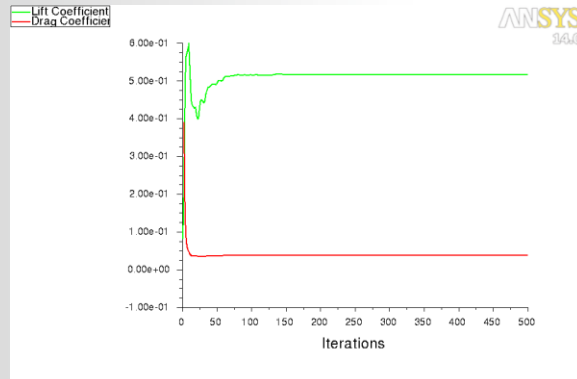


FLUENT Solver, $\alpha = 2^\circ$



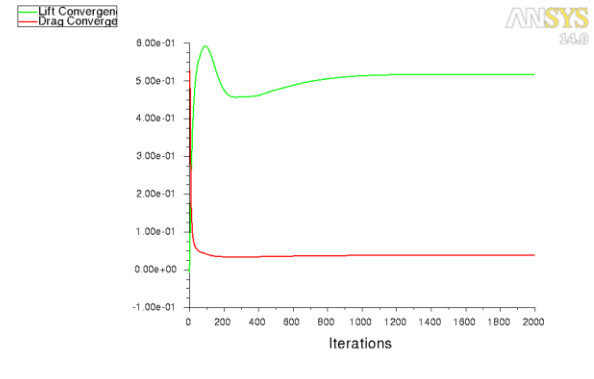
Mar 20, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, lam)

Grid 1



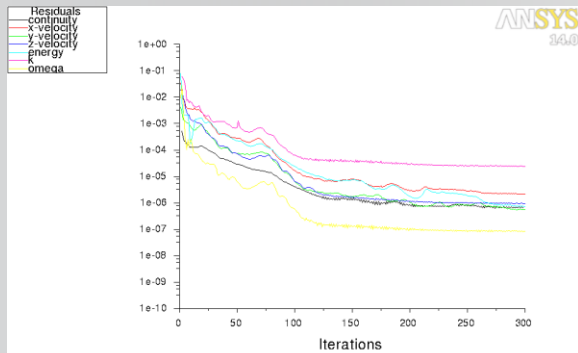
Mar 20, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, lam)

Grid 2

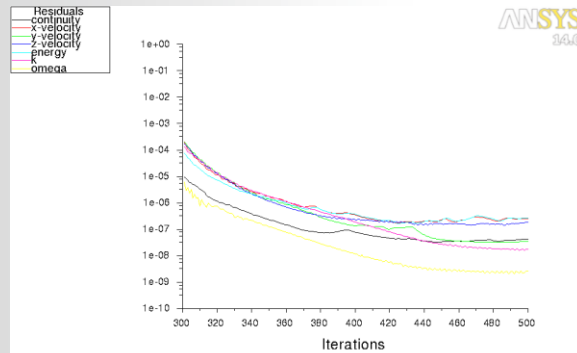


Apr 16, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, sstk)

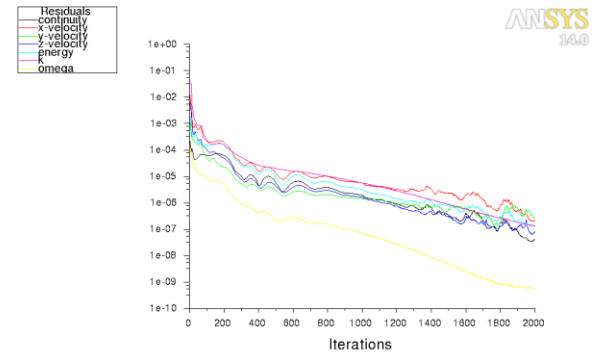
Grid 3



Apr 16, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, sstk)

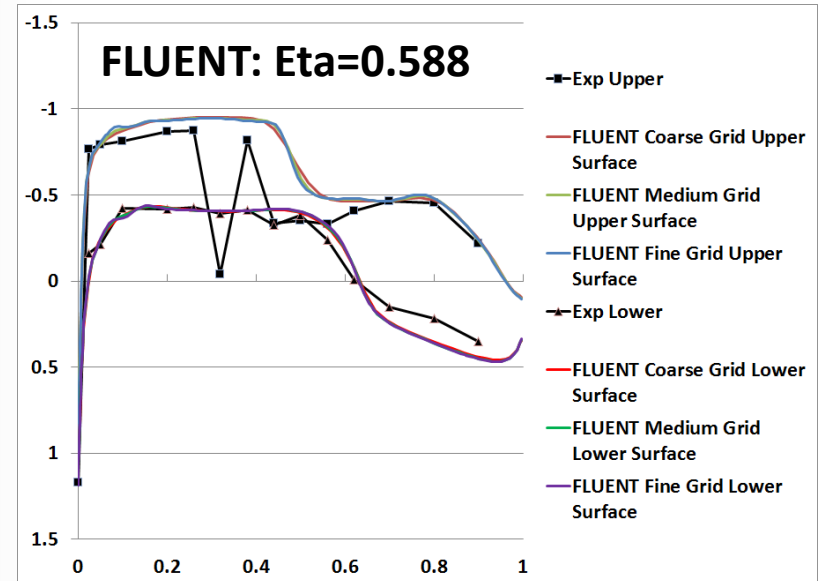
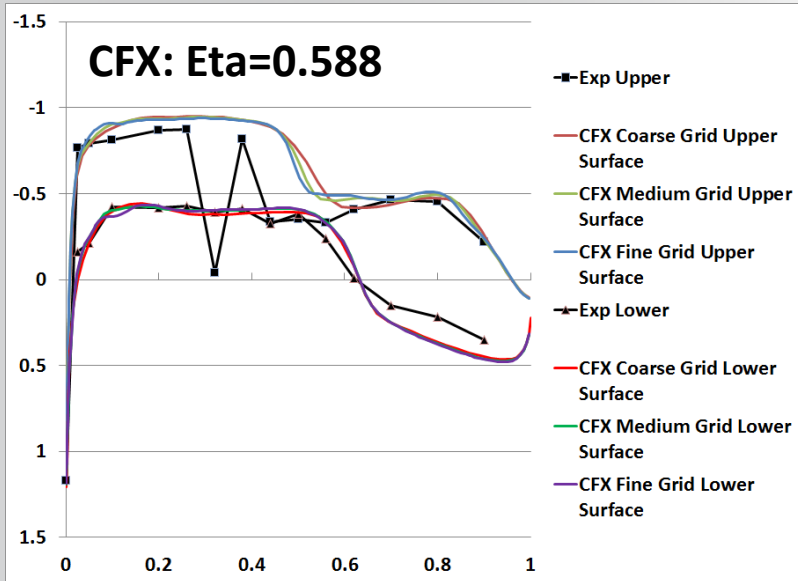
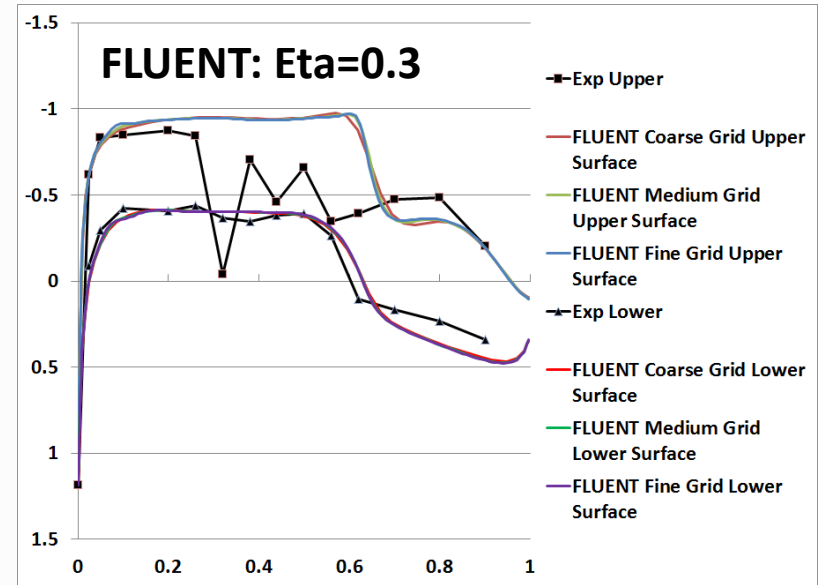
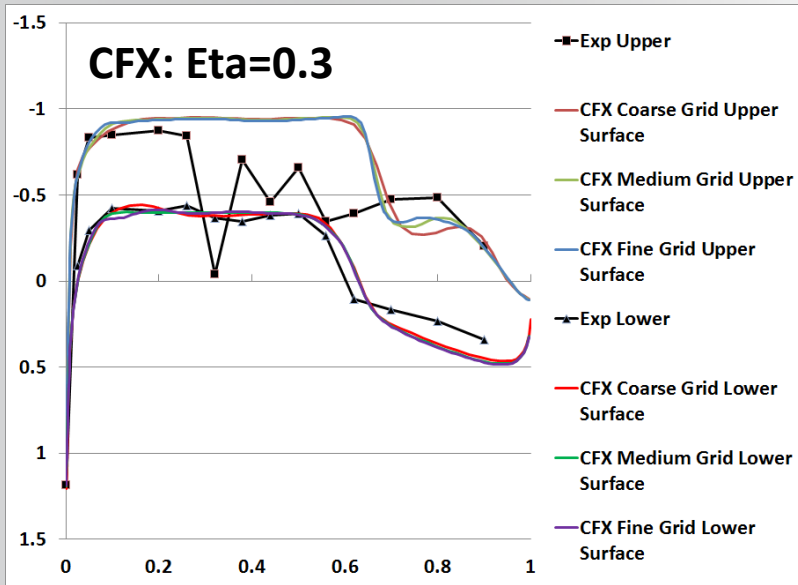


Apr 16, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, sstk)

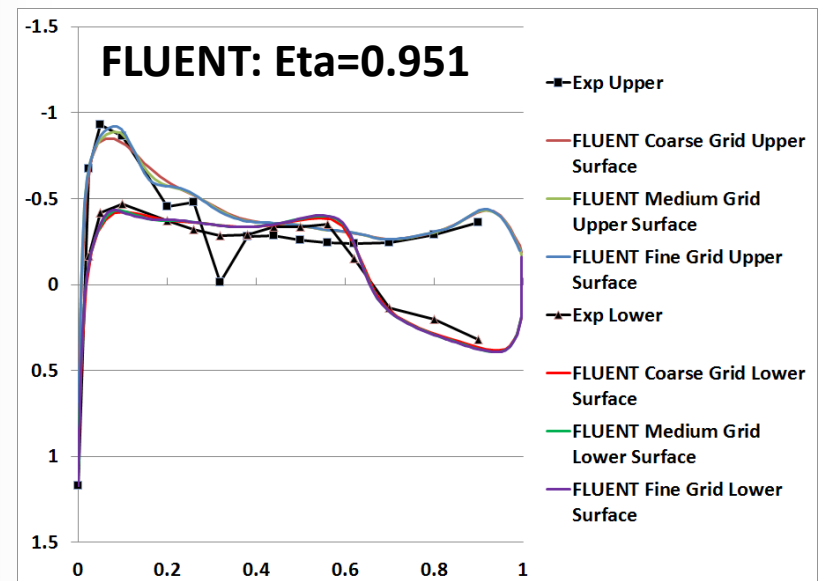
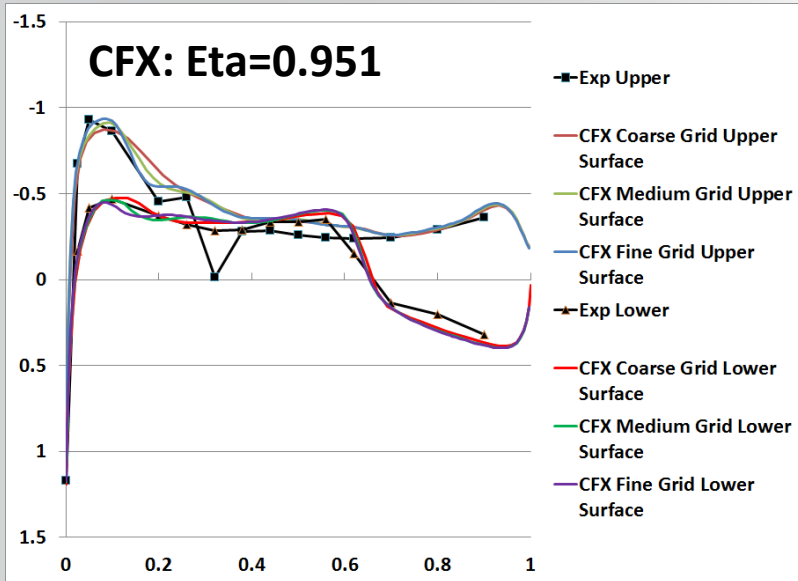
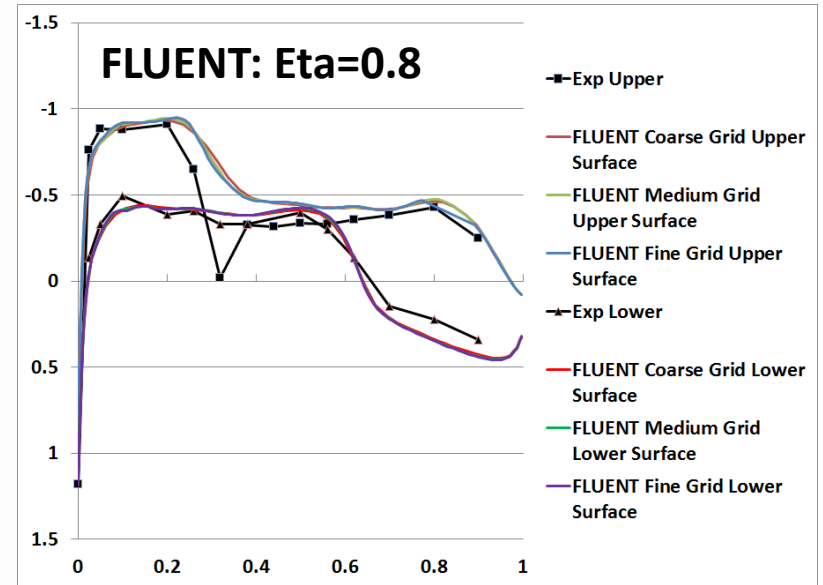
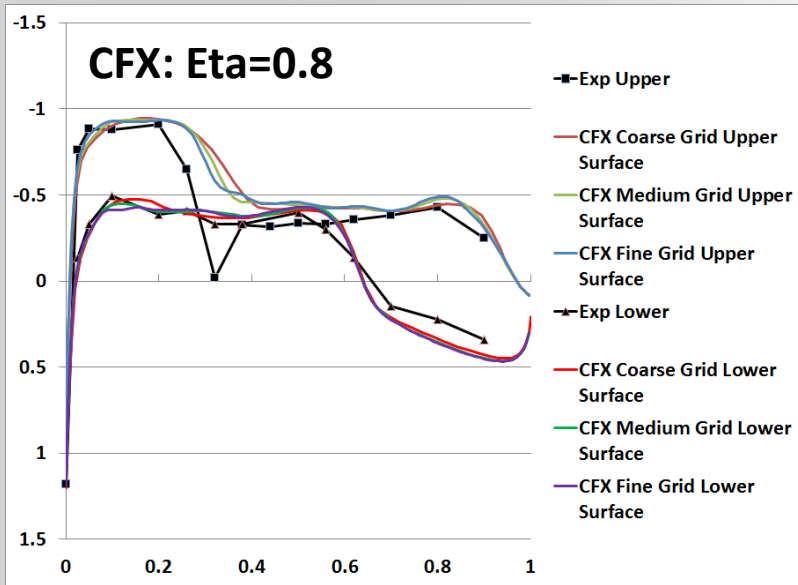


Apr 16, 2012
ANSYS FLUENT 14.0 (3d, dp, pbns, sstk)

RSW, AoA = 2°, CP @ Eta = 0.3 & 0.588



RSW, AoA = 2°, CP @ Eta = 0.8 & 0.951



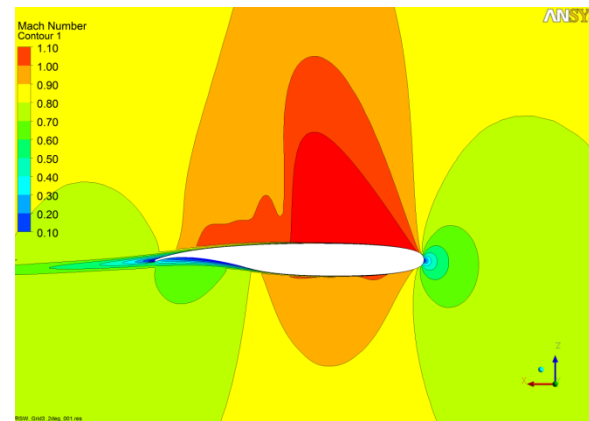
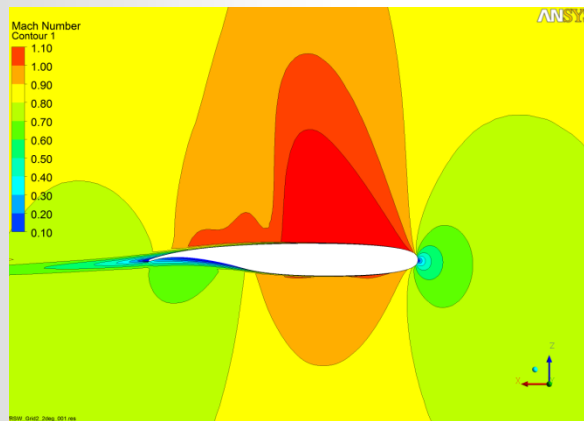
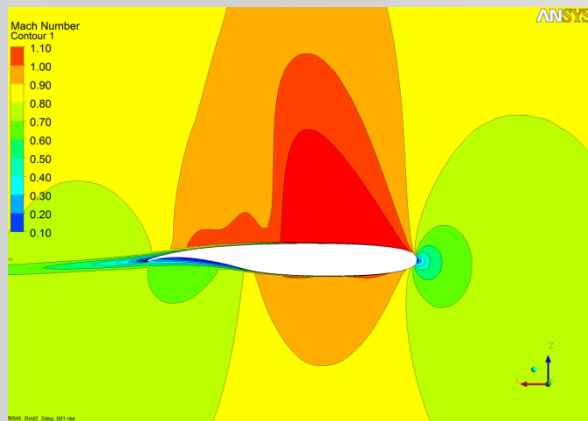
Mach Number, AoA = 2°, Eta=0.588,

Grid 1

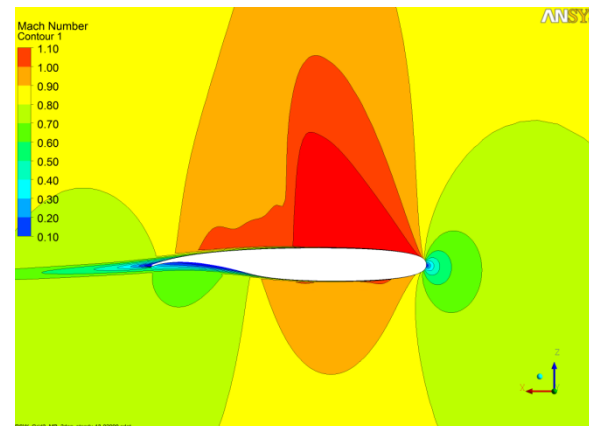
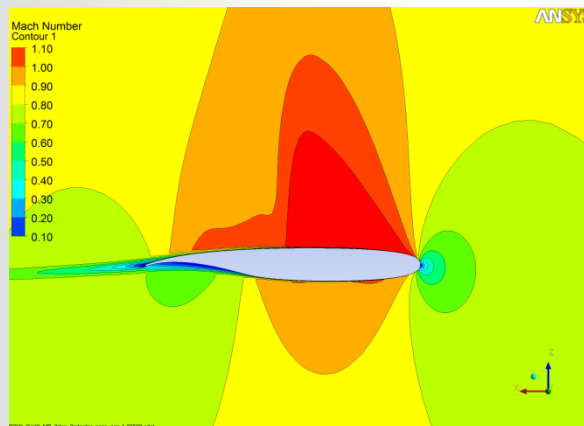
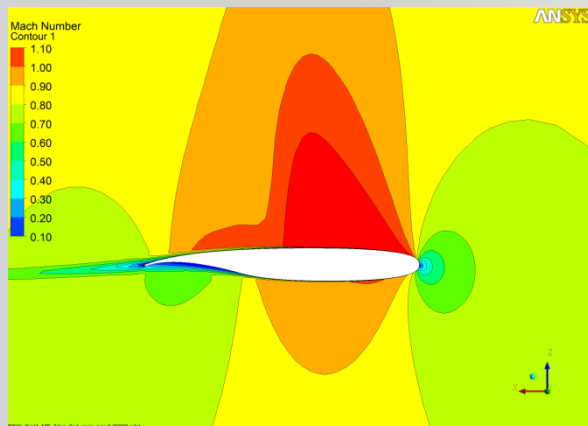
Grid 2

Grid 3

CFX

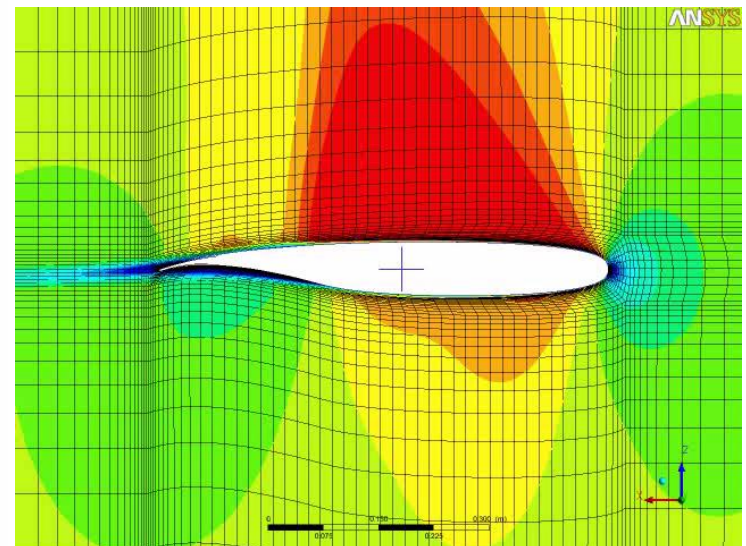
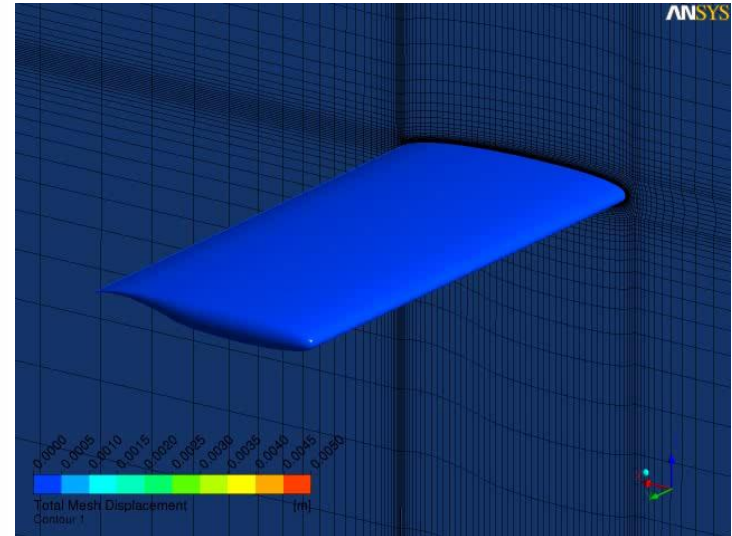


FLUENT



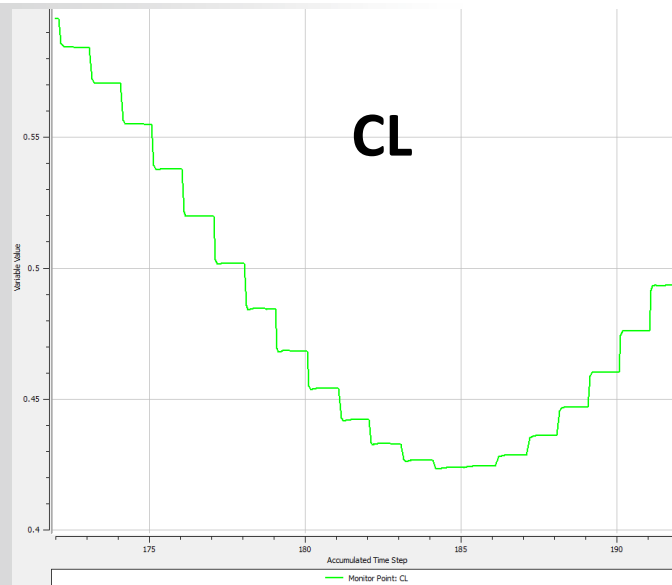
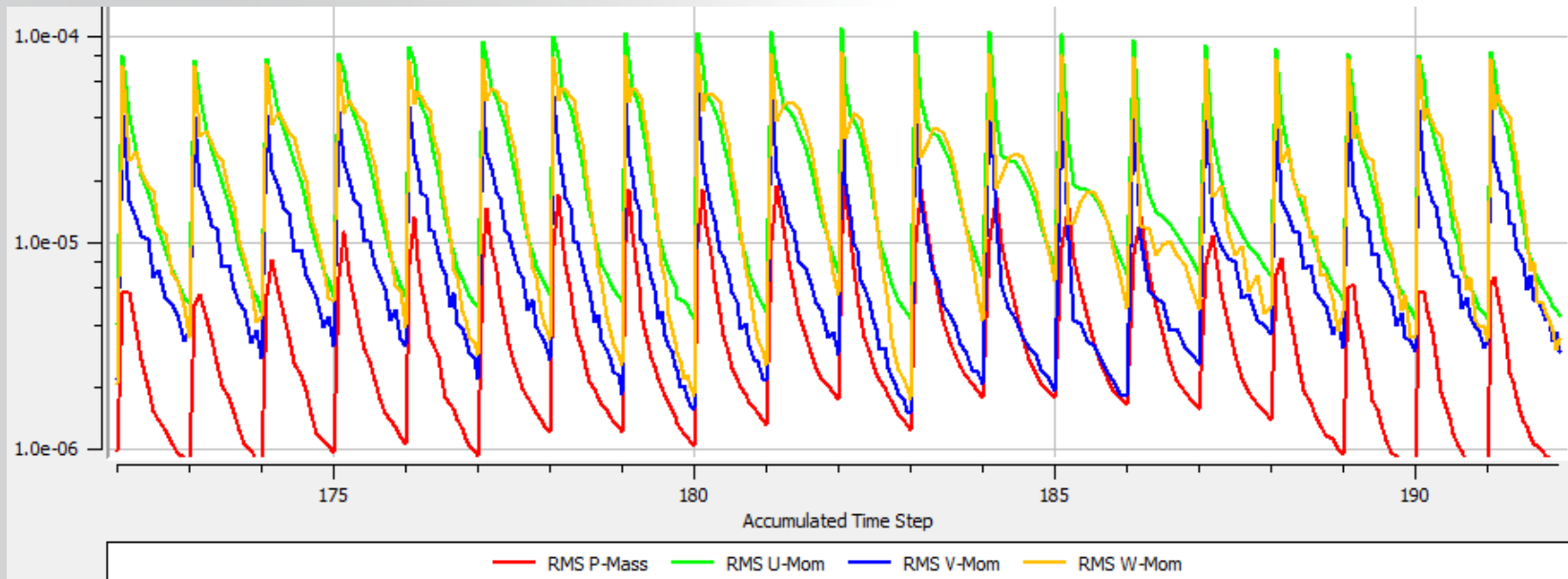
Unsteady-State Calculation

- Pitching oscillations
- Mesh displacement
 - Harmonic wing motion
 - $A \cdot \sin(\omega \cdot t)$
- Initial condition
 - Converged steady-state solution
- Monitor frequencies
- FFT

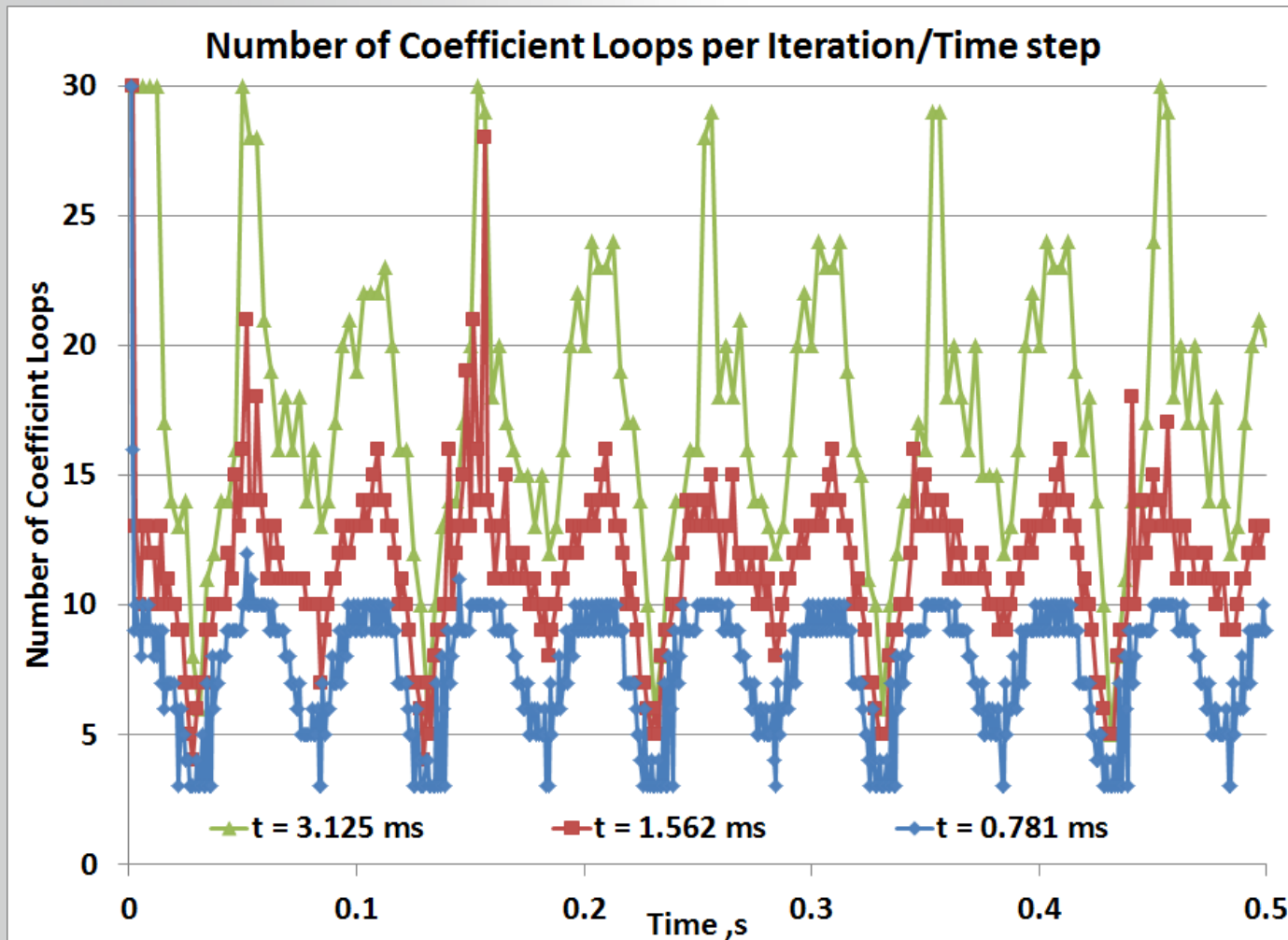


- Transient scheme
 - Second order backward Euler
- Convective discretization
 - High Resolution
- Initial condition
 - Steady-state solution
- Time steps per period
 - Run1: **32** > 3.125 ms
 - Run2: **64** > 1.562 ms
 - Run3: **128** > 0.781 ms
- Total time = 5 * period
 - $32 * 5 = 160$ iterations
 - $64 * 5 = 320$ iterations
 - $128 * 5 = 640$ iterations

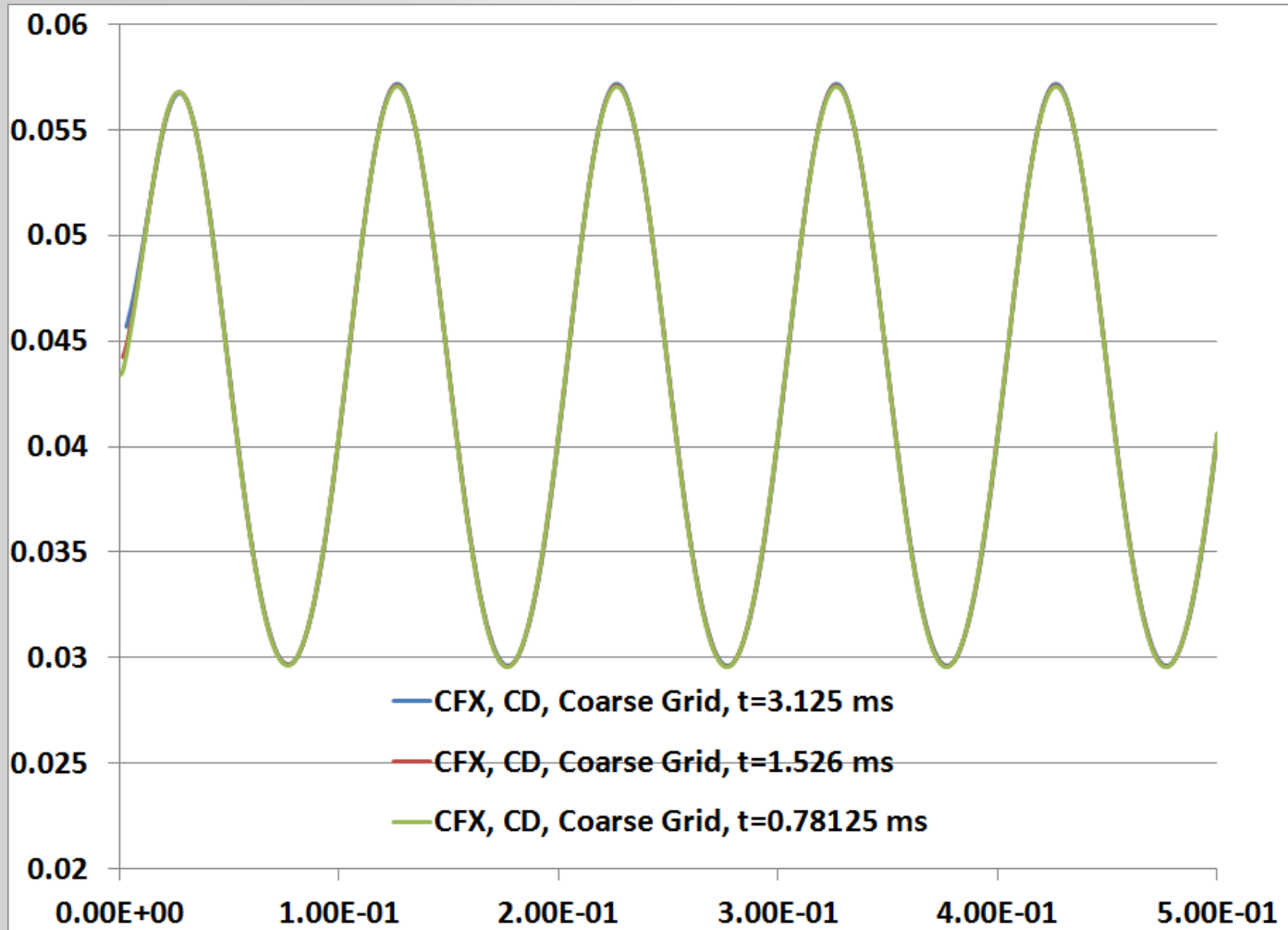
CFX: RMS Residuals & Inner Loops



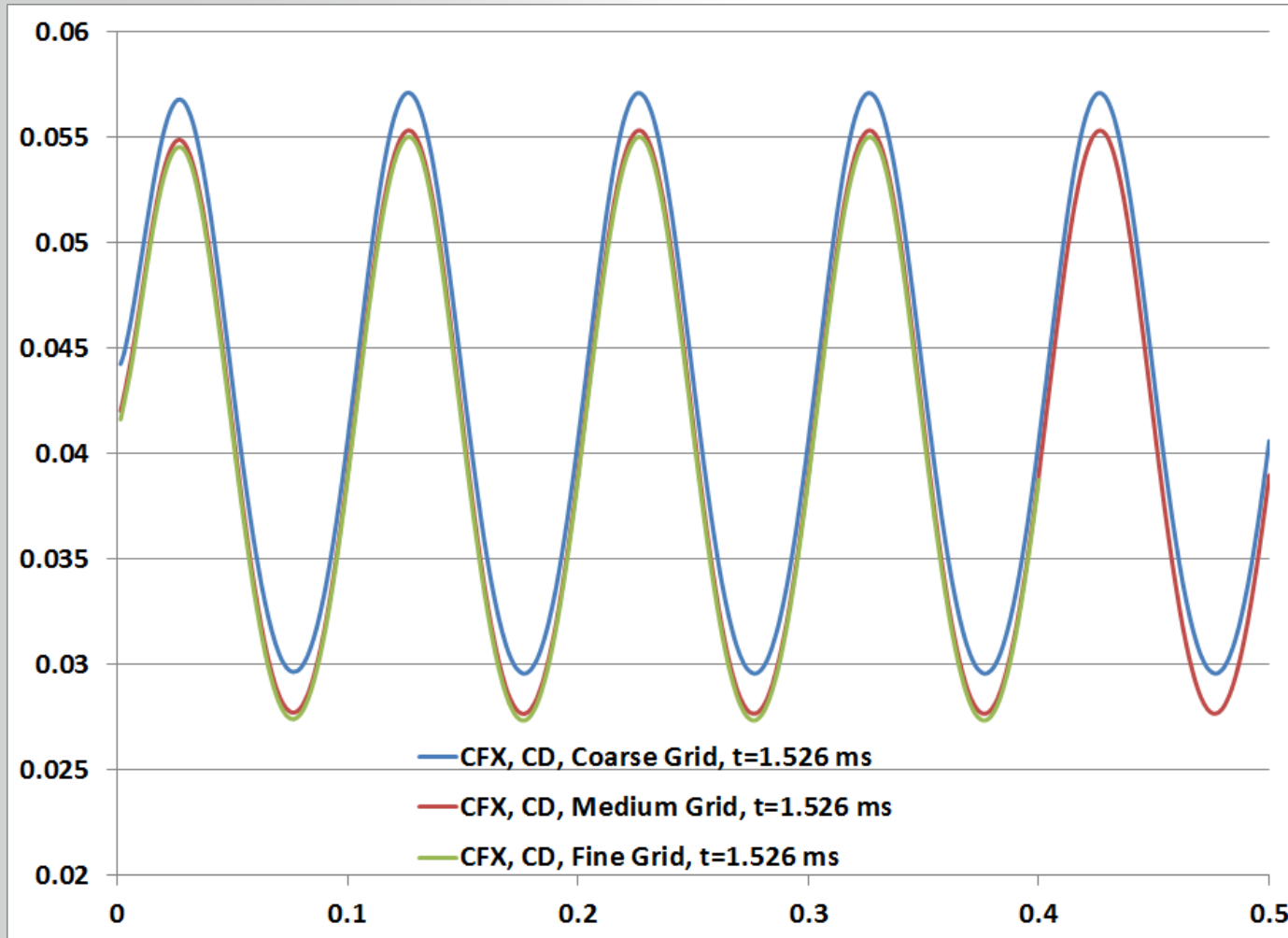
CFX, Grid 2, # of Coefficient Loops



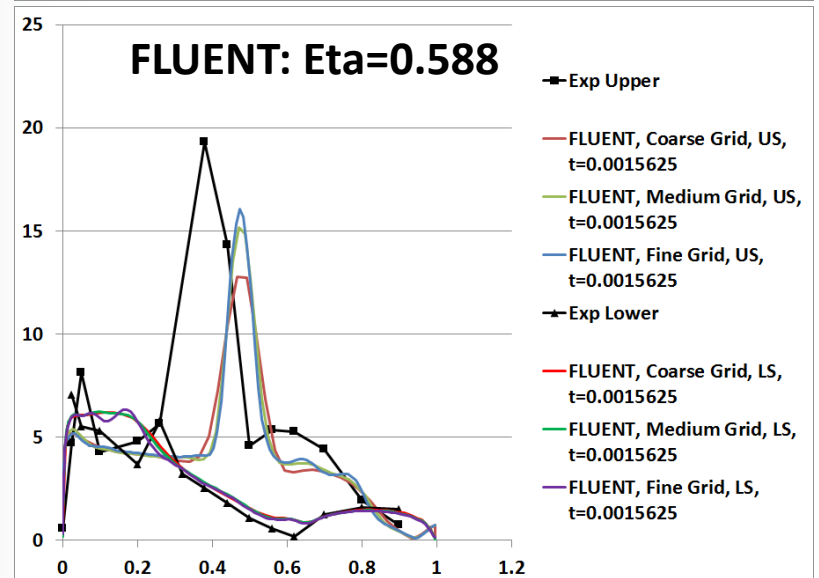
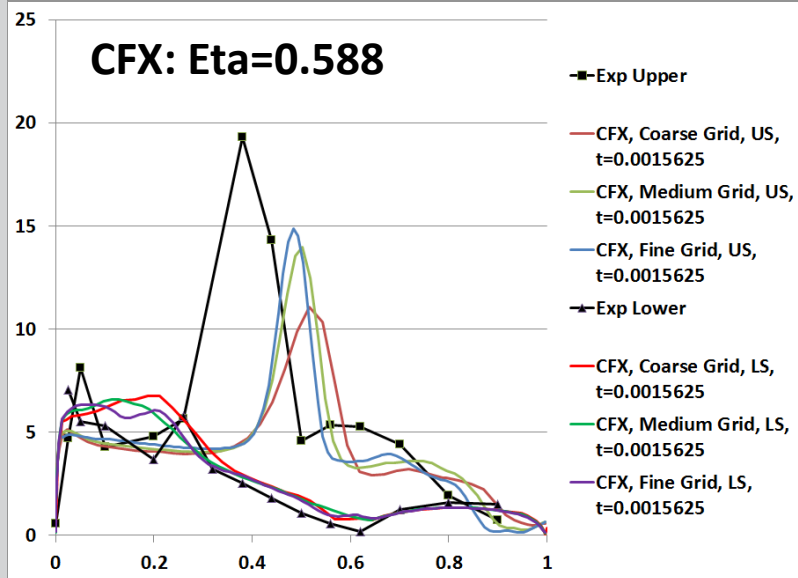
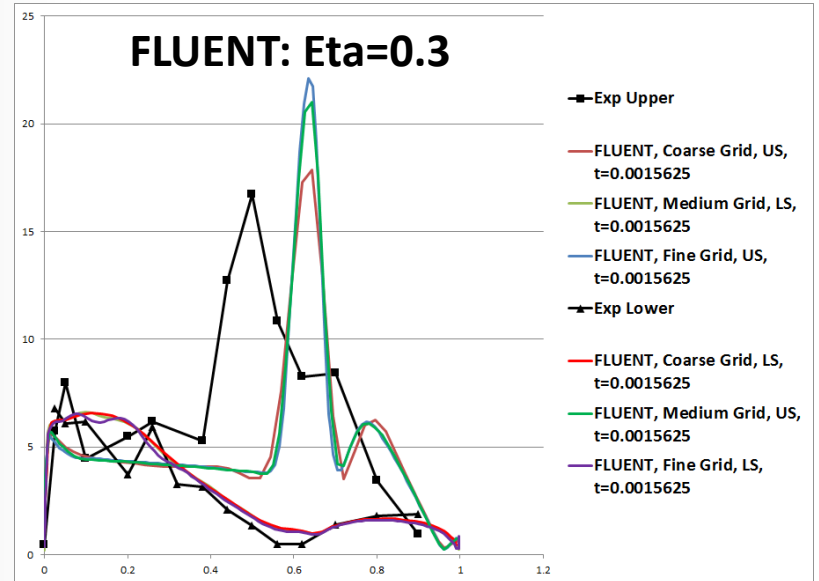
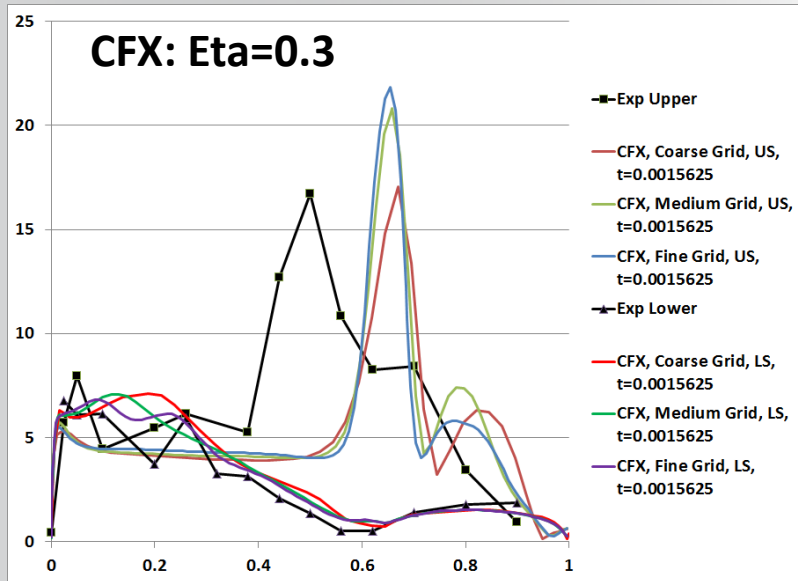
Drag: Temporal Error



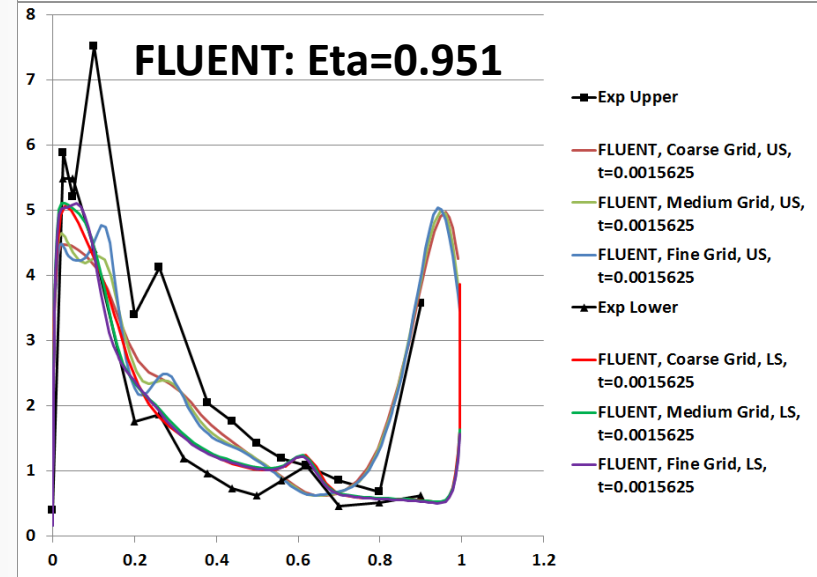
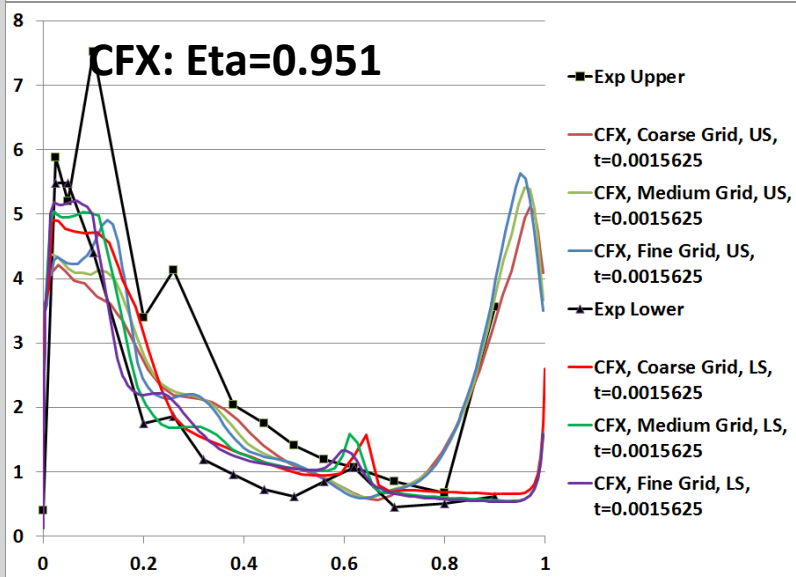
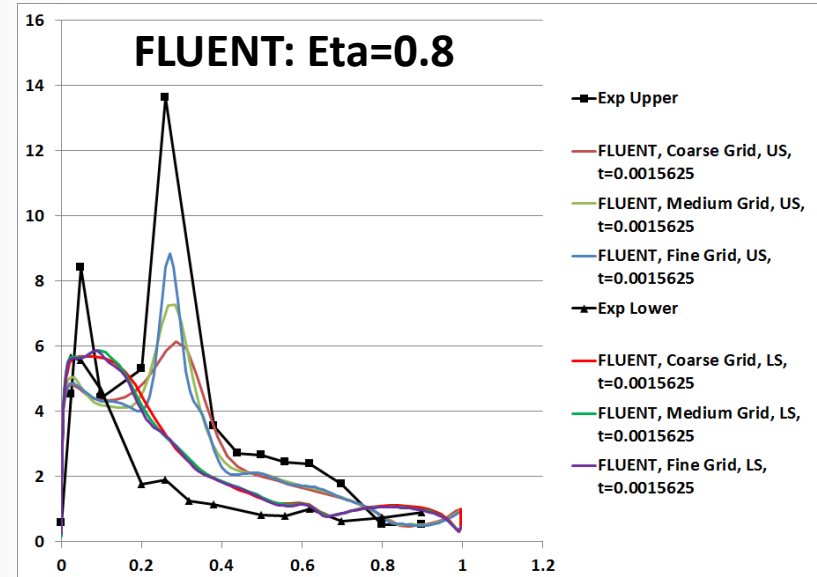
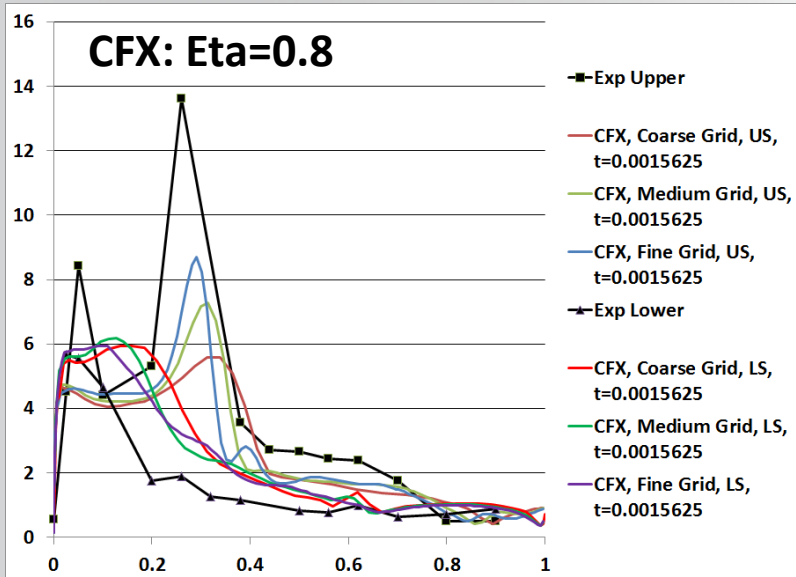
Draft: Spatial Error



RSW, 10 Hz, CP Magnitude



RSW, 10 Hz, CP Magnitude



Summary & Outlook

- **ANSYS CFD calculation of a forced oscillation pitching motion of a Rectangular Supercritical Wing**
- **Detailed quality assurance of numerical errors**
 - **Iteration error**
 - **Discretization error (Spatial and temporal)**
- **Discrepancies to experimental data at the upper surface close to the splitter plate**

- **Systematical error**
 - **Model splitter plate, tunnel wall, incoming bl**
- **Model error**
 - **Run different turbulence models**