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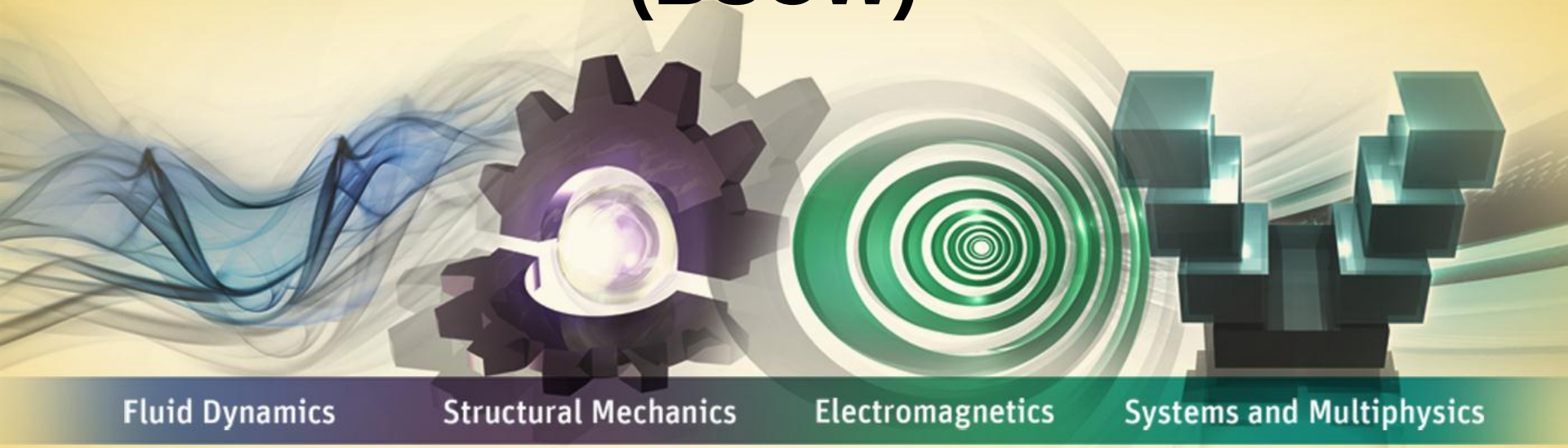
Benchmark Supercritical Wing (BSCW)

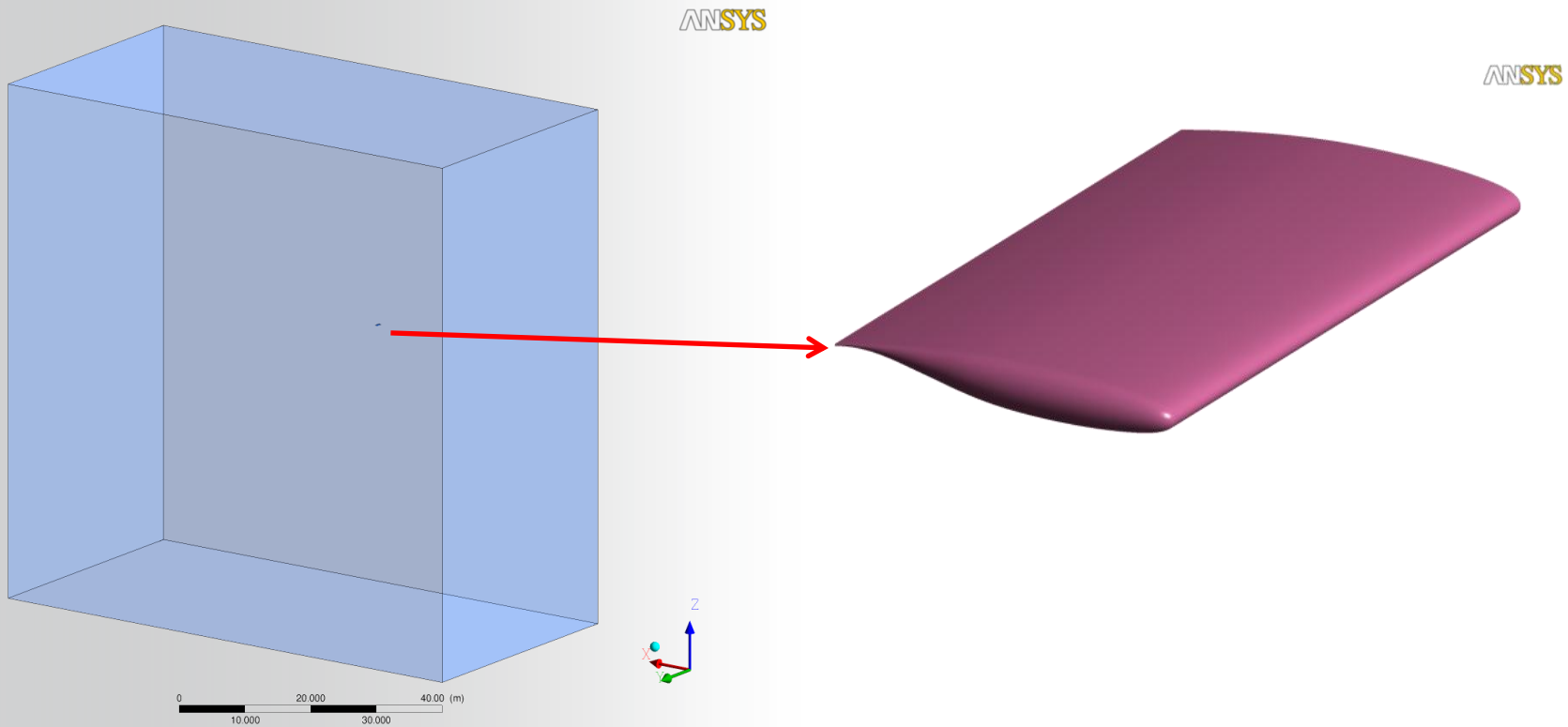


Angela Lestari, Thorsten Hansen

ANSYS

Computational Domain

- **Cref = 16.0 inches (406.4 mm)**
- **100 * Cref in all directions**



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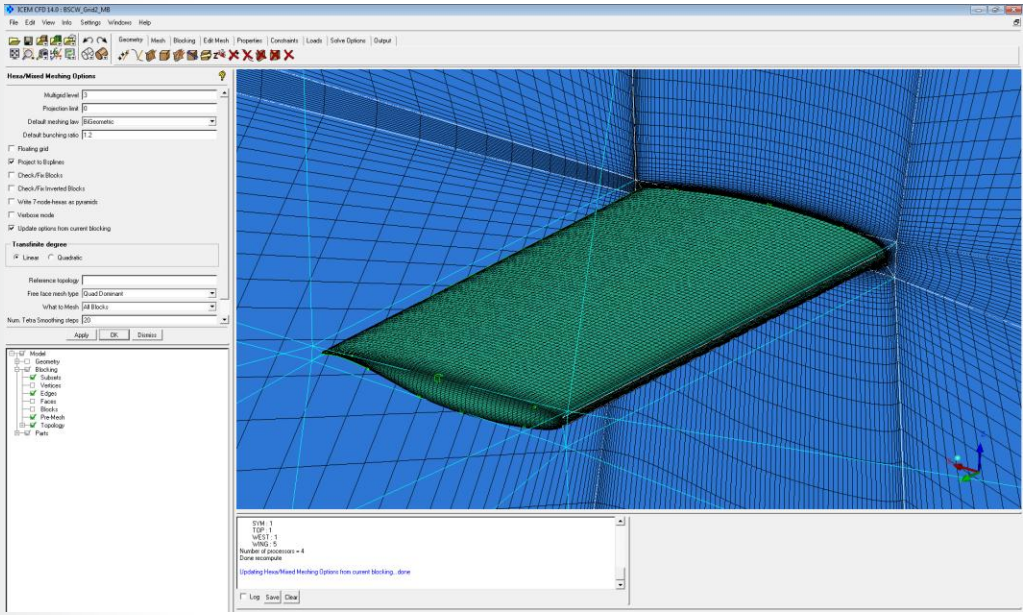
Grid Information

- ANSYS ICEM CFD 14
- Hexahedral elements
- Scalable grids
  - Consistent mesh quality upon grid refinement
- Multigrid
  - levels = 3



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Grid Information

	Grid 1	Grid 2	Grid 3
Number of nodes	1,488,809	5,025,665	13,926,249
Number of elements	1,448,960	4,935,680	13,747,200
Minimum grid angle	31.41°	32.43°	29.07°
Maximum aspect ratio	23,250	19,356	16,387
First grid node @ Wall, inch	0.000094” ($y^+ = 0.62$)	0.000063” ($y^+ = 0.41$)	0.000042” ($y^+ = 0.26$)

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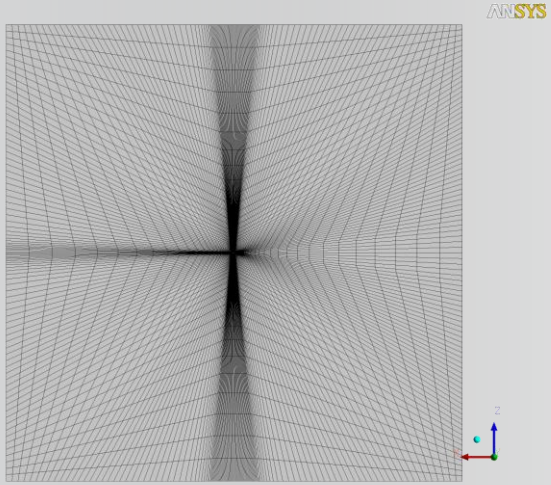
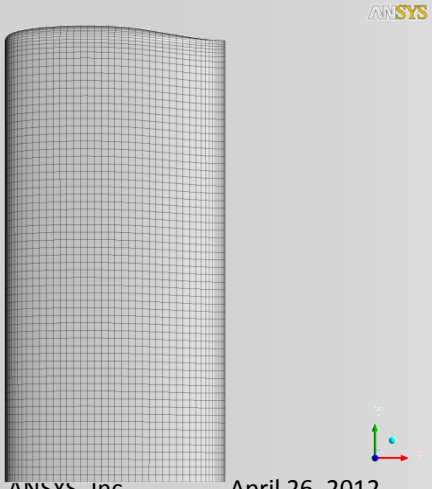
Grid Information

Grid 1





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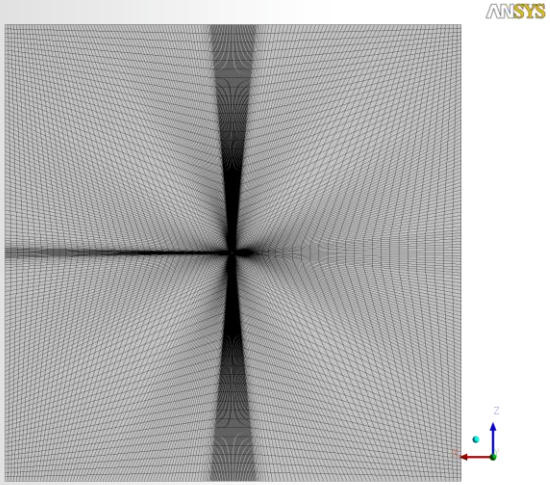

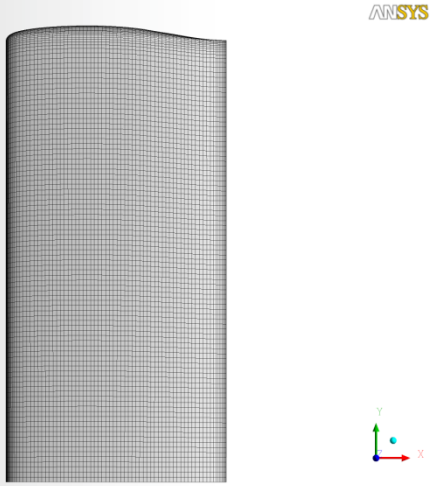

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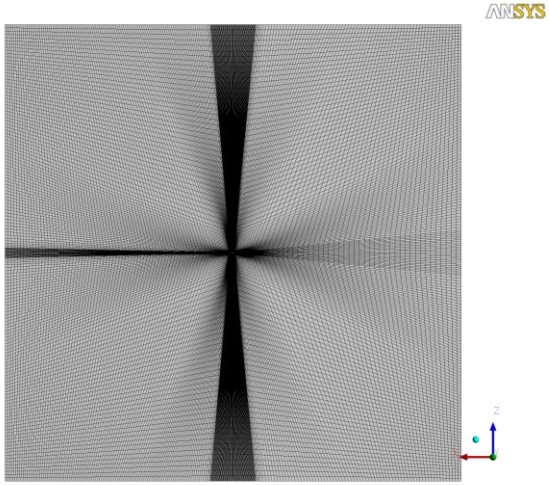

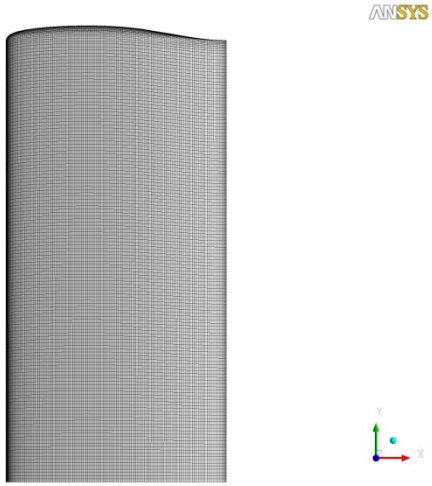

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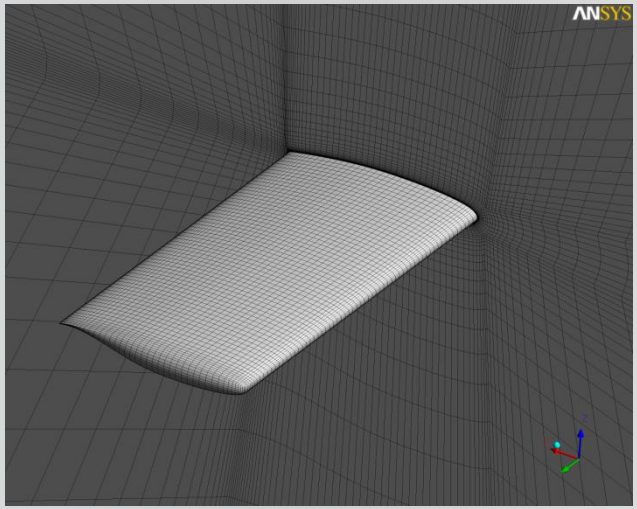
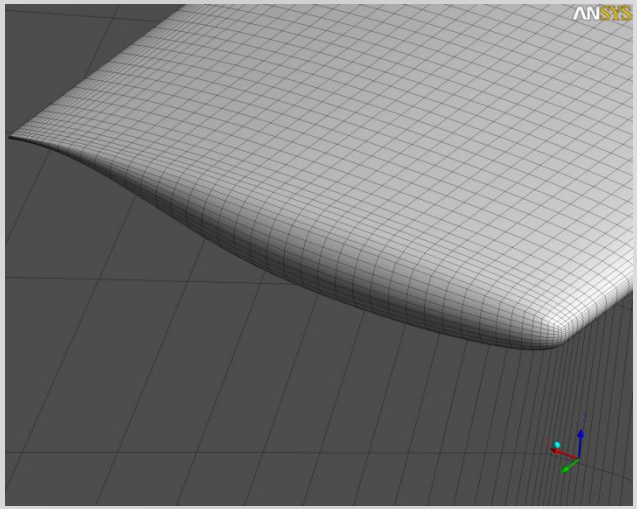
Grid Information

Grid 1





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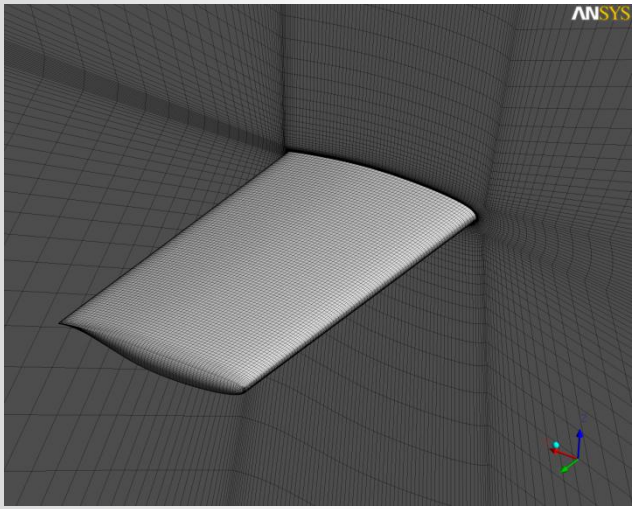

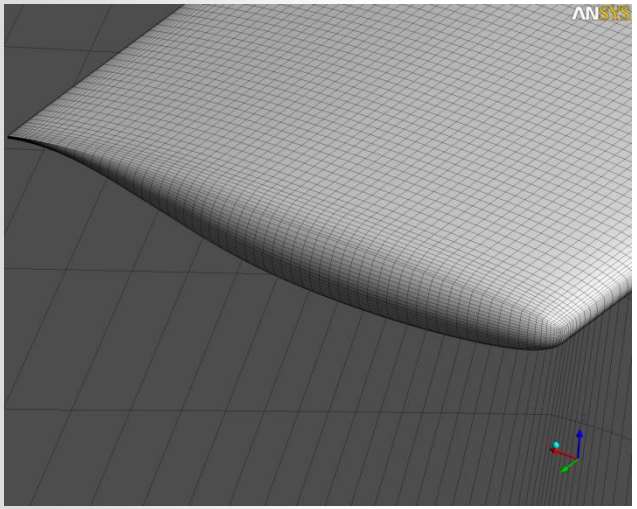

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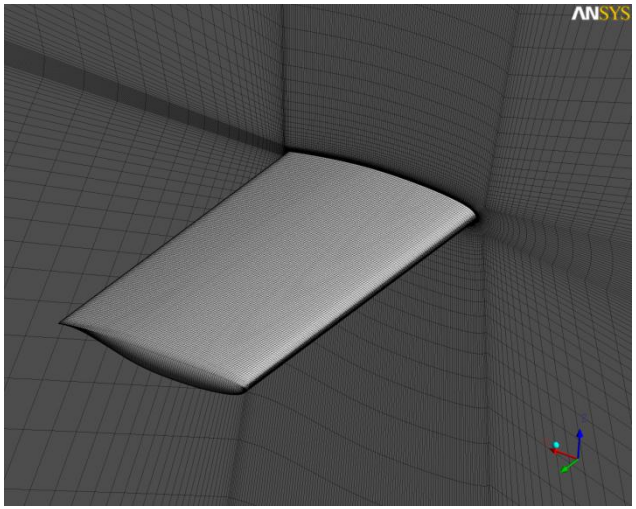
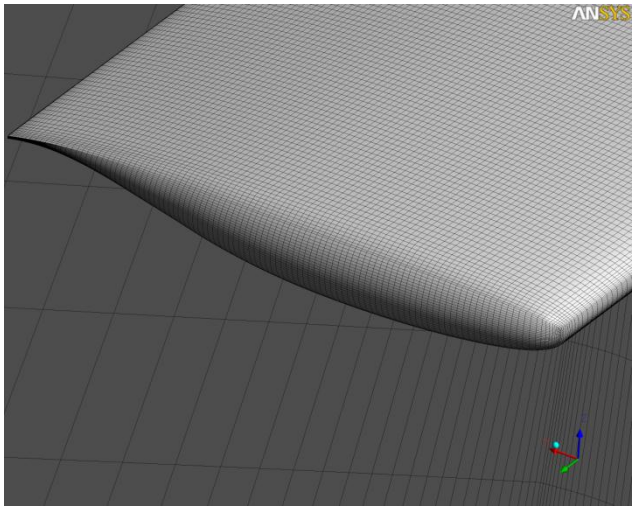
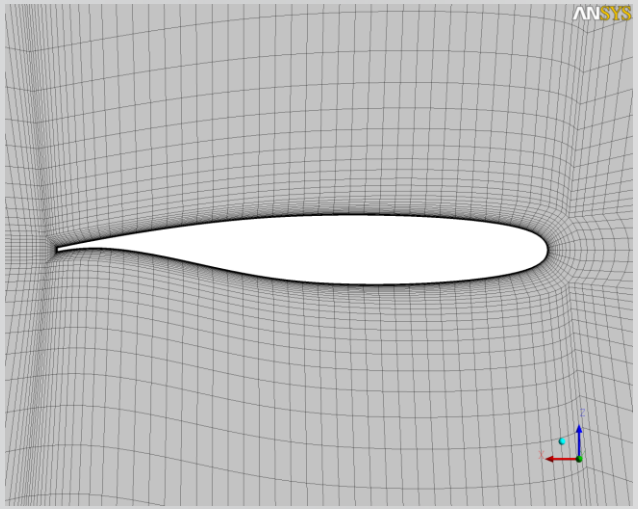
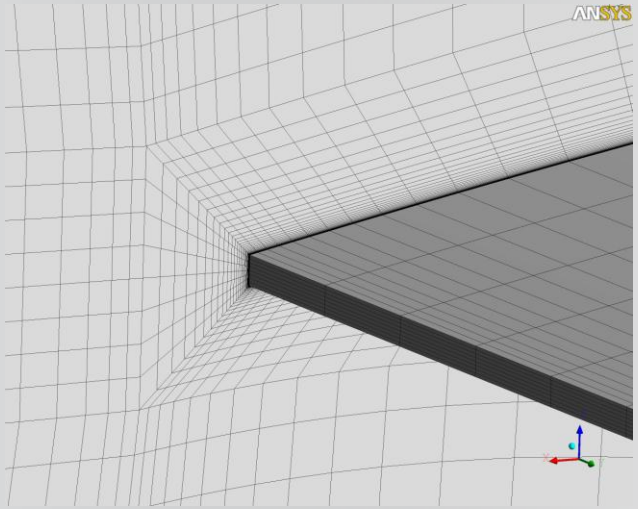




Grid Information

Grid 1





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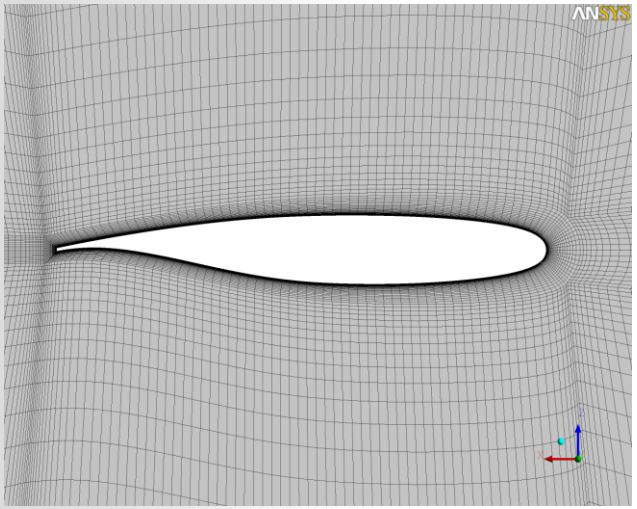

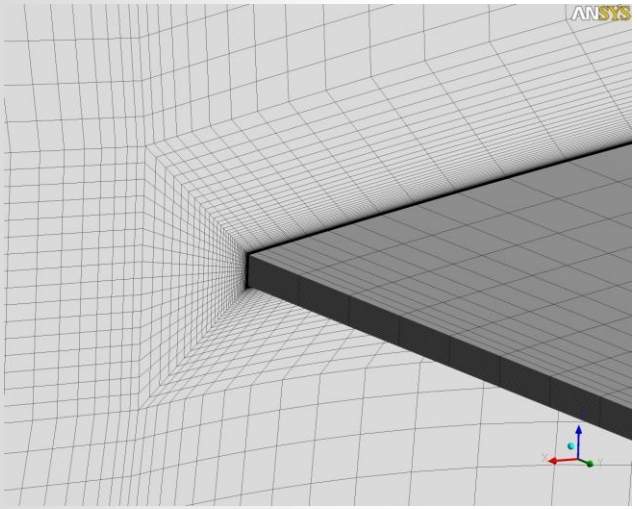

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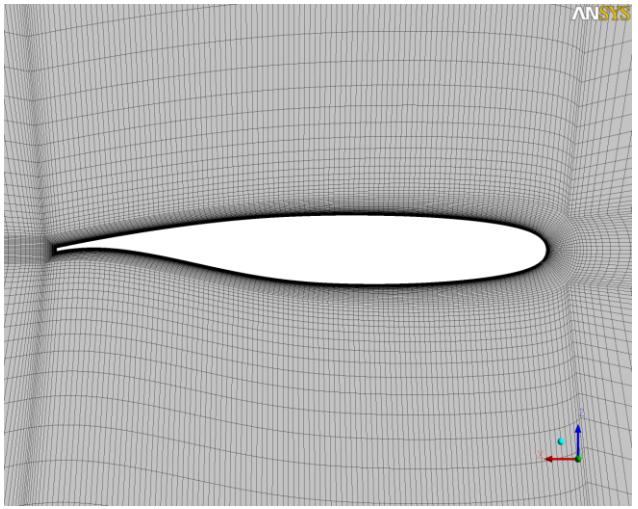
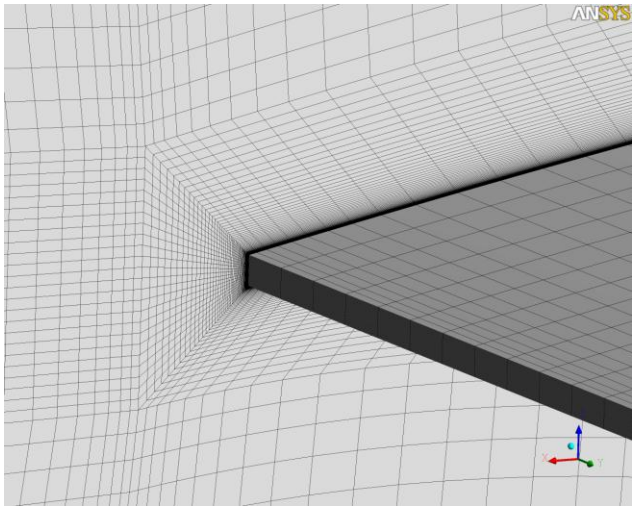
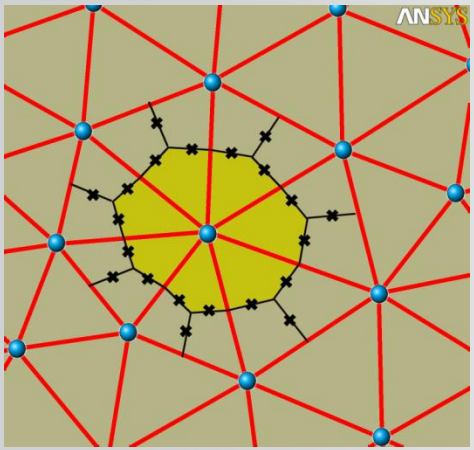


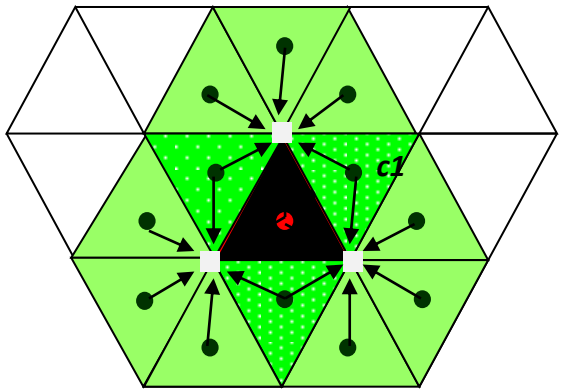


Numerical Method @ ANSYS CFD

- 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



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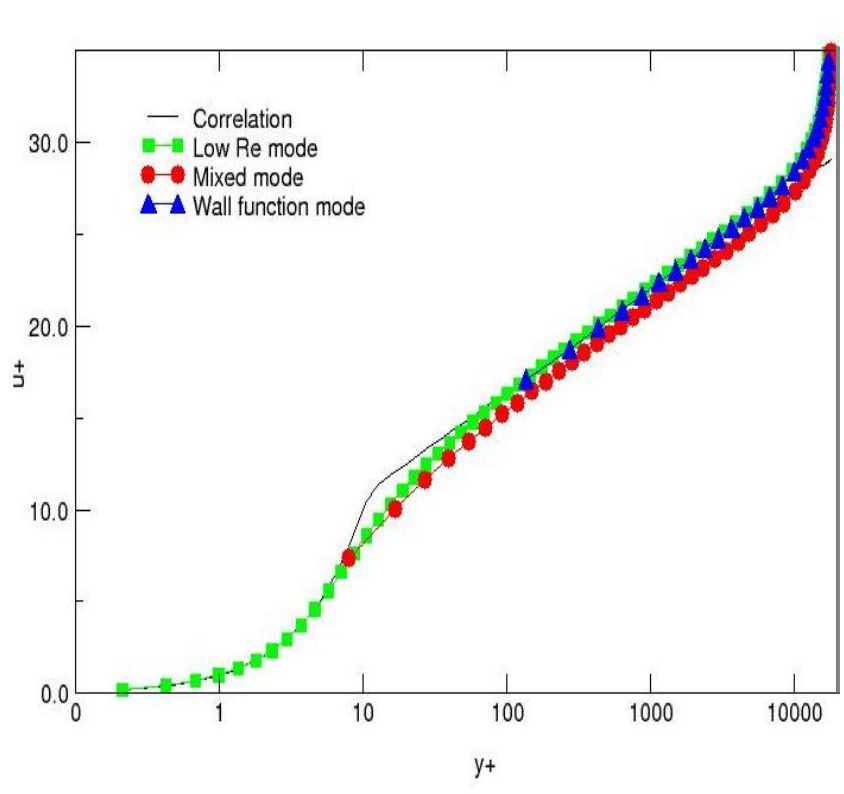
Mathematical Model

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



Automatic Wall Treatment

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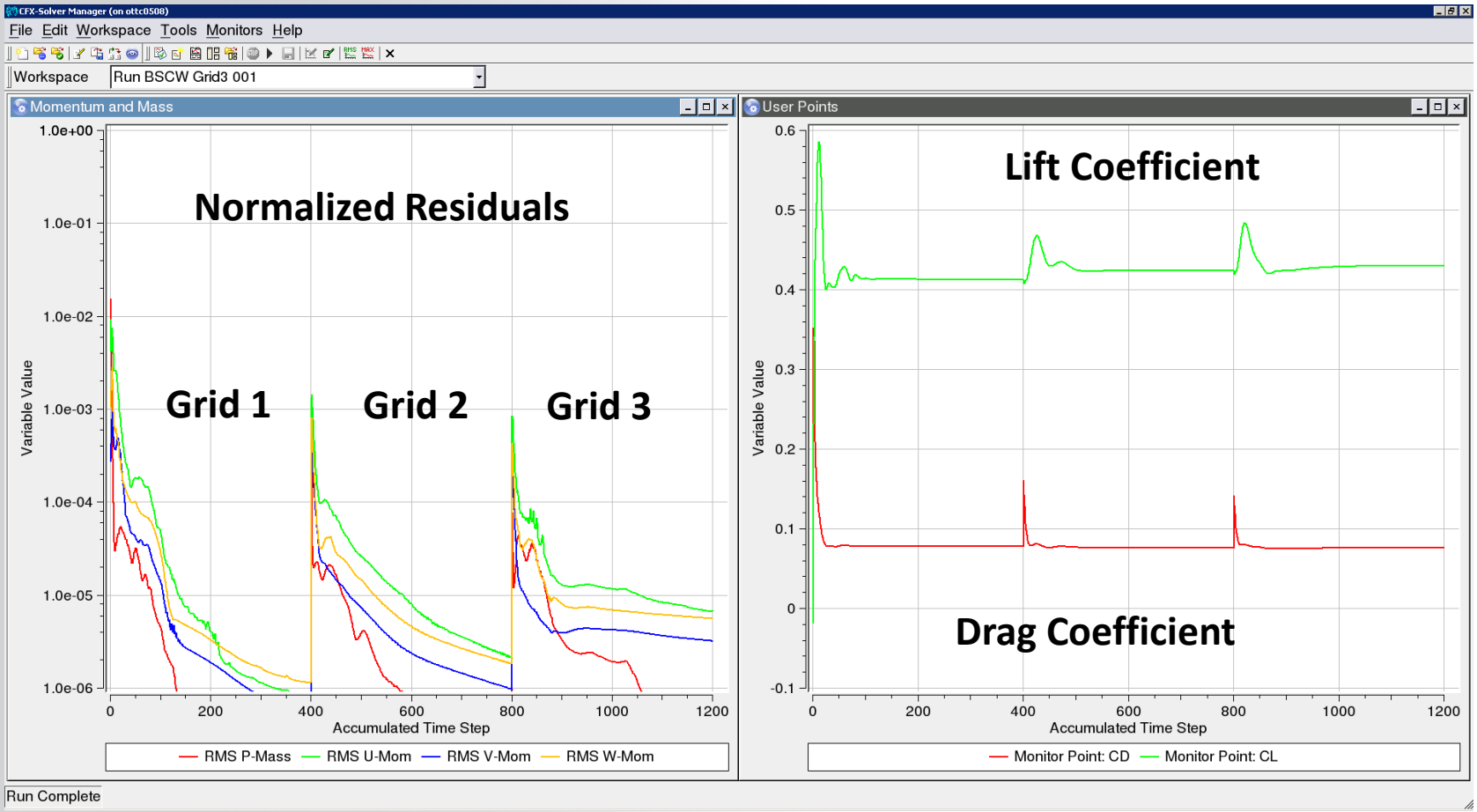
CFX Solver, Steady-State



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CFX Solver, Steady-State

	# of elements, mio	# of iterations	# of CPUs	Total Wall Clock Time	Memory, Gbyte
Grid 1	1,45	400	36 14.5 % Ovlp	0 h 26 min	3.67
Grid 2	4,94	400	36 10.5 % Ovlp	1 h 21 min	7.61
Grid 3	13,75	400	36 7.8 % Ovlp	3 h 46 min	19.97

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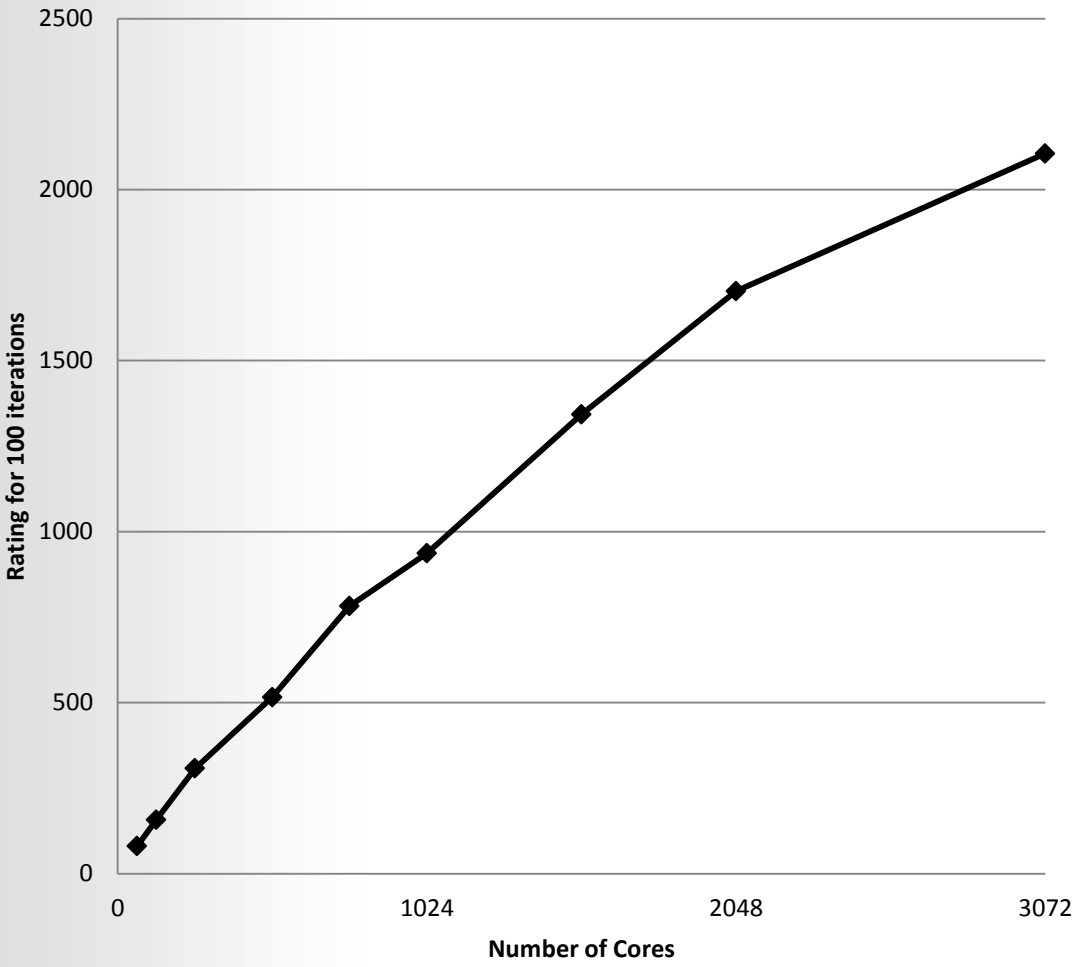
CRAY HPC Performance

- BSCW Grid-3
  - 13.7 million cells
- ANSYS Fluent
- CRAY XE6 Environment
  - Cray MPI
  - Cray "Gemini" Interconnect
  - AMD "Interlagos", 16 core/socket, 2.1GHz



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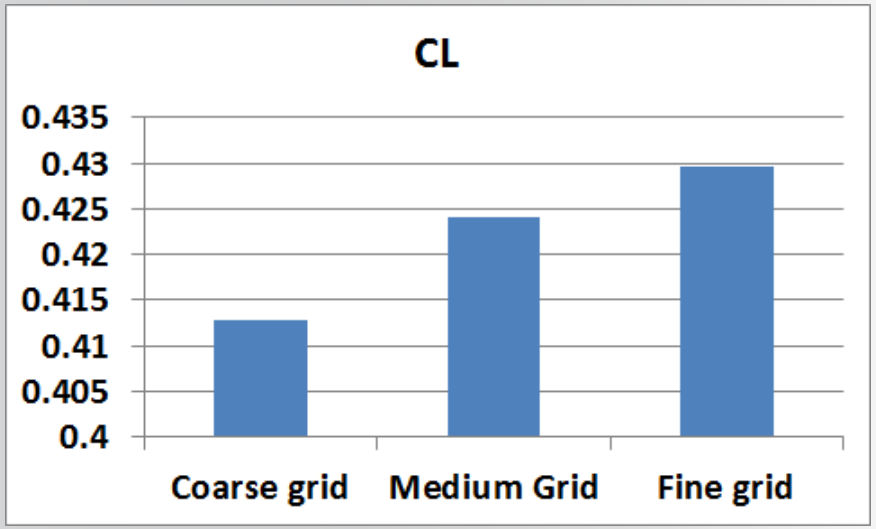
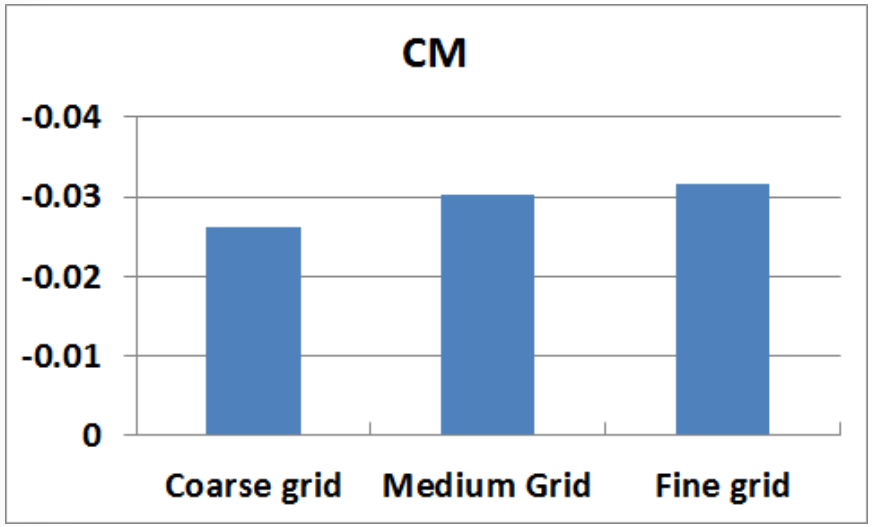
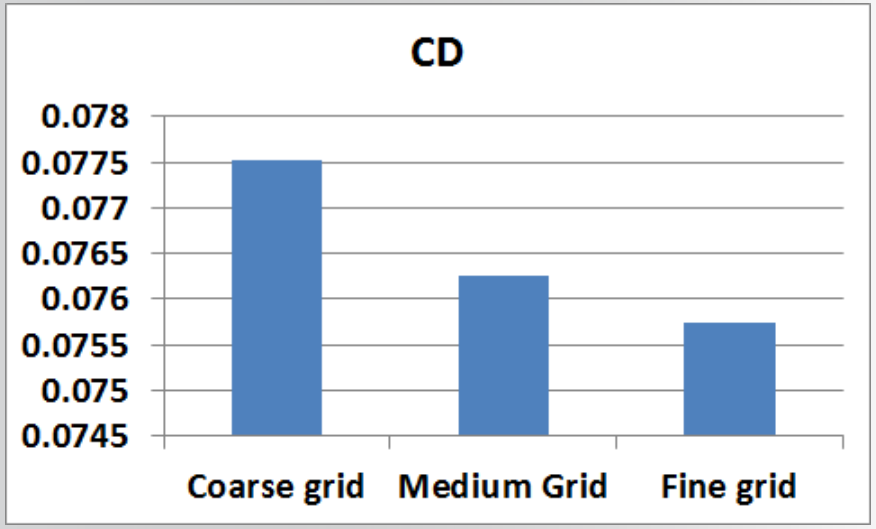
ANSYS CFX: Lift, Moment, Drag







	CL	CM	CD
Grid 1	0.41277 (3.94 %)	-0.02630 (16.86 %)	0.07752 (2.34 %)
Grid 2	0.42417 (1.29 %)	-0.03020 (4.55 %)	0.07625 (0.67 %)
Grid 3	0.42972 -	-0.03164 -	0.07574 -

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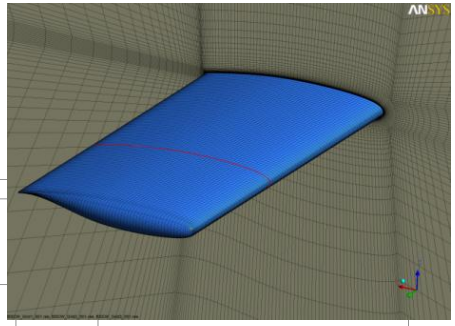
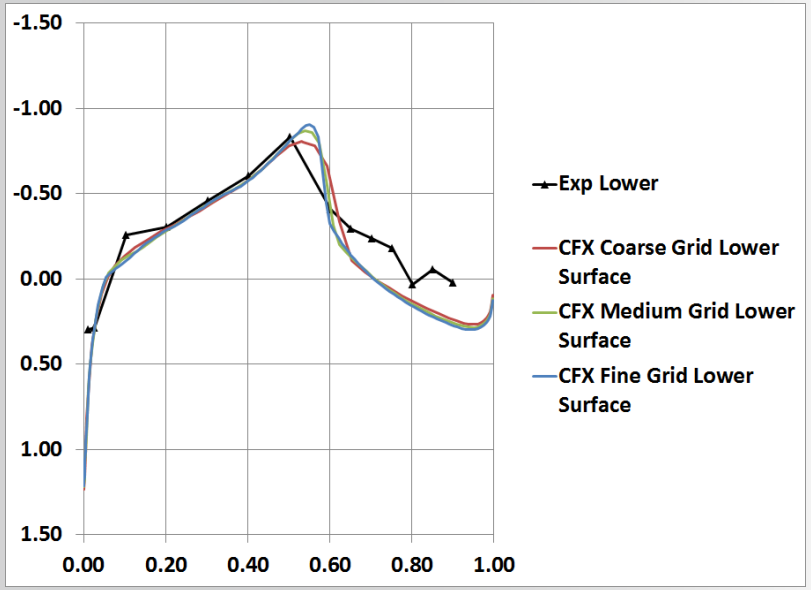
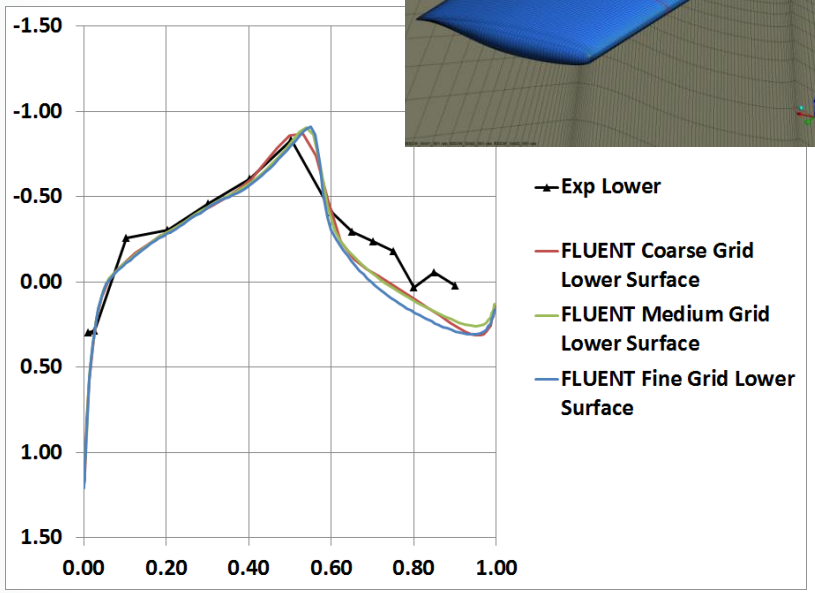
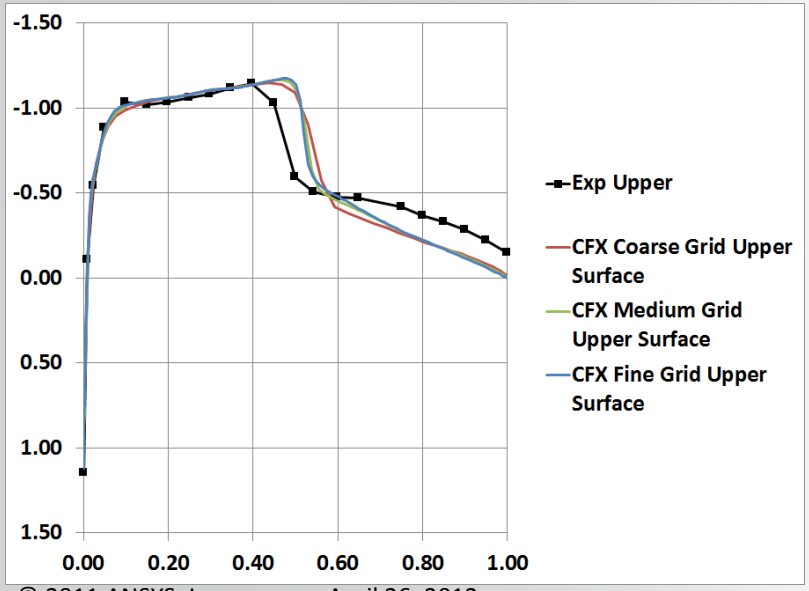
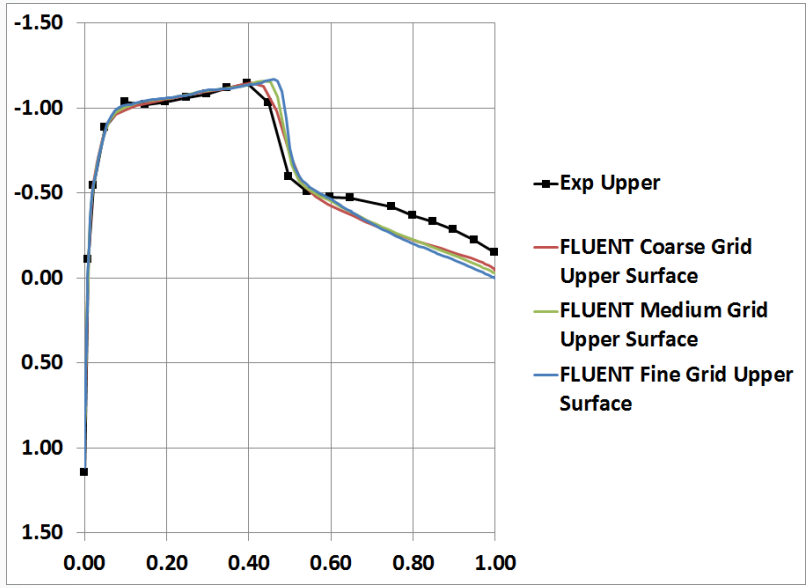
BSCW, CP @ Eta = 60 %











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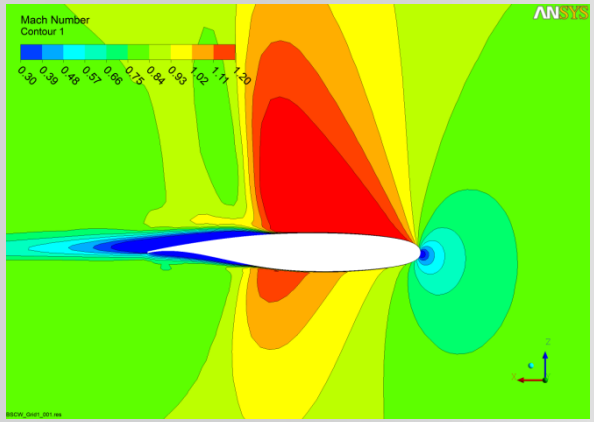
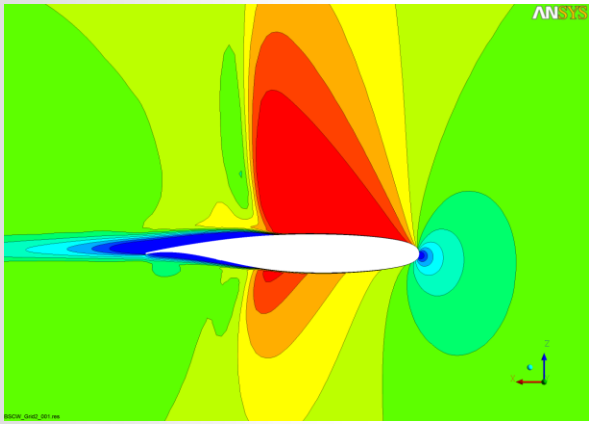
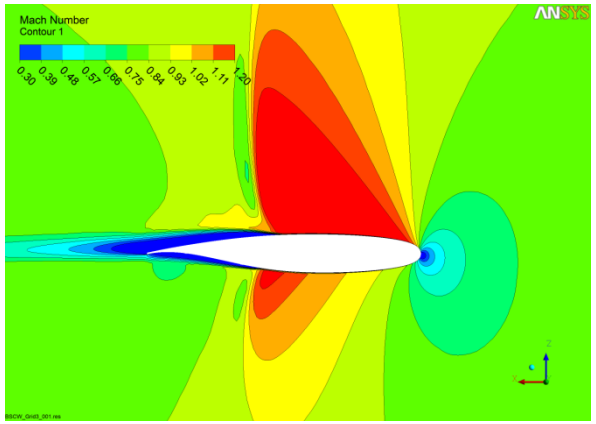
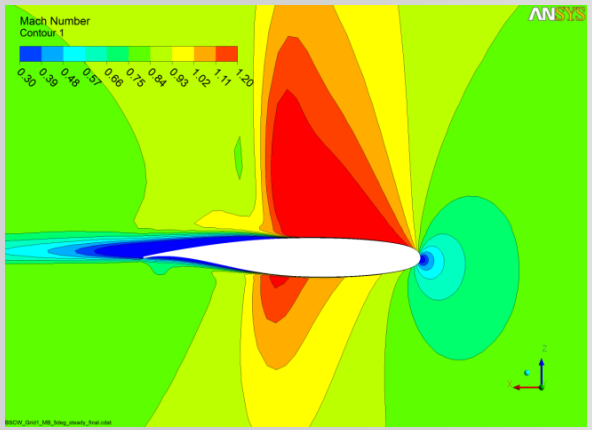
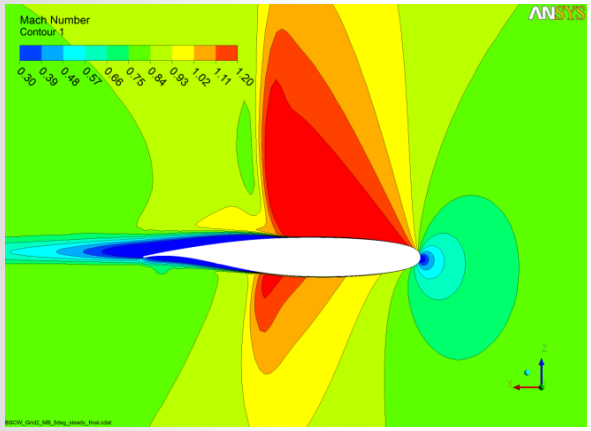
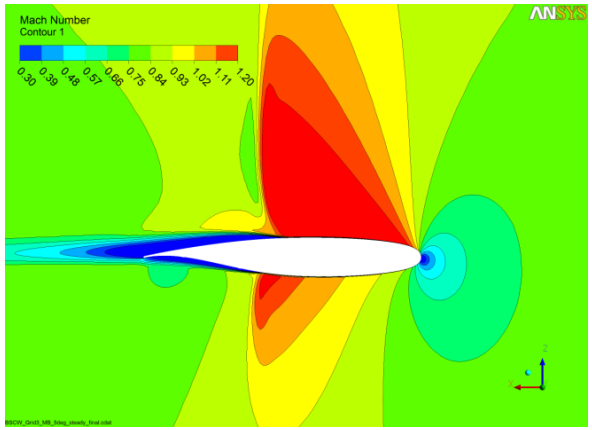
BSCW, Mach Number @ Eta = 60 %

	Grid1	Grid2	Grid 3
CFX			
FLUENT			

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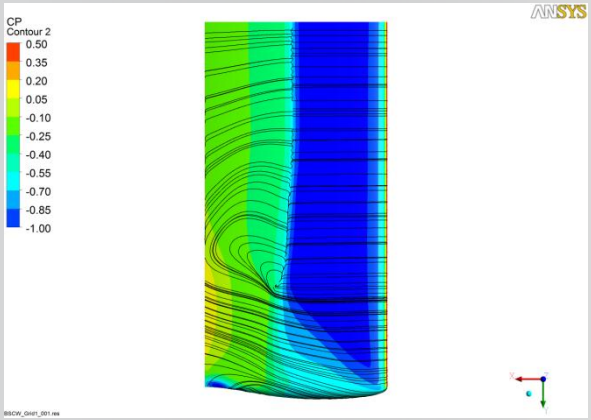
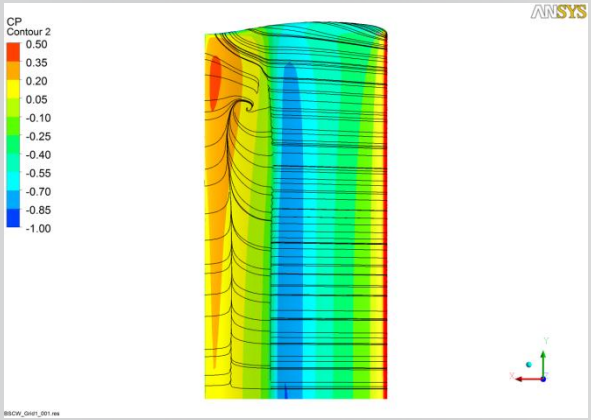
BSCW, CP @ Wing Surface, CFX

Grid1





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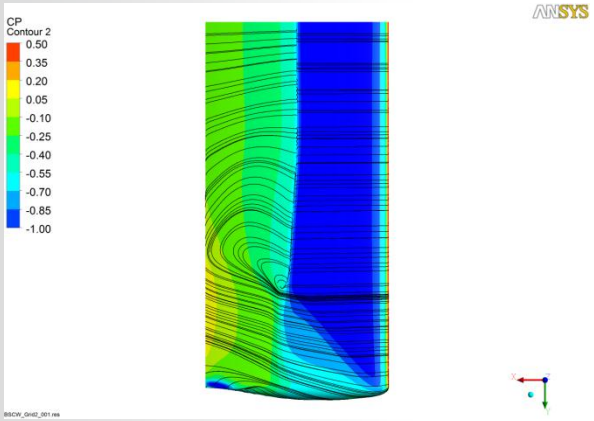
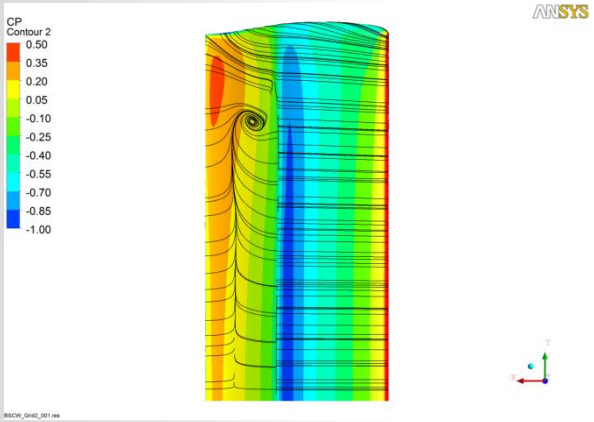
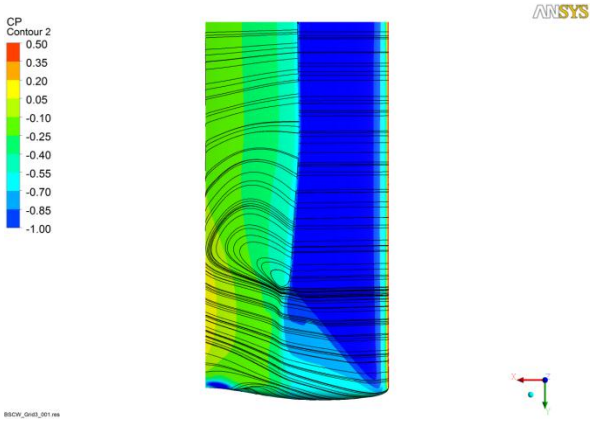
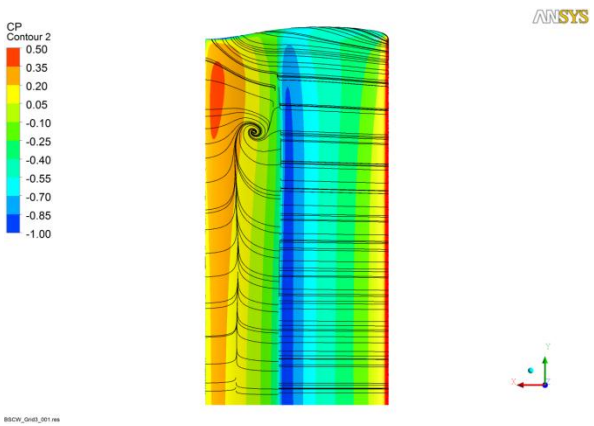




Grid 3





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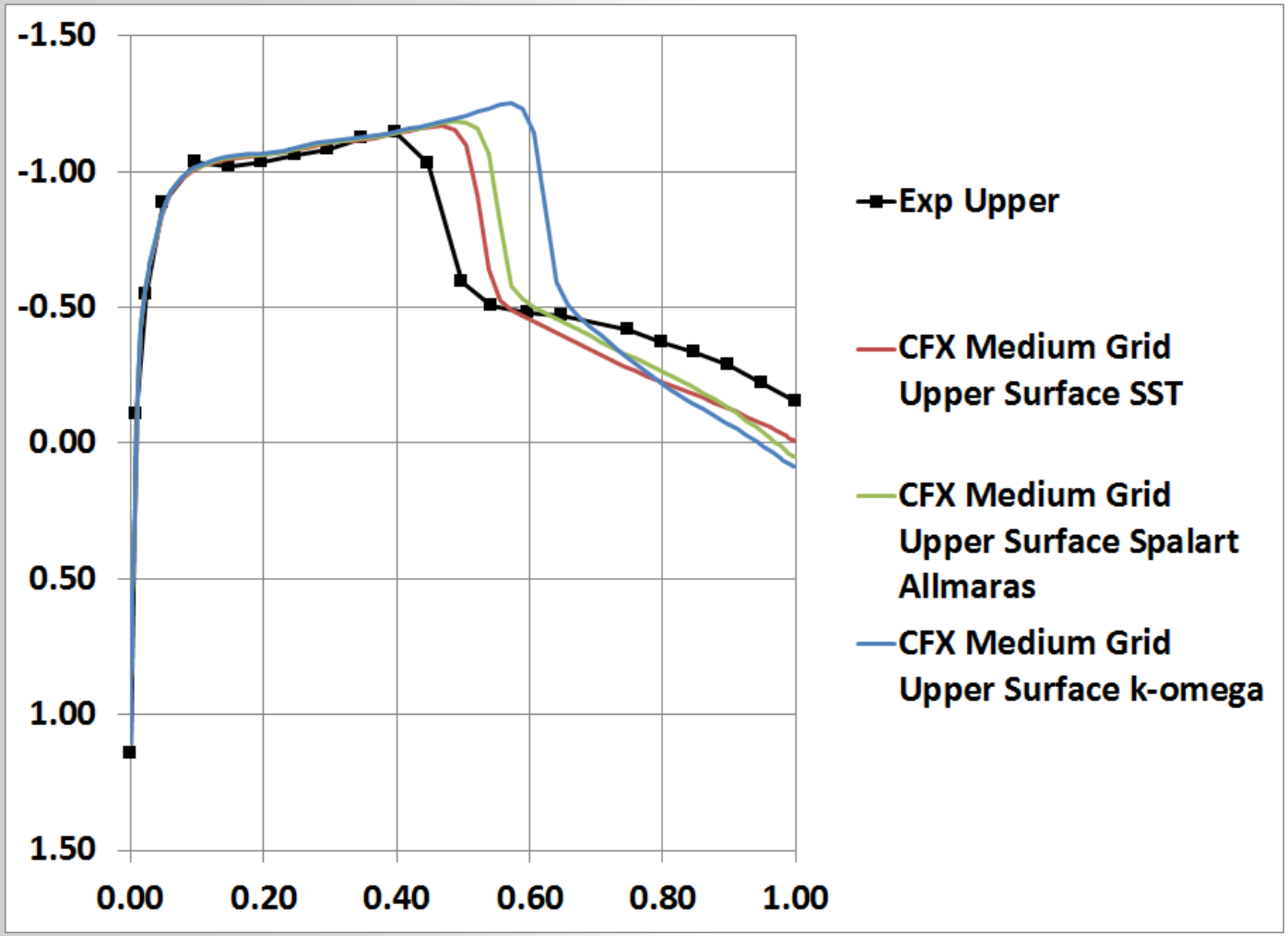
Turbulence Model Error Estimation



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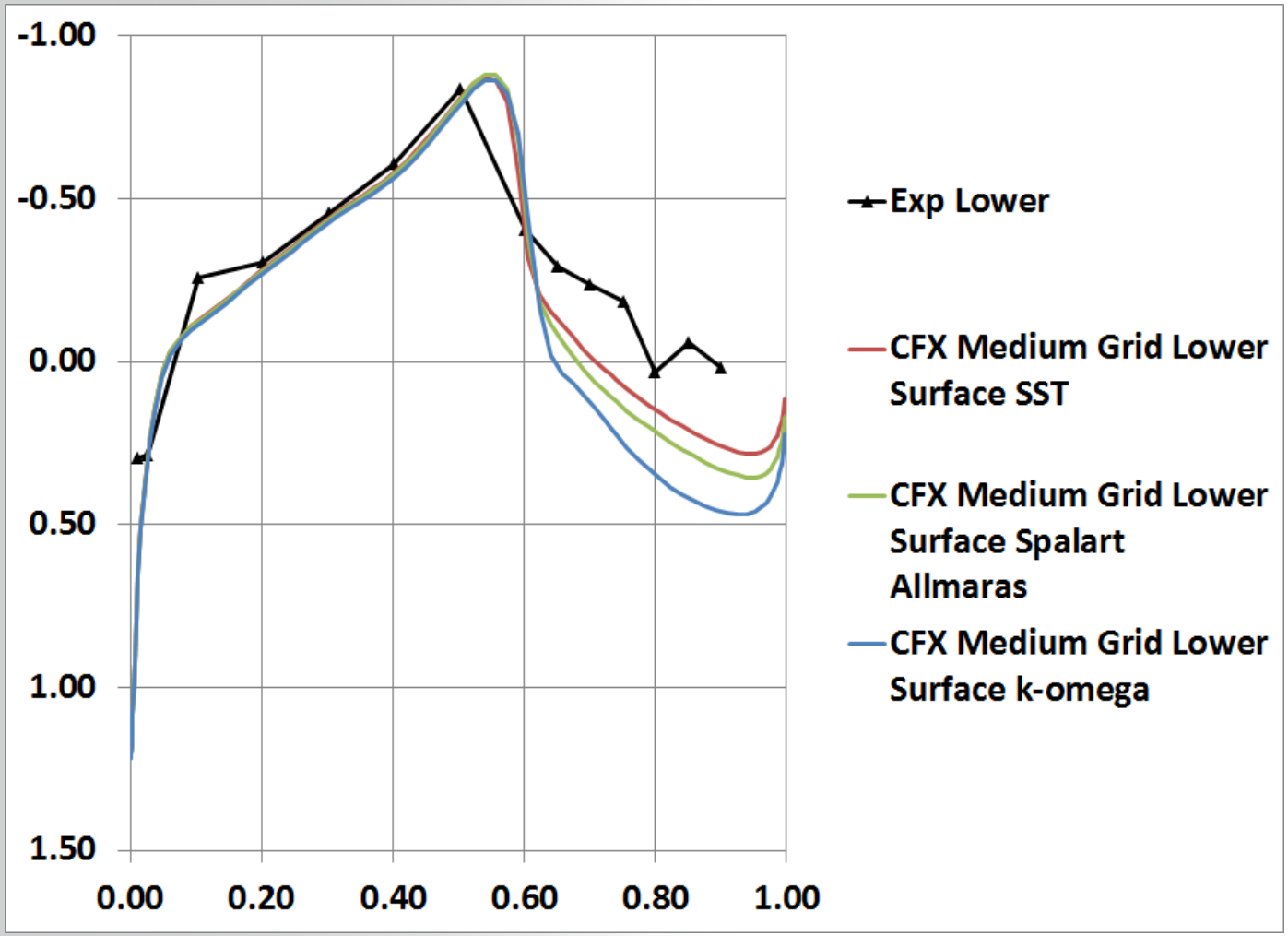
Turbulence Model Error Estimation



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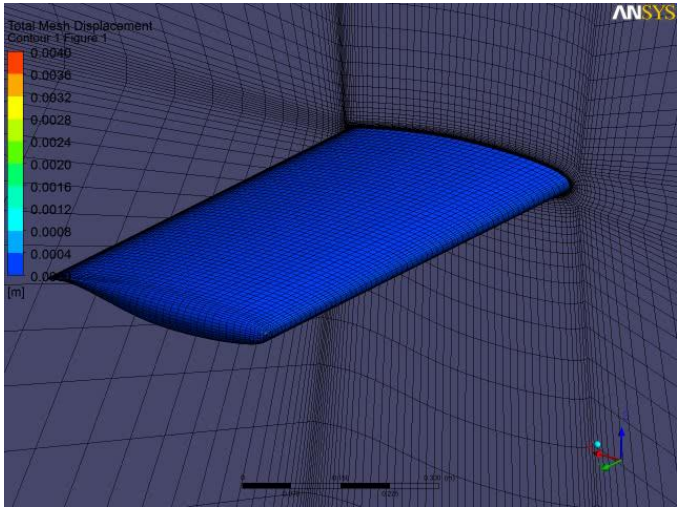
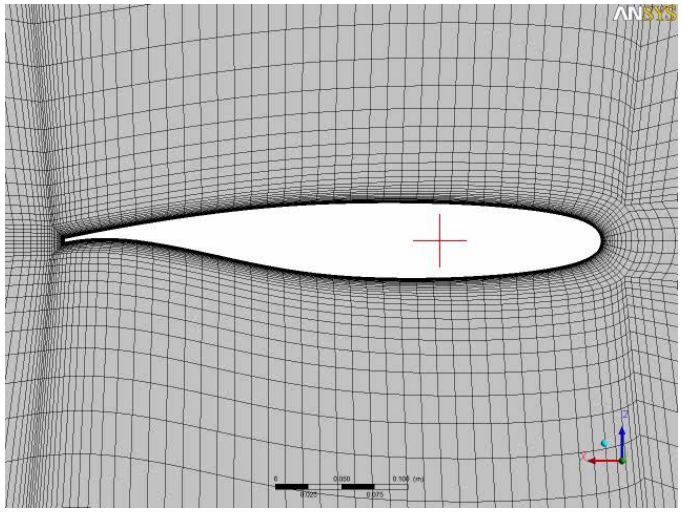
Unsteady-State Calculation

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





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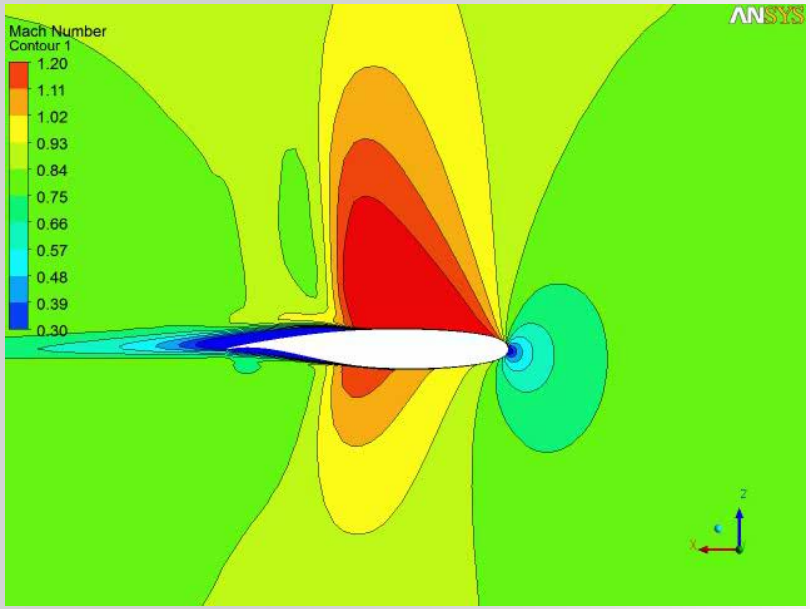
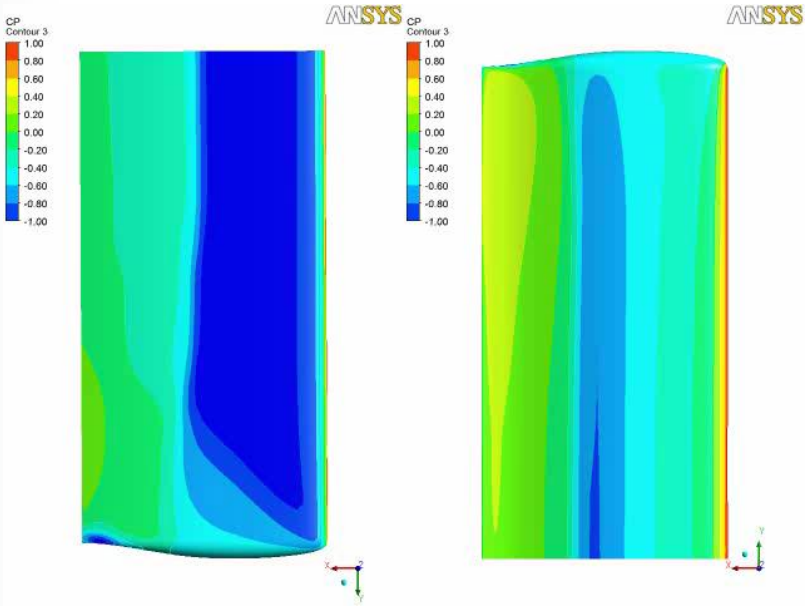
Animation

Mach Number @ eta = 60 %



CP @ Lower & Upper Surface



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Numerical Information

- 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

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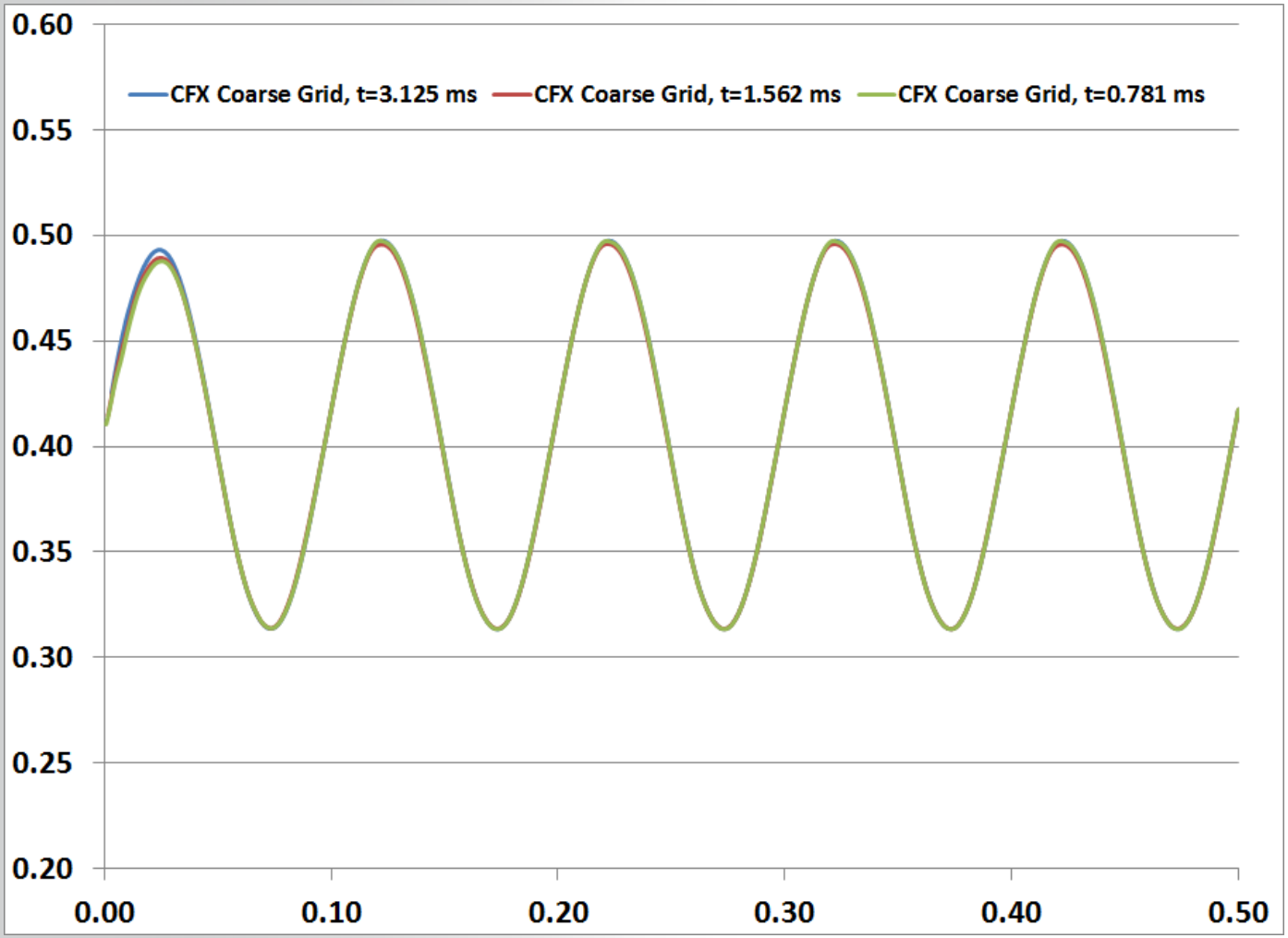
Lift Coefficient, 10 Hz, Temporal Error



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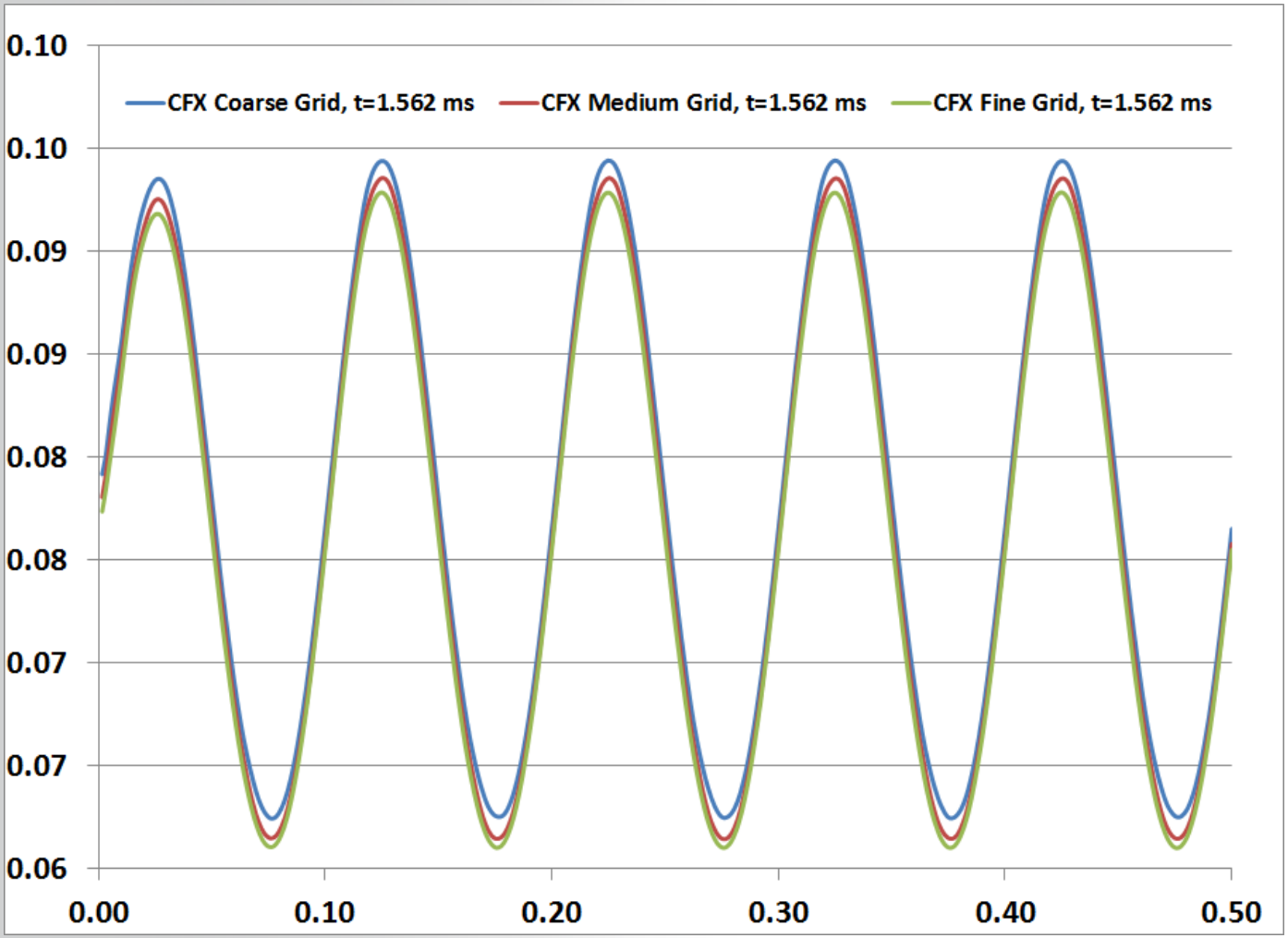
Drag Coefficient, Spatial Error



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Frequency Response Function

- **Fourier Series is written in form of sines and cosines**

$$x(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(n\omega_0 t) + b_n \sin(nw_0 t)$$

- **where for n > 0:**

$$a_n = \frac{2}{T}\int_{t_0}^{t_0+T} x(t)\cos(nw_0 t)dt,\ b_n \frac{2}{T}\int_{t_0}^{t_0+T} x(t)\sin(nw_0 t)dt$$

- **and where**

$$\omega_0 = \frac{2\pi}{T}, \quad a_0 = \frac{1}{T}\int_{t_0}^{t_0+T} x(t)dt$$

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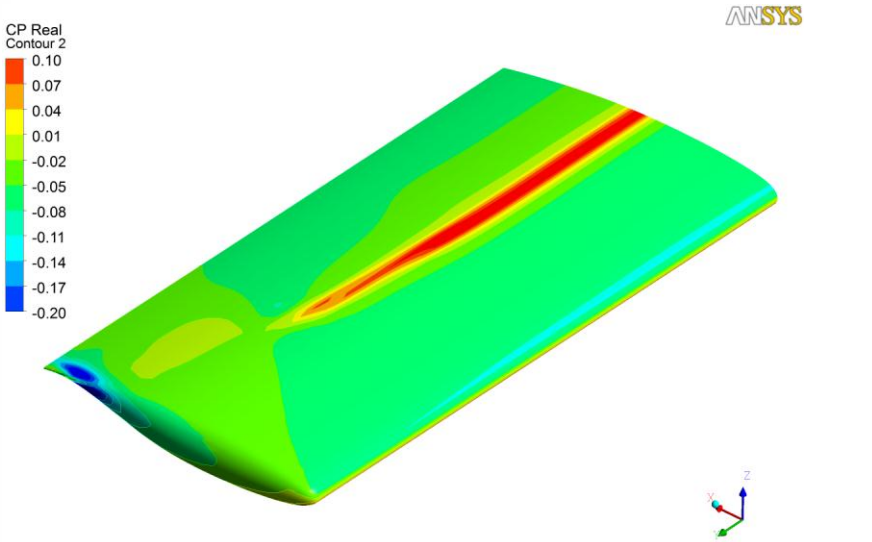
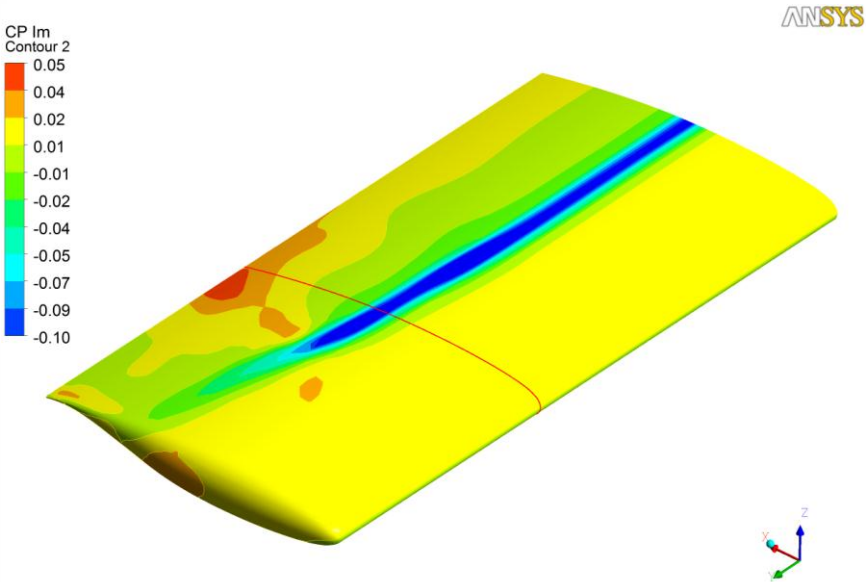
Frequency Response Function

- **Fourier coefficients calculated in CFD solver**

- **CFX**
  - **Additional Variable**
    - **CP Real**
    - **CP Im**
    - **Magnitude = sqrt(CP Real^2+CP Im^2)**
    - **Phase = atan2(CP im/CP Real)**

- **FLUENT**
  - **User Defined Function**
    - **CP Real**
    - **CP Im**
    - **Magnitude = sqrt(CP Real^2+CP Im^2)**
    - **Phase = atan2(CP im/CP Real)**





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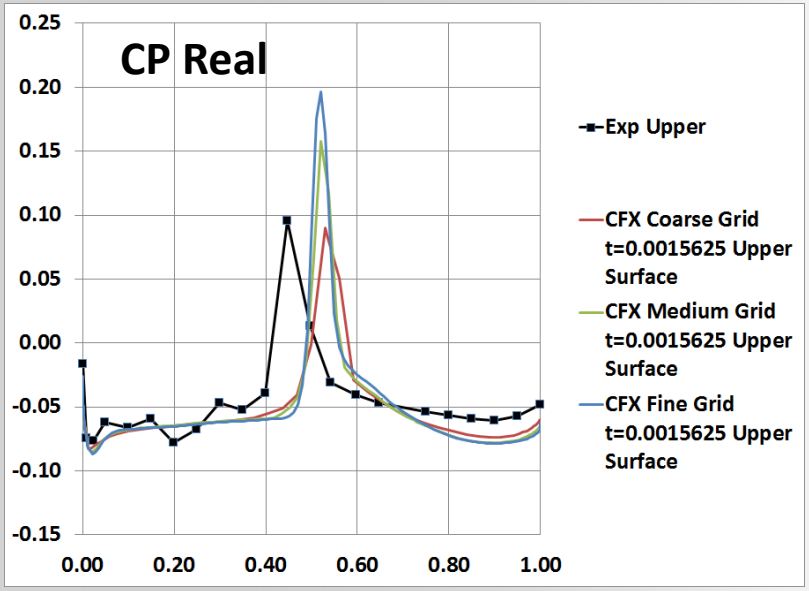
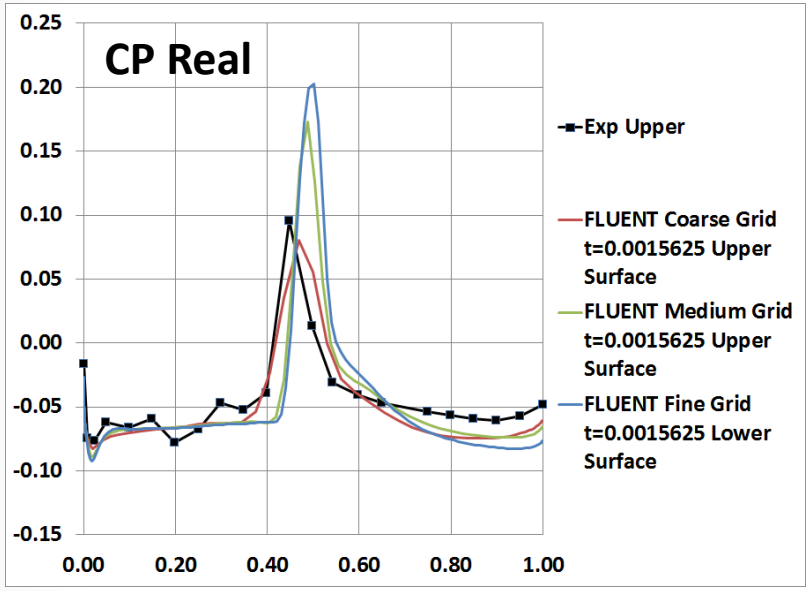
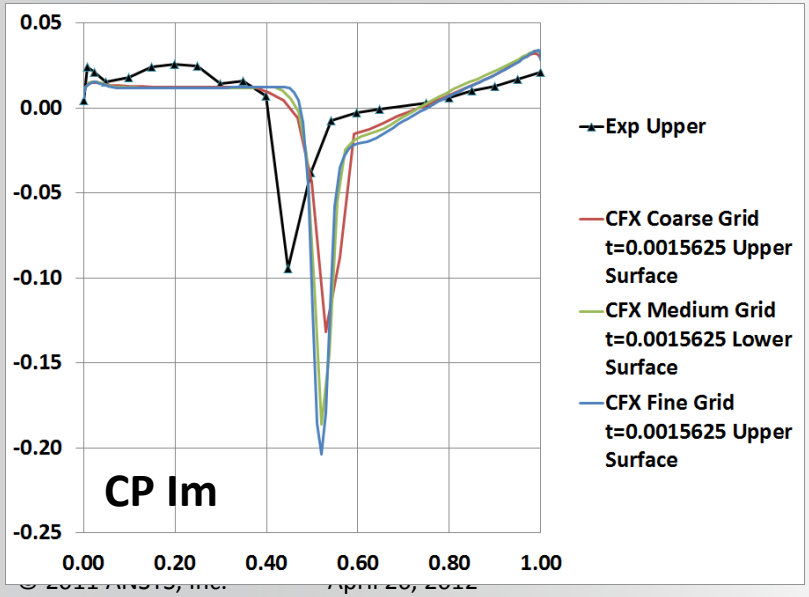
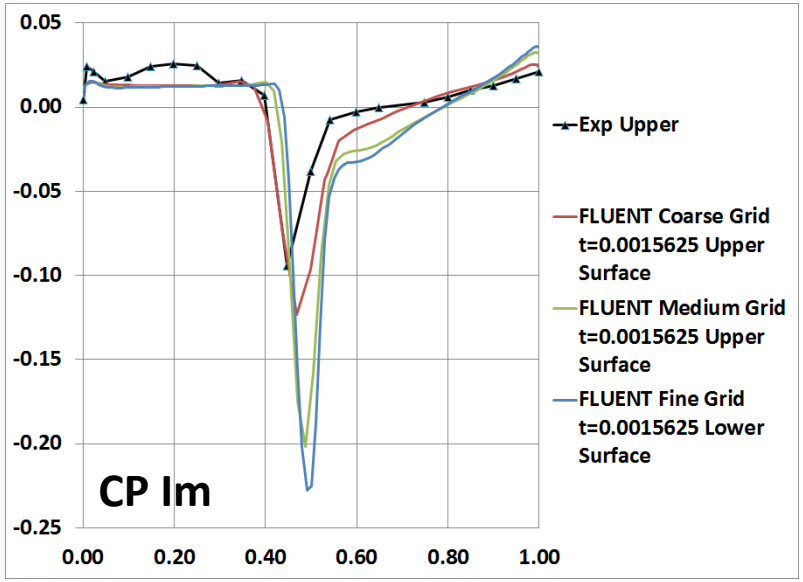
BSCW 10 Hz @ Eta=0.6, Upper









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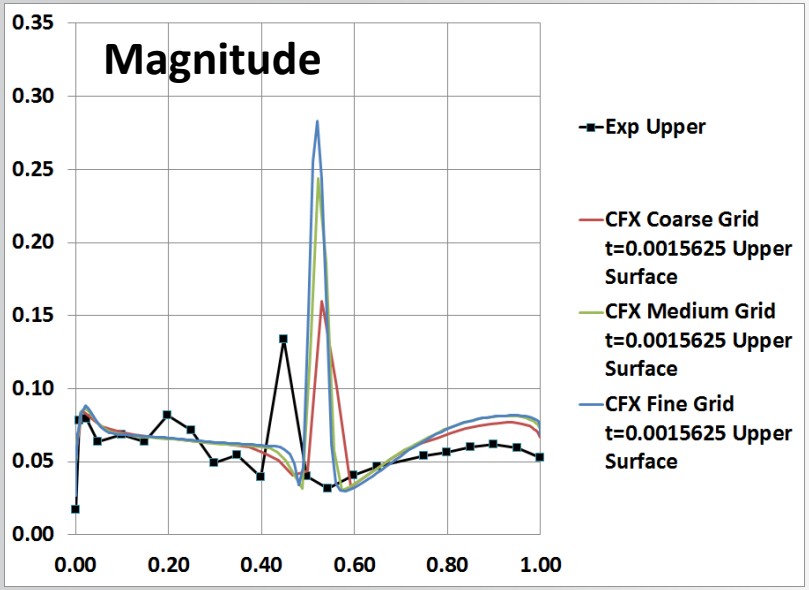
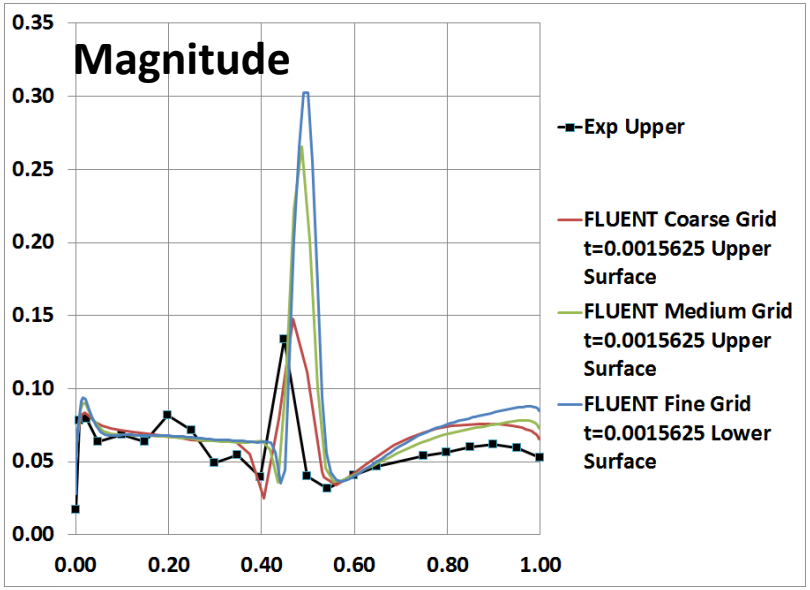
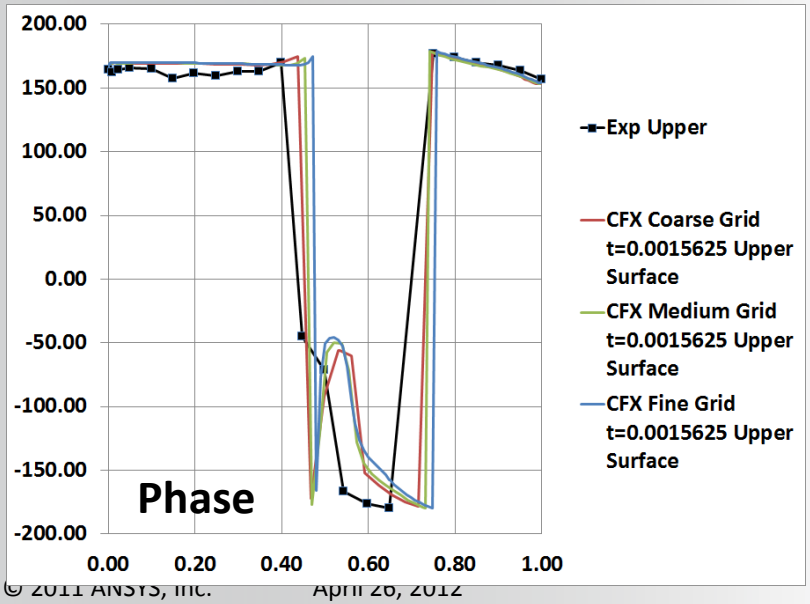
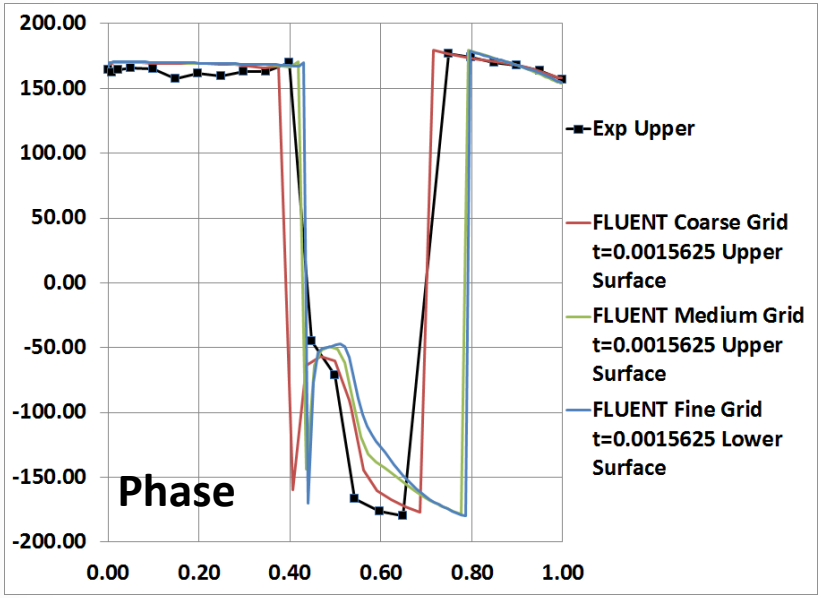
BSCW 10 Hz @ Eta=0.6, Upper









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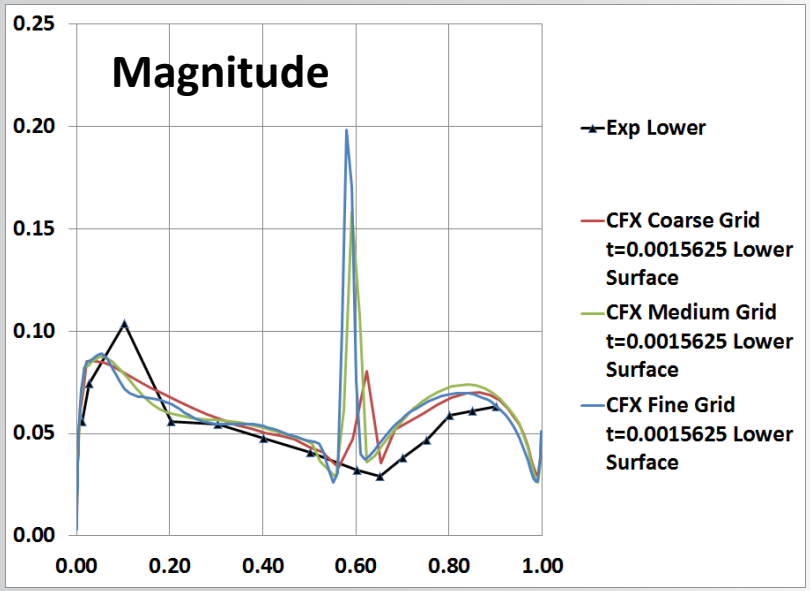
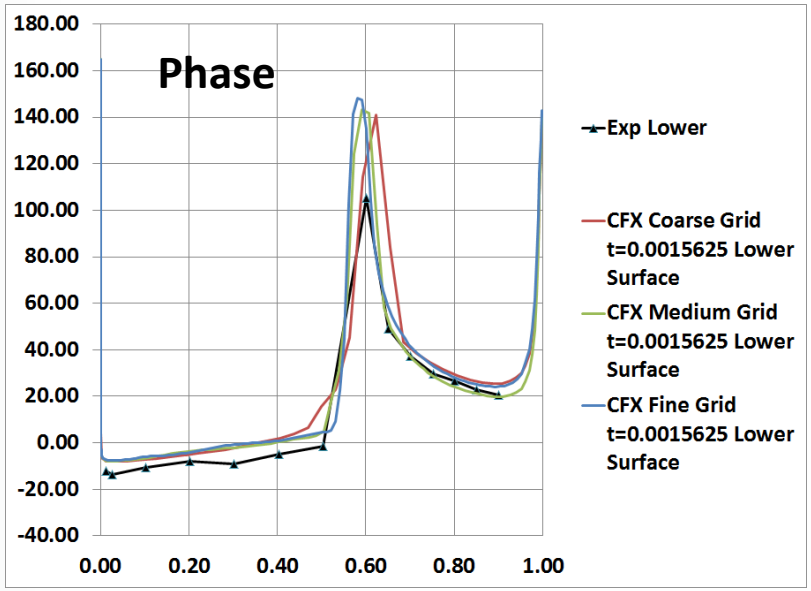
BSCW 10 Hz @ Eta=0.6, Lower





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Summary & Outlook

- ANSYS CFD calculation of a forced oscillation pitching motion of a Supercritica lWing
- Detailed quality assurance of numerical errors
  - Iteration error
  - Discretization error (Spatial and temporal)
  - Model error

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