Evaluation of the Eppler 1210 Airfoil

January 24, 2020

1 Introduction

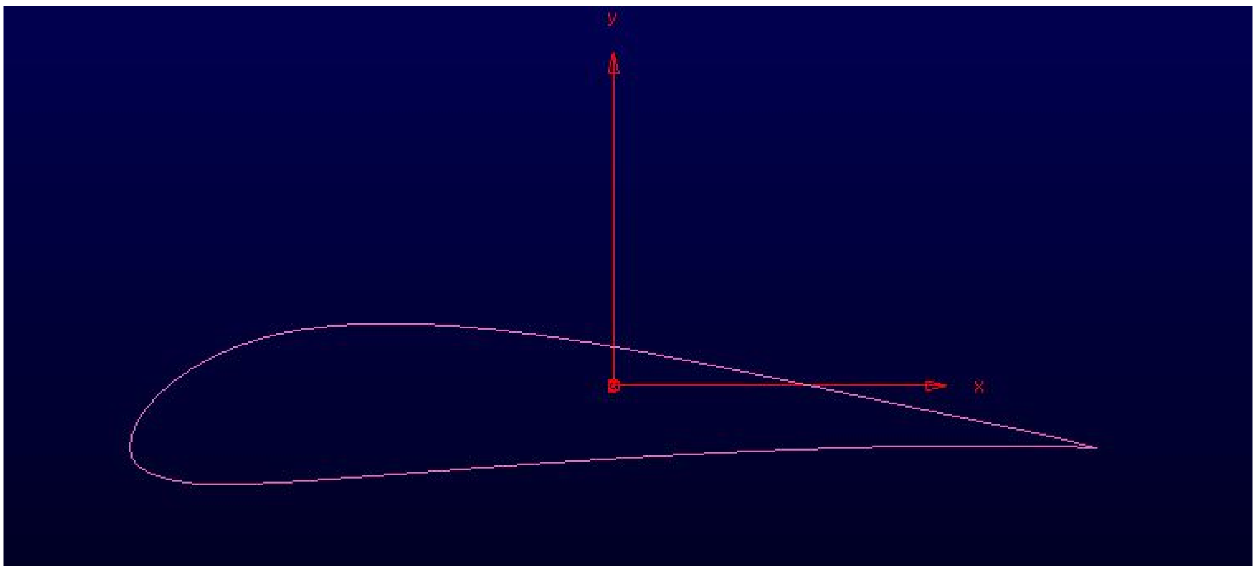


Figure 1: Eppler 1210 Airfoil shown in Pointwise

Table 1: Operating conditions for all cases

Quantity	Value
Pressure	101,325 Pa
Temperature	298 K
Velocity	17.88 ms^{-1}
Viscosity	1.789e-05 $kgm^{-1}s^{-1}$
Re #	1,224,315

Table 2: XFoil Predictions, Re = 1e9, ncrit = 9 (clean wind tunnel)

	Value	AoA
Max L/D	117.1309	8
Max C_L	1.8542	16

2 Methodology

2.1 Screenshots of grid

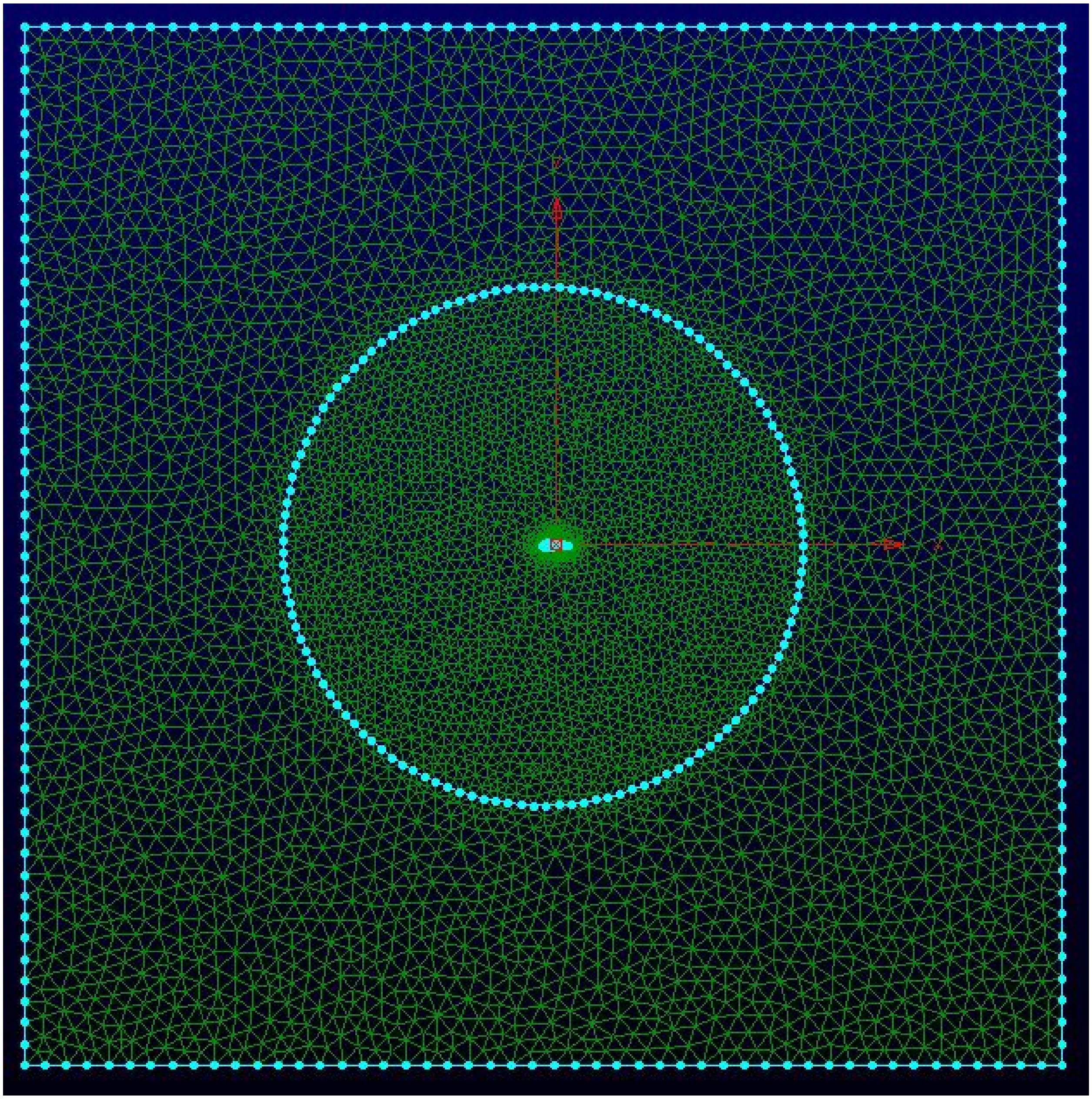


Figure 2: Farfield

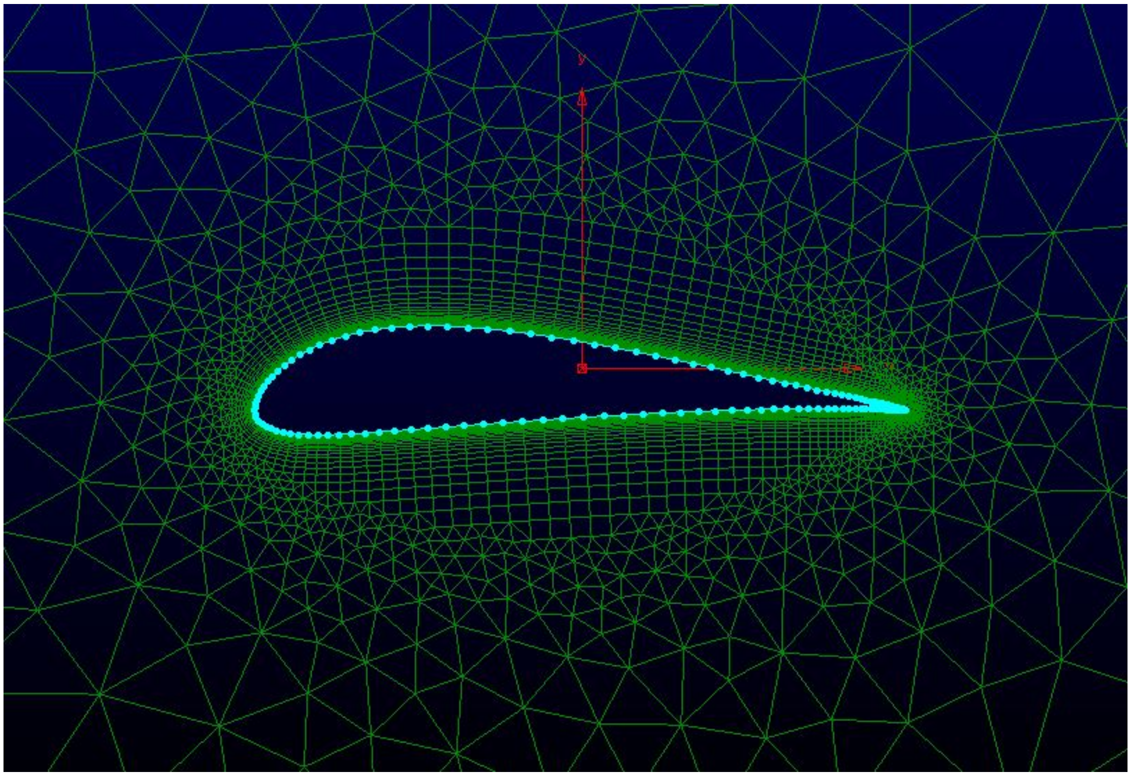


Figure 3: Nearfield

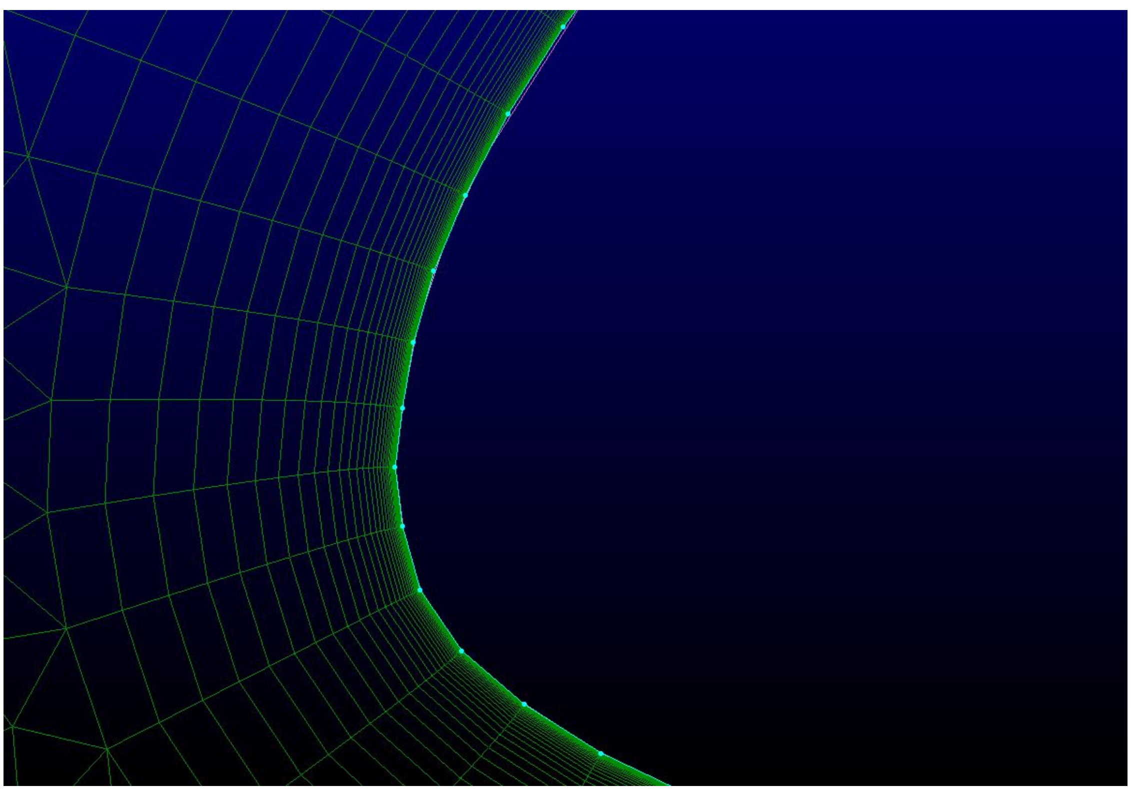


Figure 4: Leading edge zoomed-in view

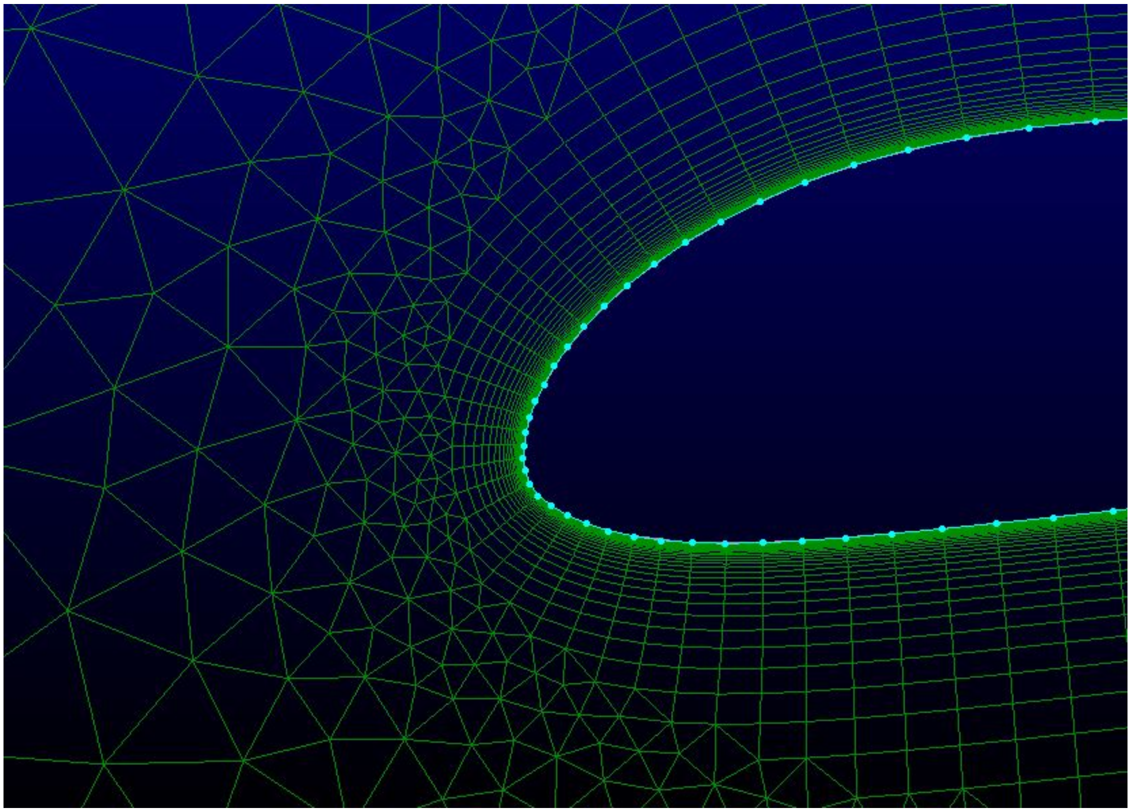


Figure 5: Leading edge zoomed-out view

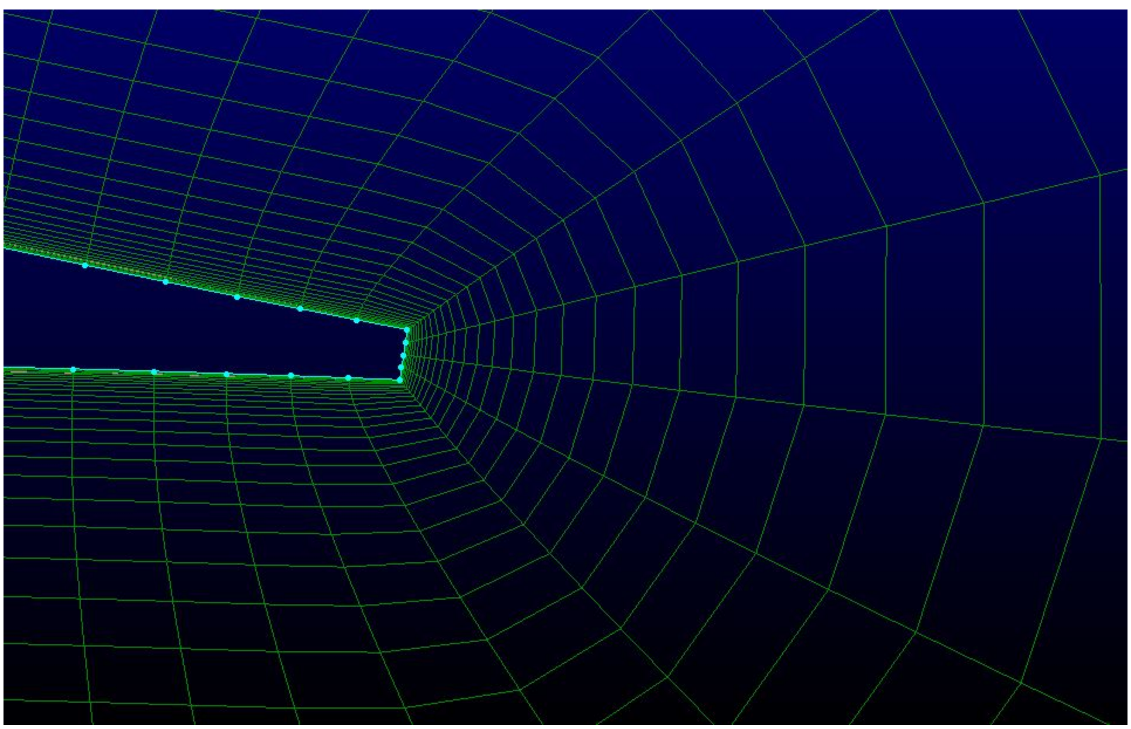


Figure 6: Trailing edge zoomed-in view

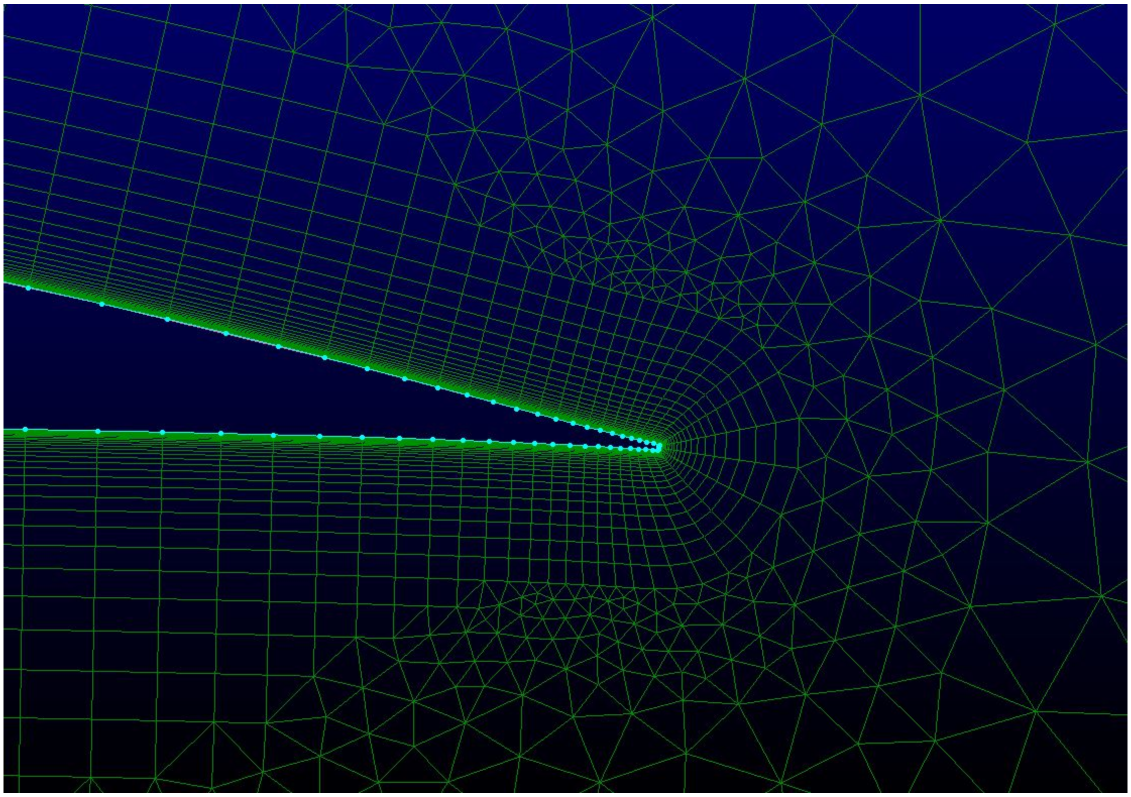


Figure 7: Trailing edge zoomed-out view

Table 3: General grid information

Cell count	**Inner mesh** (i.e. rotated grid): 11,890 **Outer mesh** (i.e. stationary grid): 6204
Normal-to-wall spacing	$\mathbf{\Delta s}$ = 1e-5
Boundary conditions	**Left edge**: velocity inlet **Right edge**: pressure outlet **Airfoil surface**: wall **Upper and lower grid edge**: tunnel
Reference values	**Area**: 1 [m^2] **Density**: 1.225 [kgm^{-3}] **Pressure**: 101,325 [Pa] **Temperature**: 298 [K] **Velocity**: 17.88 [m/s] **Viscosity**: 1.789e-05 [$kgm^{-1}s^{-1}$] **Ratio of specific heat**: 1.4
Submodels	**Viscous**: transitional SST
Numerical Schemes	**Gradient**: least-squares cell based **Pressure**: second order **Momentum**: second order upwind **Turbulent kinetic energy**: first order upwind **Specific dissipation rate**: first order upwind **Intermittency**: first order upwind **Momentum thickness Re**: first order upwind

3 Results

3.1 Plots of convergence history for all runs

See Appendix A

3.2 Table of final force/moment coefficient values

Table 4: Results of CFD calculation

AoA	C_l	C_d	C_m	L/D	Lift [N]	Drag [N]	Moment [N·m]
-7	-0.247	0.013	-0.094	-19.350	-48.317	2.497	-18.332
-4	0.077	0.010	-0.091	7.356	15.123	2.056	-17.808
-2	0.295	0.010	-0.090	28.122	57.755	2.054	-17.540
0	0.516	0.011	-0.089	48.617	100.953	2.076	-17.422
5	1.074	0.012	-0.088	90.362	210.222	2.326	-17.186
8.5	1.436	0.017	-0.083	82.787	281.182	3.396	-16.229
12	1.736	0.026	-0.073	66.487	339.897	5.112	-14.334
14.5	1.847	0.038	-0.063	48.517	361.756	7.456	-12.288
17	1.646	0.089	-0.074	18.489	322.236	17.429	-14.557
19.5	1.390	0.164	-0.100	8.498	272.115	32.019	-19.526
22	1.271	0.234	-0.126	5.431	248.919	45.834	-24.579

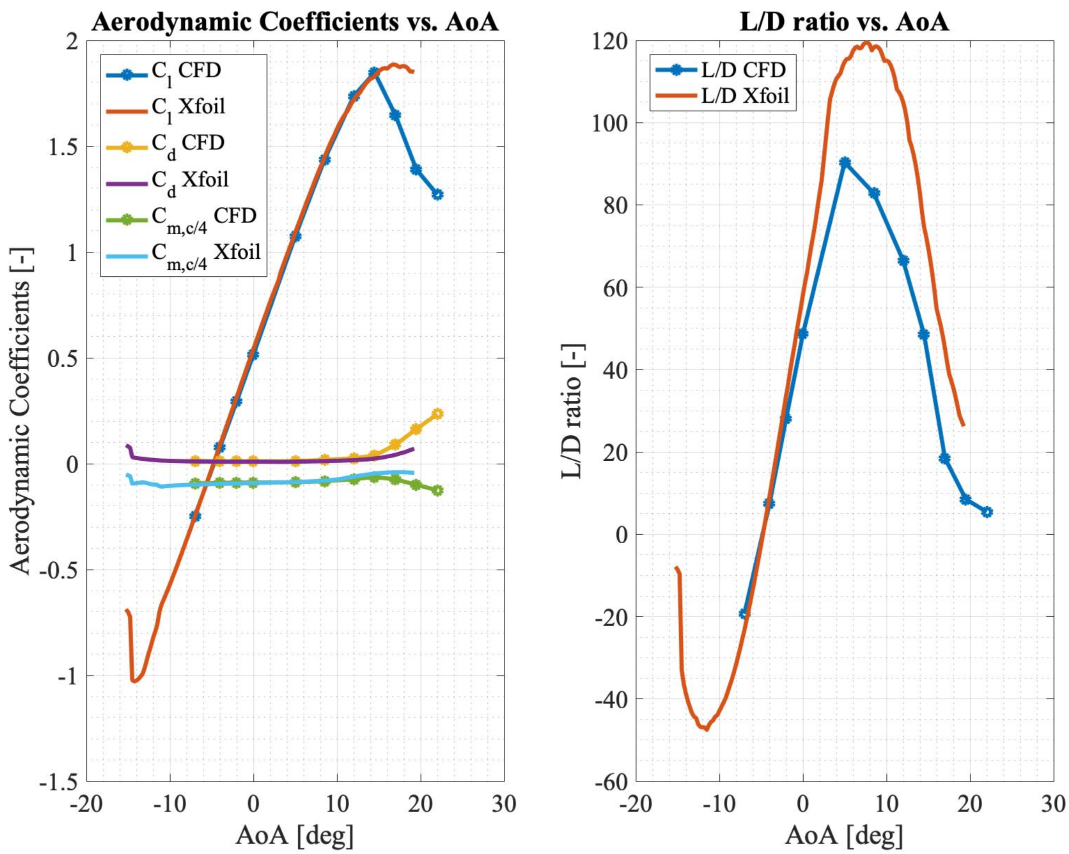


Figure 8: Comparison of aerodynamic coefficients from Xfoil and CFD

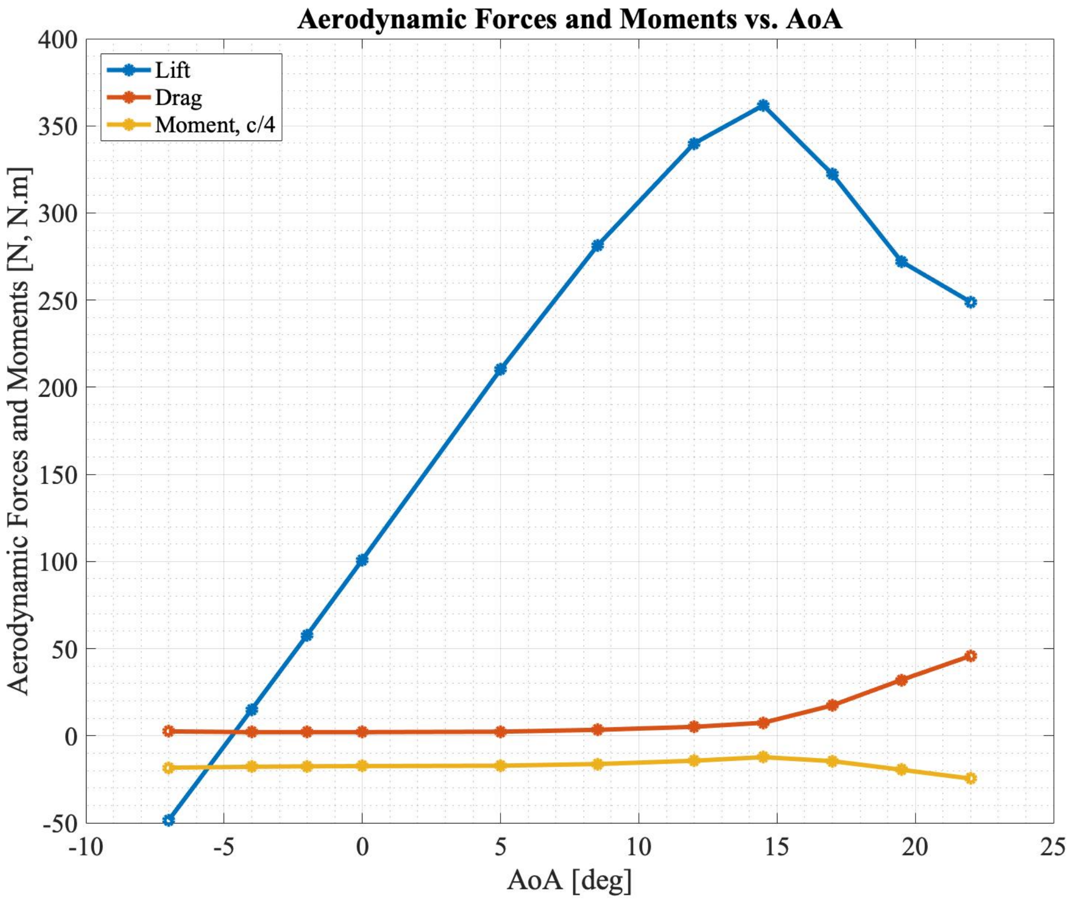


Figure 9: Aerodynamics forces and moments from CFD

3.3 Pressure contours and streamlines

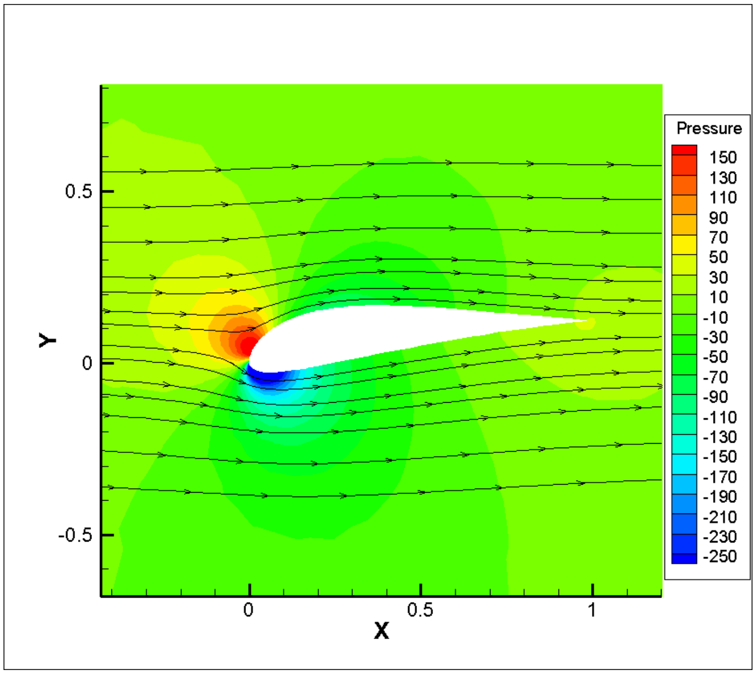


Figure 10: Pressure contours and streamlines for AoA = -7°

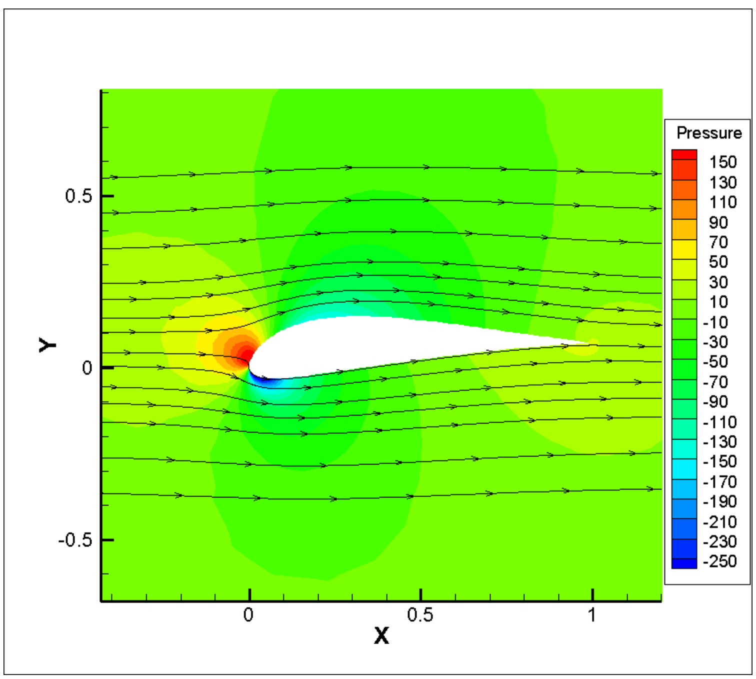


Figure 11: Pressure contours and streamlines for AoA = -4°

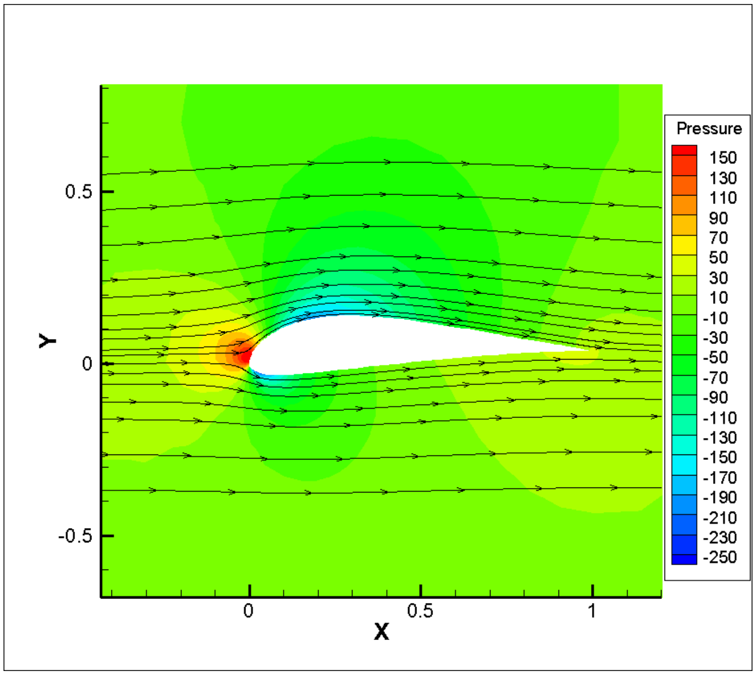


Figure 12: Pressure contours and streamlines for AoA = -2°

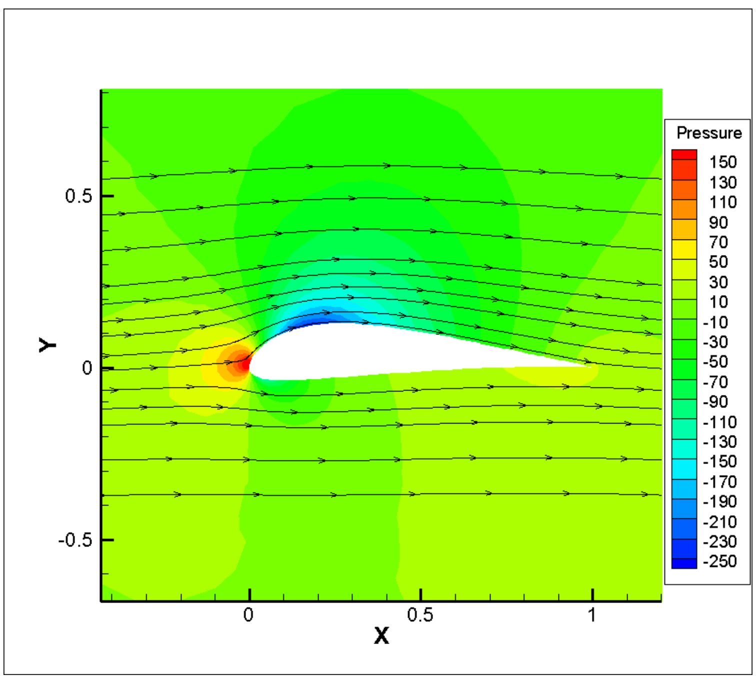


Figure 13: Pressure contours and streamlines for AoA = 0°

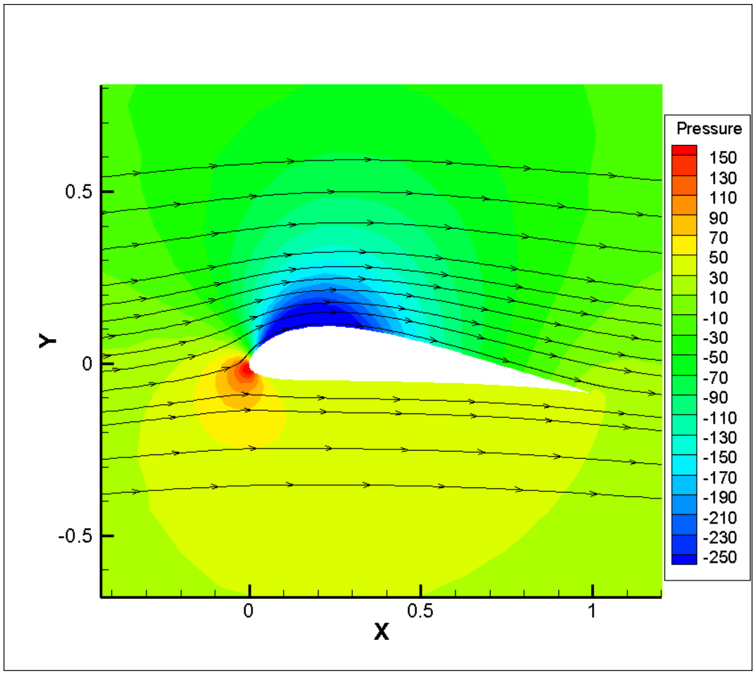


Figure 14: Pressure contours and streamlines for AoA = $5°$

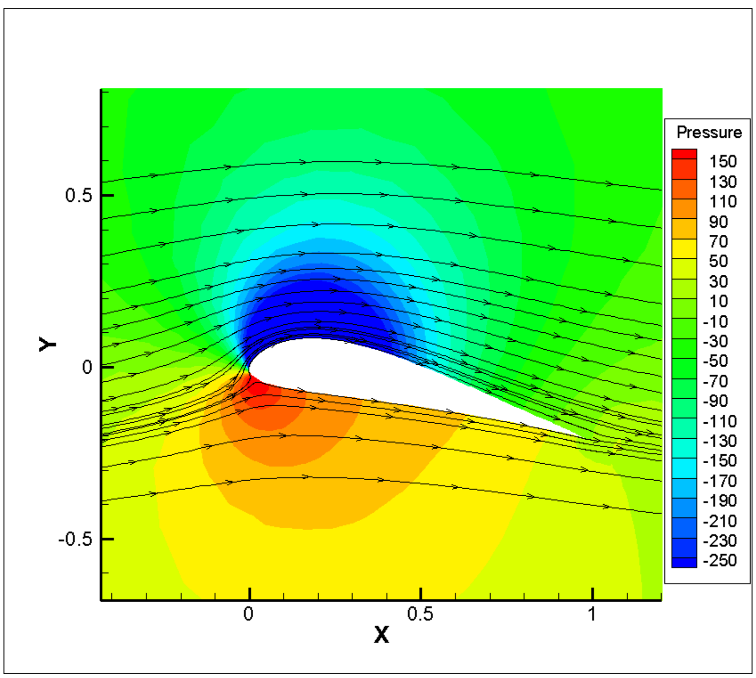


Figure 15: Pressure contours and streamlines for AoA = $12°$

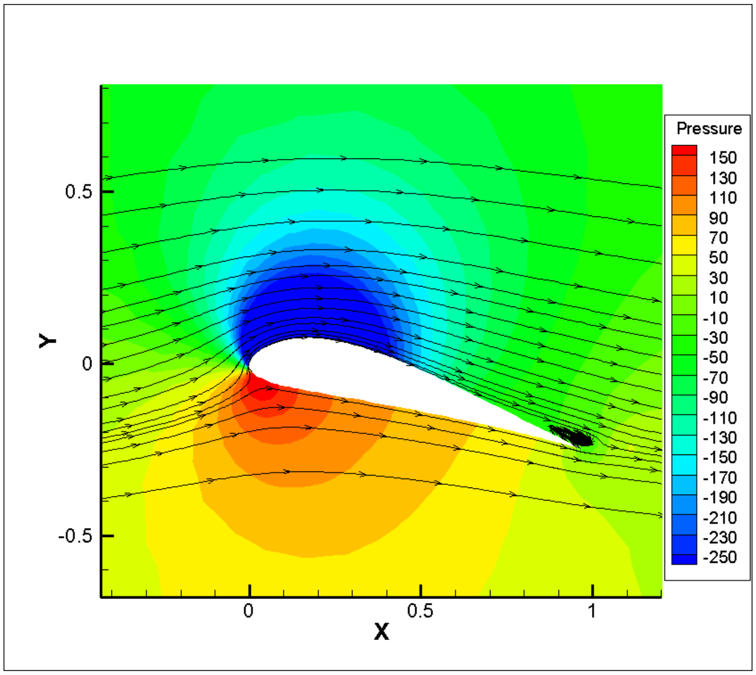


Figure 16: Pressure contours and streamlines for AoA = 14.5°

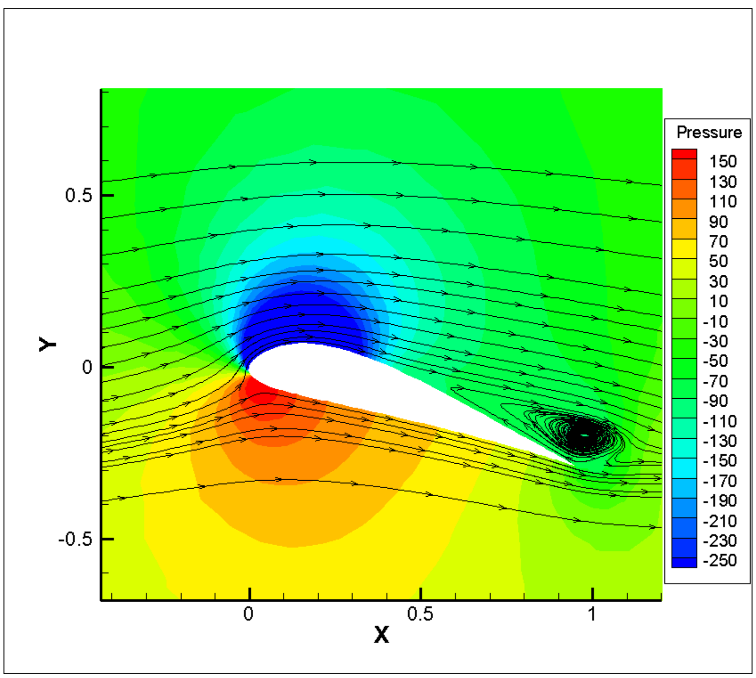


Figure 17: Pressure contours and streamlines for AoA = 17°

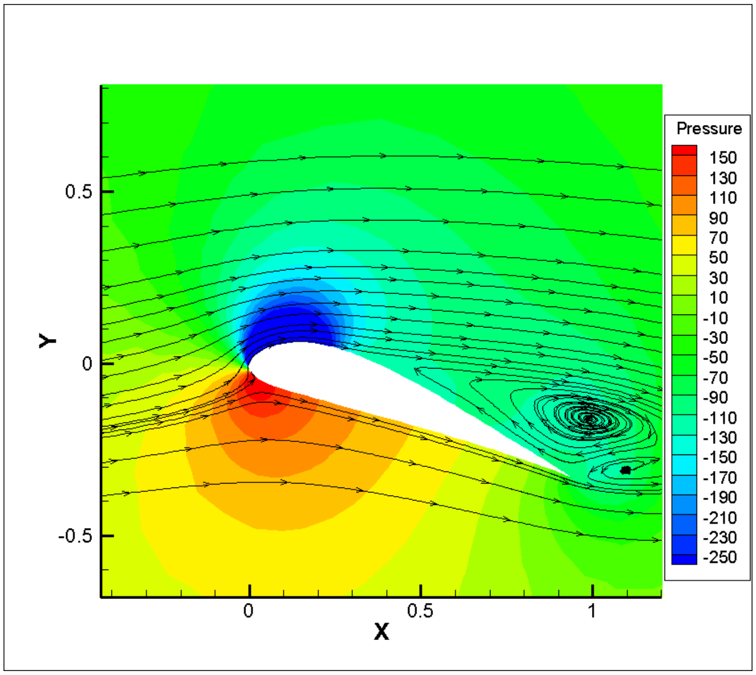


Figure 18: Pressure contours and streamlines for AoA = 19.5°

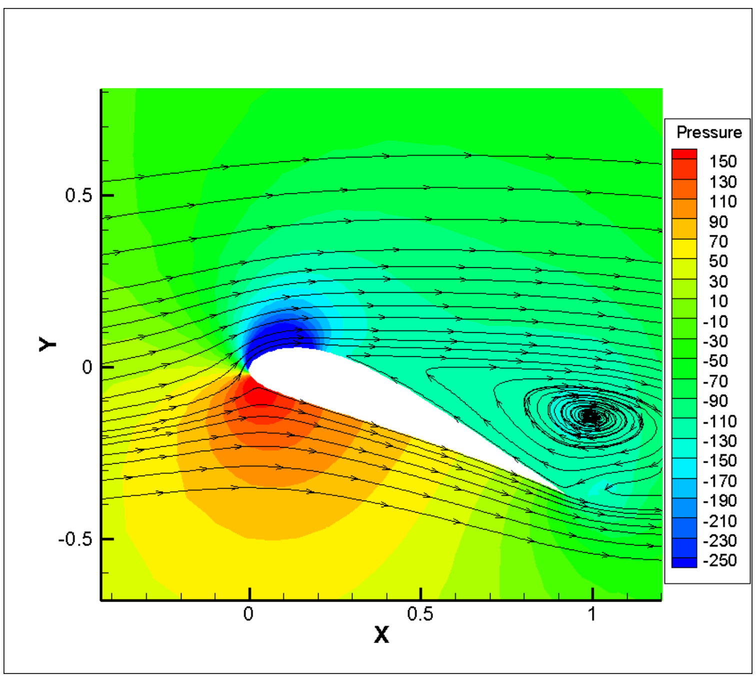


Figure 19: Pressure contours and streamlines for AoA = 22°

3.4 y+ Curve

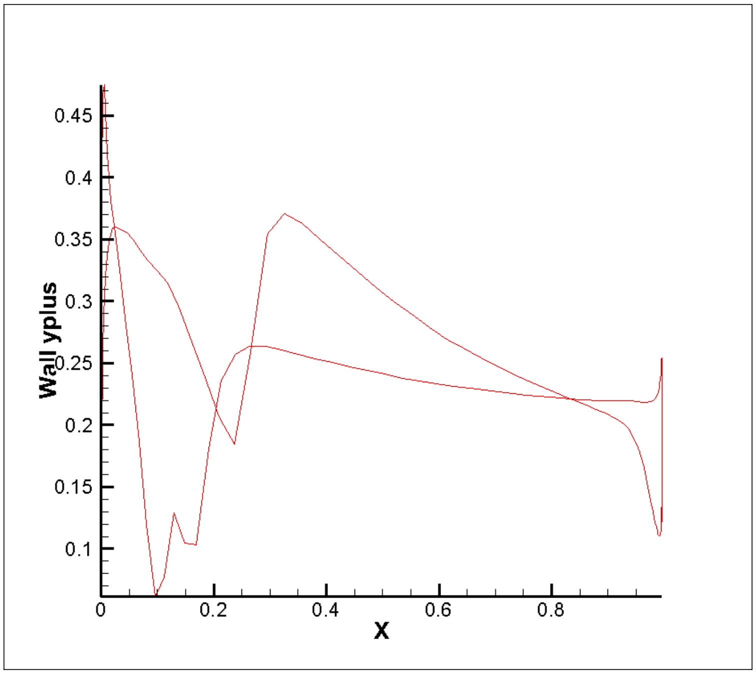


Figure 20: y plus graph

3.5 Turbulent Boundary Layer Development

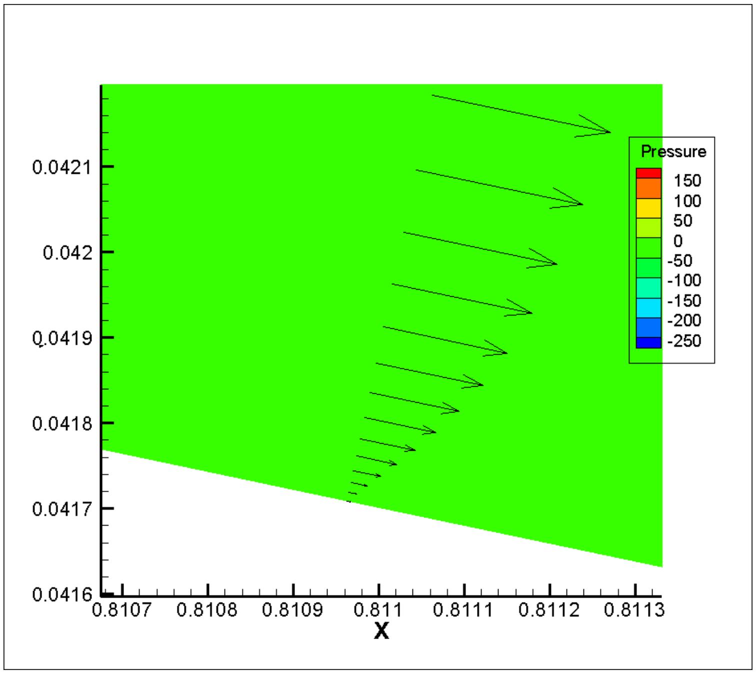


Figure 21: Boundary layer near trailing edge of wing

4 Discussion

In this discussion, the XFoil data is taken as "experimental" and the CFD data as numerical prediction; in addition, error bars of ±10% were drawn from each XFoil data point. Observing the C_l first in Fig. 22, XFoil and CFD agree very well until separation, which CFD predicted to happen at a lower AoA. In this case, the CFD simulation might be more trustworthy, as it is difficult to predict separation, especially with low-fidelity methods. Regarding C_d, a separate figure, Fig 23, more clearly illustrates the differences. The CFD generally overpredicted the XFoil solution. Near moderate AoAs of -5° to +5°, the CFD prediction is about 10% above that of XFoil; this was as close as the two solutions ever came. More extreme AoAs led to larger discrepancies, where the CFD predictions increasingly overpredicted the XFoil estimates. In general, the over estimate can at least partially be attributed to numerical diffusion of second order schemes. However, the discrepancy becomes larger with AoA which implies some correlation. It is this author's suspicion that both increasing suction near the leading edge and separation at the trailing edge may be impacting the fidelity of the CFD prediction.

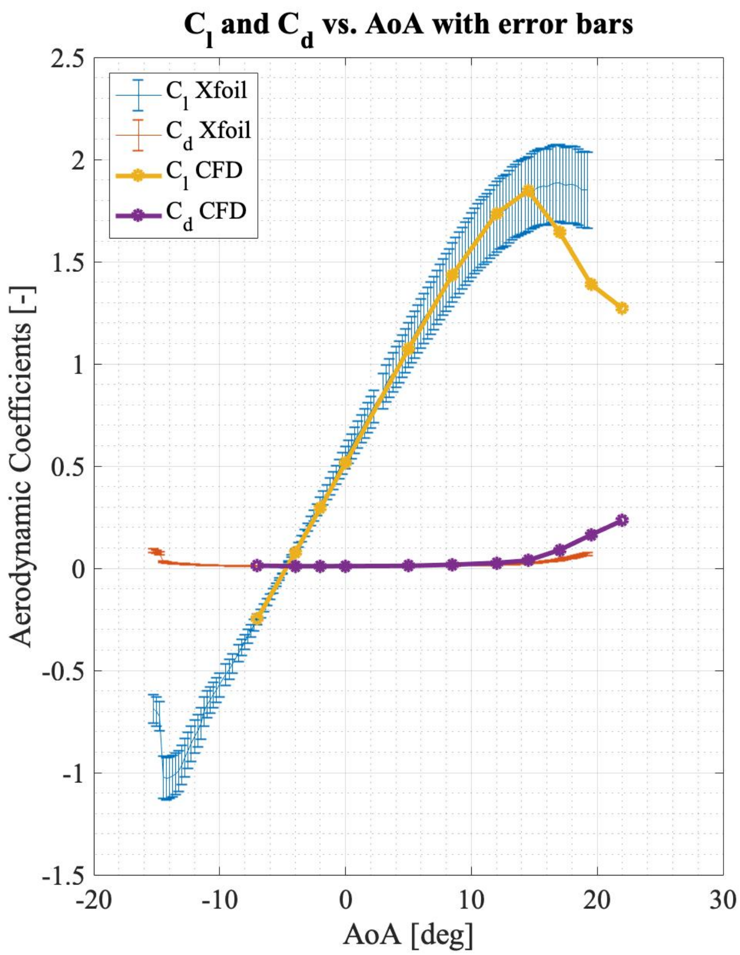


Figure 22: C_l and C_d comparisons with error bars of ±10%

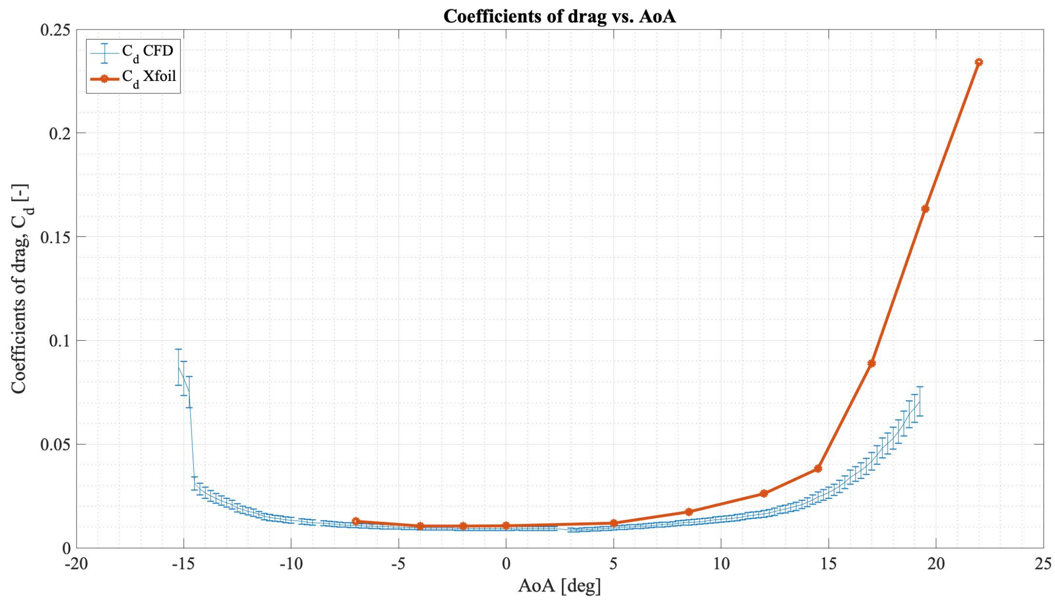
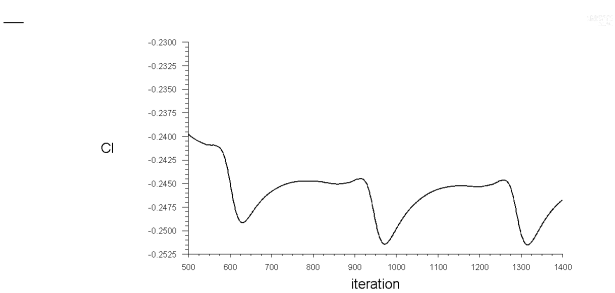


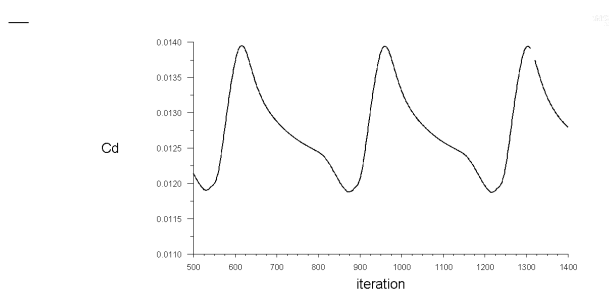
Figure 23: C_d comparisons with error bar of ±10%

Appendix A

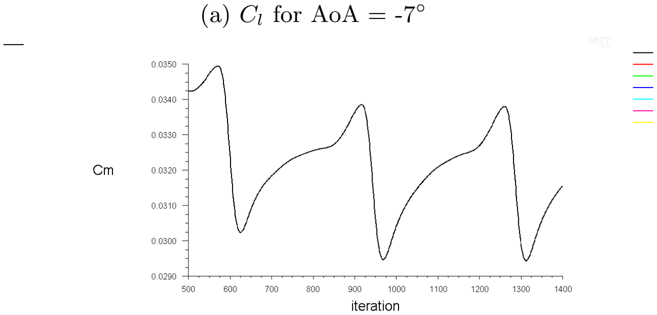
AoA = -7°



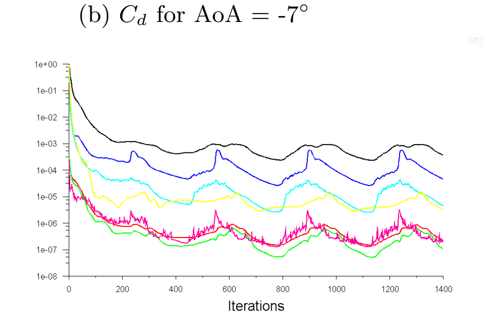
(a) C_l for AoA = -7°



(b) C_d for AoA = -7°

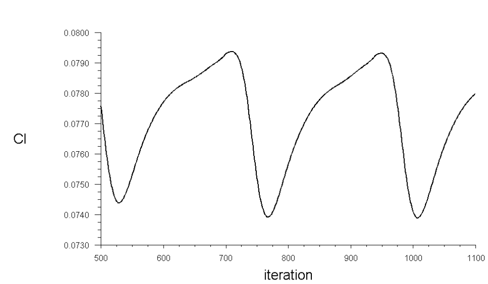


(c) C_m for AoA = -7°

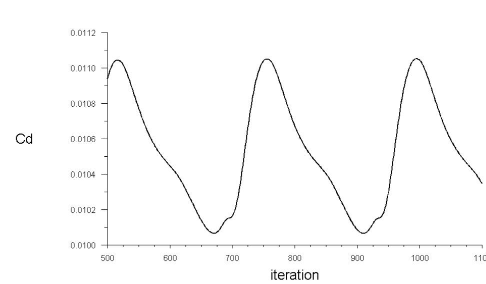


(d) Residual plot for AoA = -7°

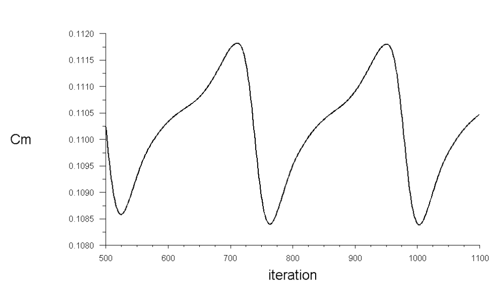
AoA = -4°



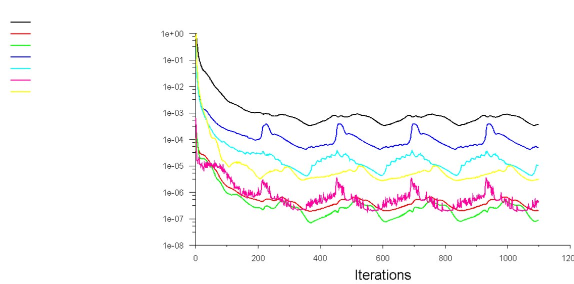
(a) C_l for AoA = -4°



(b) C_d for AoA = -4°

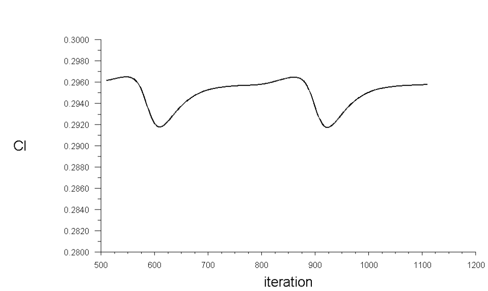


(c) C_m for AoA = -4°

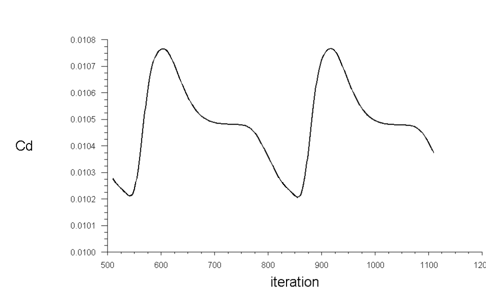


(d) Residual plot for AoA = -4°

AoA = -2°



(a) C_l for AoA = -2°



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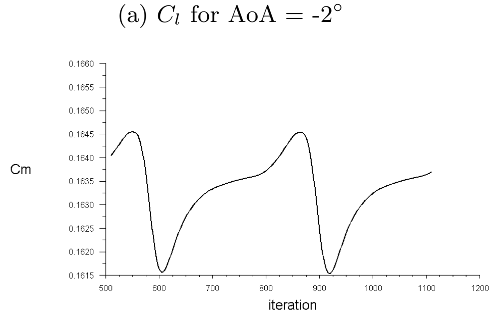

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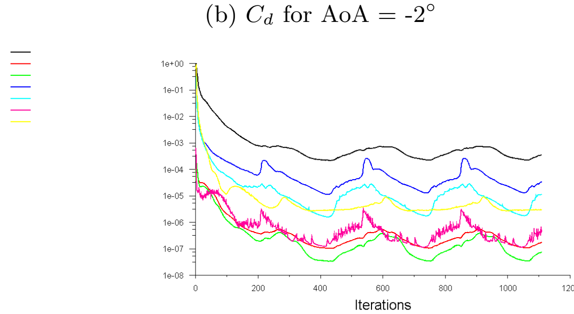
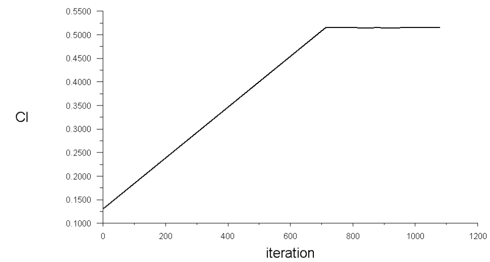
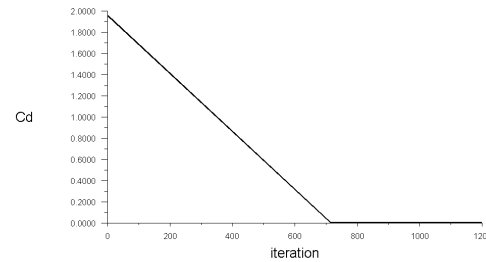


(d) Residual plot for AoA = -2°

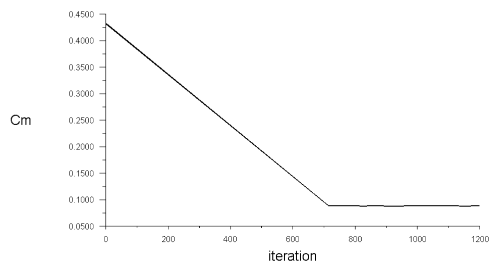
AoA $= 0°$



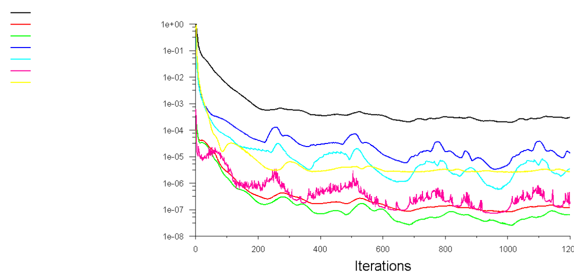
(a) C_l for AoA $= 0°$



(b) C_d for AoA $= 0°$

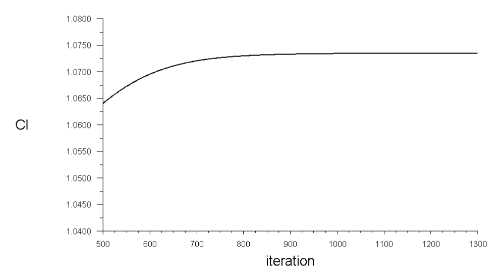


(c) C_m for AoA $= 0°$

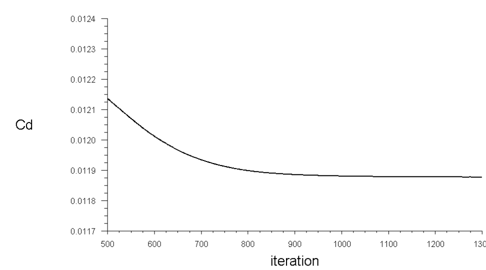


(d) Residual plot for AoA $= 0°$

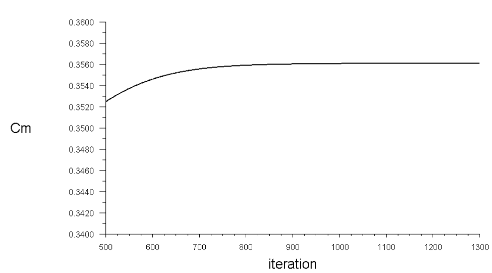
AoA $= 5°$



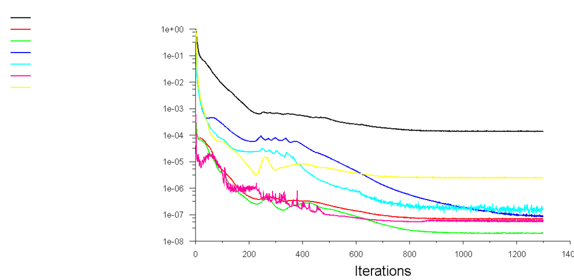
(a) C_l for AoA $= 5°$



(b) C_d for AoA $= 5°$

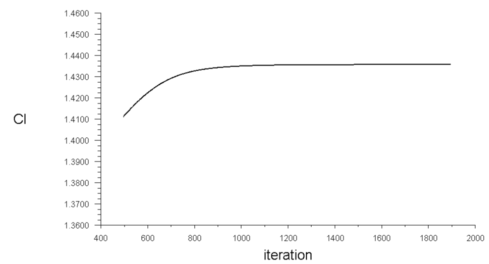


(c) C_m for AoA $= 5°$

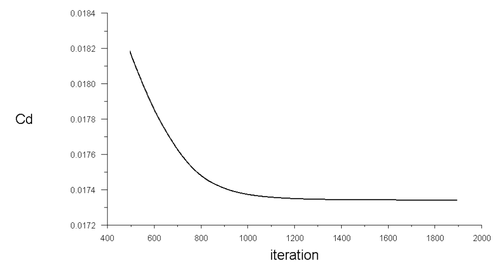


(d) Residual plot for AoA $= 5°$

AoA $= 8.5°$



(a) C_l for AoA $= 8.5°$



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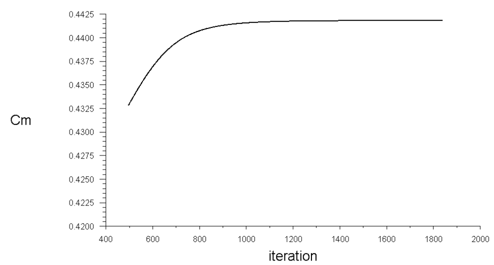
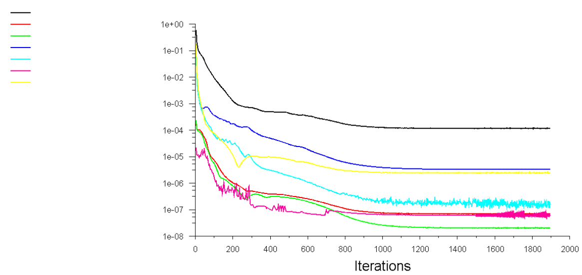
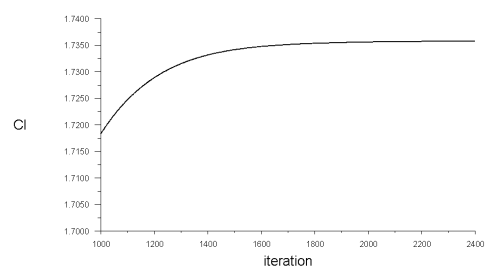


(c) C_m for AoA $= 8.5°$

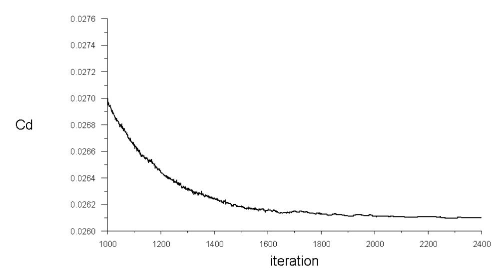


(d) Residual plot for AoA $= 8.5°$

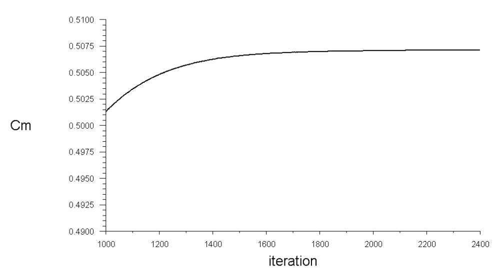
AoA $= 12°$



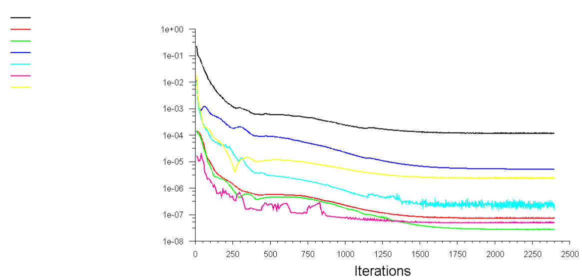
(a) C_l for AoA $= 12°$



(b) C_d for AoA $= 12°$

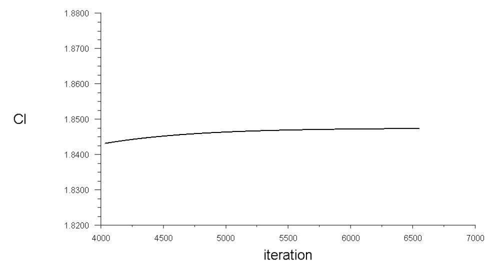


(c) C_m for AoA $= 12°$

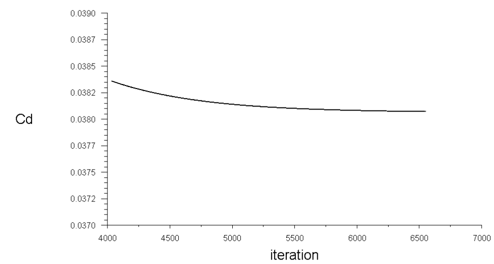


(d) Residual plot for AoA $= 12°$

AoA = 14.5°



(a) C_l for AoA = 14.5°



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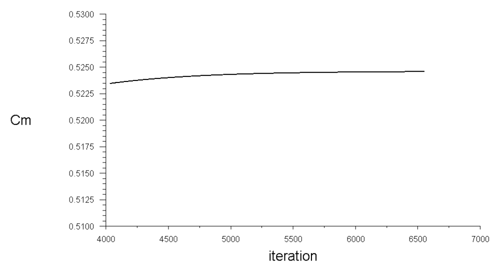
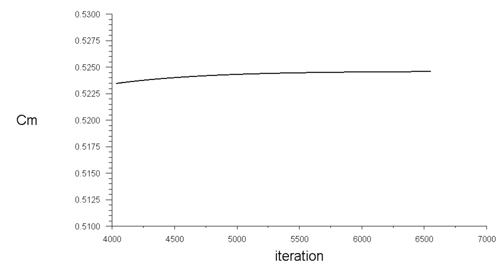
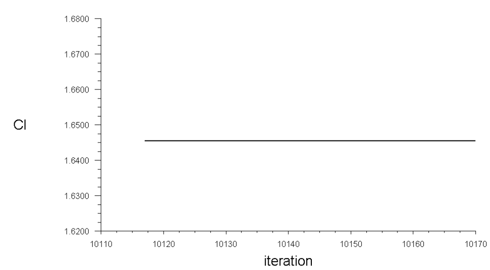


(c) C_m for AoA = 14.5°

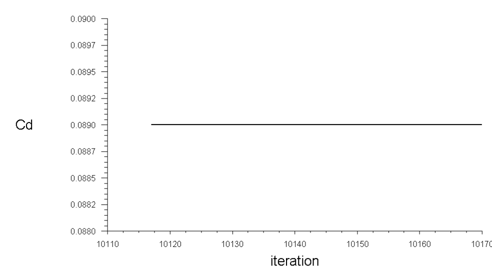


(d) Residual plot for AoA = 14.5°

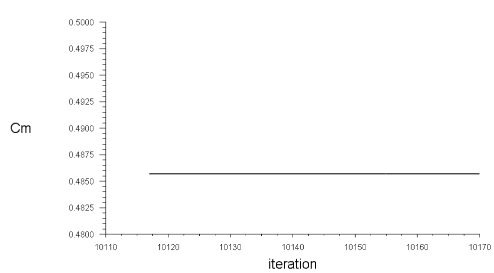
AoA = 17°



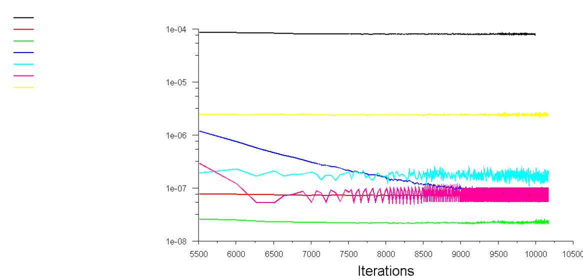
(a) C_l for AoA = 17°



(b) C_d for AoA = 17°

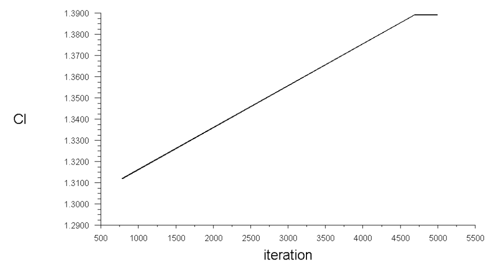


(c) C_m for AoA = 17°

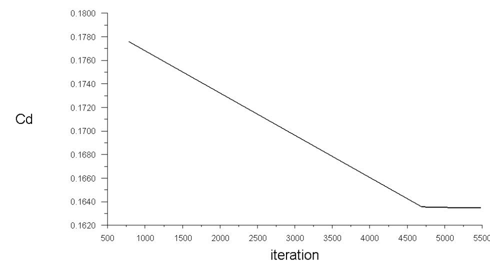


(d) Residual plot for AoA = 17°

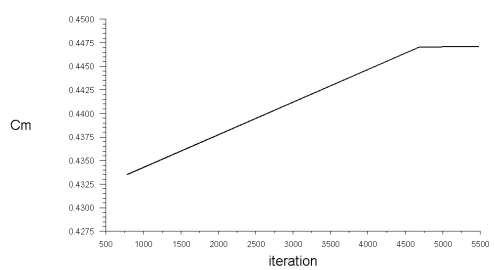
AoA = 19.5°



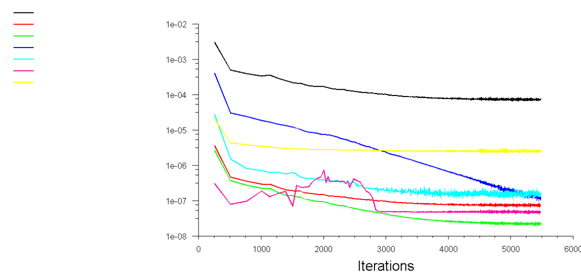
(a) C_l for AoA = 19.5°



(b) C_d for AoA = 19.5°

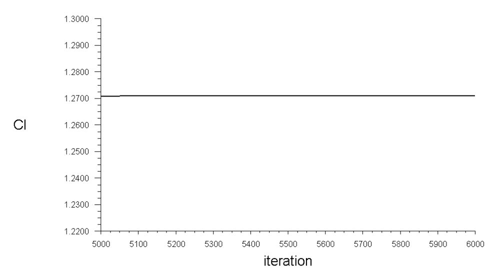


(c) C_m for AoA = 19.5°

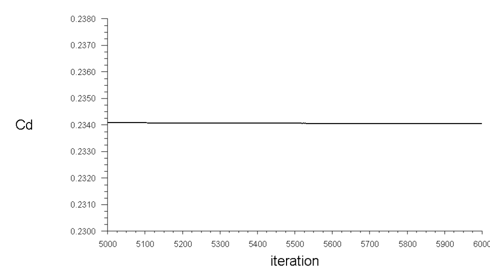


(d) Residual plot for AoA = 19.5°

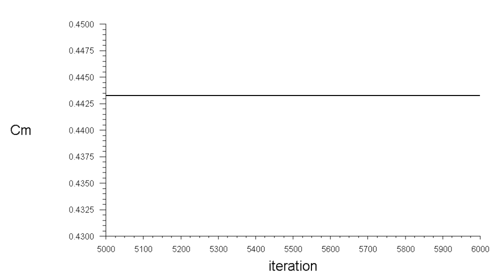
AoA = 22°



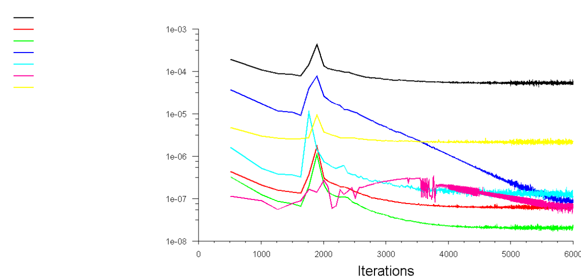
(a) C_l for AoA = 22°



(b) C_d for AoA = 22°



(c) C_m for AoA = 22°



(d) Residual plot for AoA = 22°