Evaluation of the Eppler 1210 Airfoil

January 23, 2020

1 Introduction

1. show airfoil
2. table of freestream conditions and Re
3. xfoil estimates of:
   - max L/D ratio, and AoA at which this occurs
   - max C_l, and AoA at which this occurs
   - Note: take both of the above directly from airfoiltools.com, at the closest reynolds number available

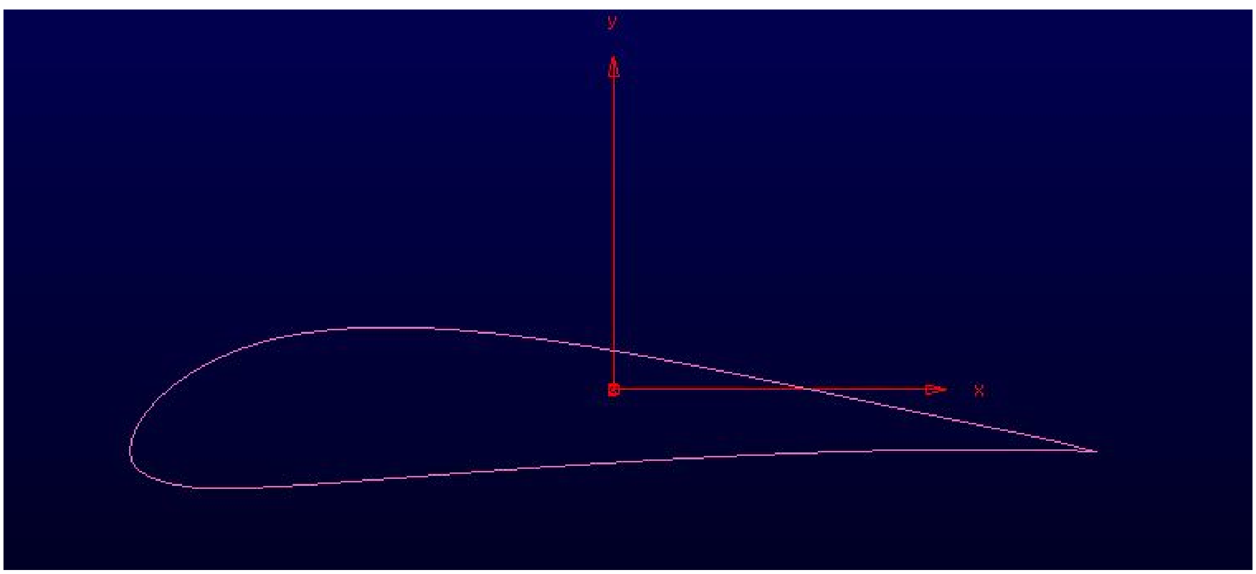


Figure 1: Eppler 1210 Airfoil shown in Pointwise

Table 1: Operating conditions for all cases

Quantity	Value
Pressure	103,000 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

1. 4 shots of grid: 1. LE 2. TE 3. near-field for entire shape 4. the entire grid domain. Note: should show T-rex feature that was used
2. table 1: cell count and normal-to-wall spacing used, list BC, list reference values, list submodels chosen (i.e. viscous model), provide numerical scheme and spacial accuracy

2.1 Screenshots of grid

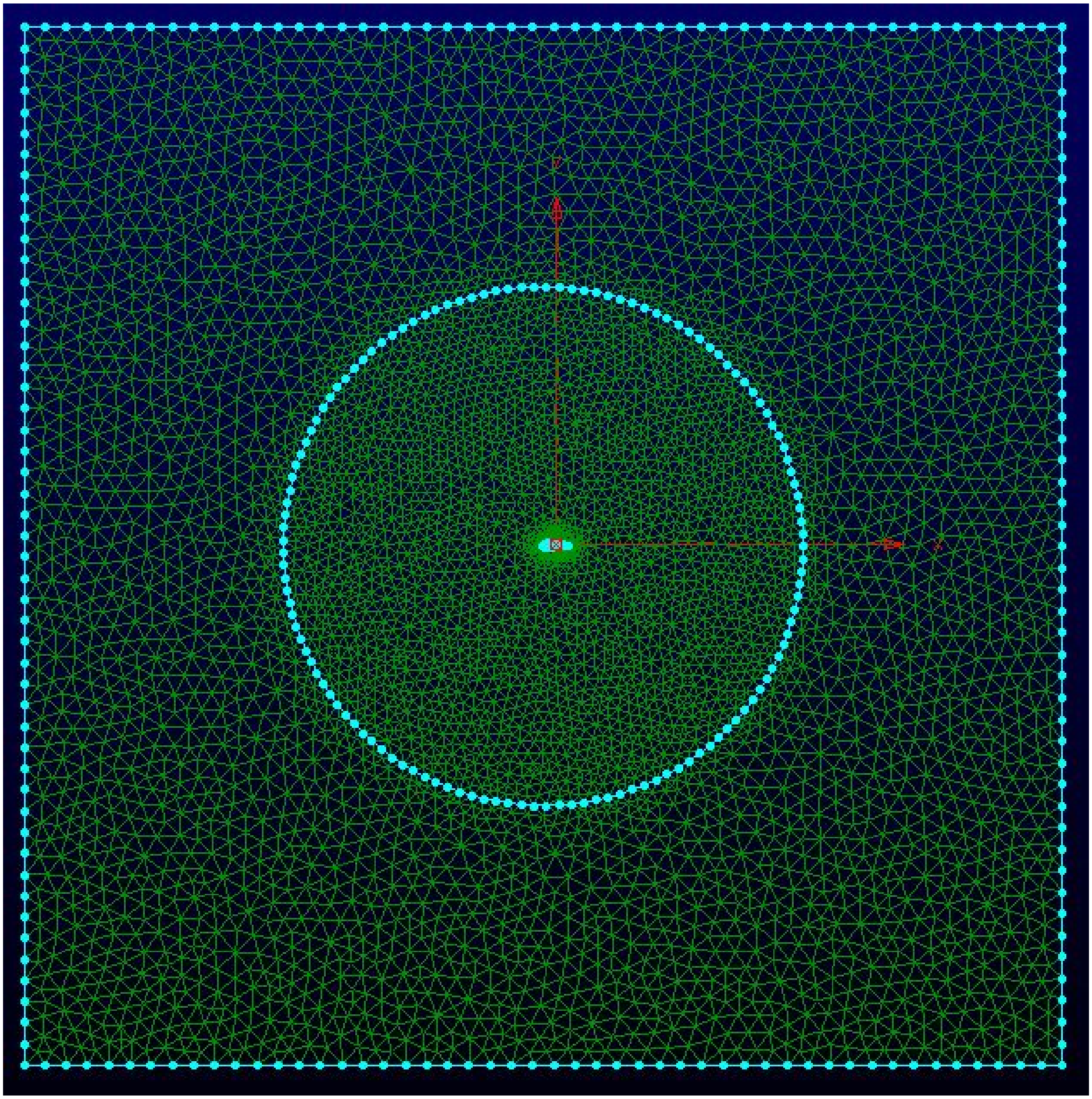


Figure 2: Farfield

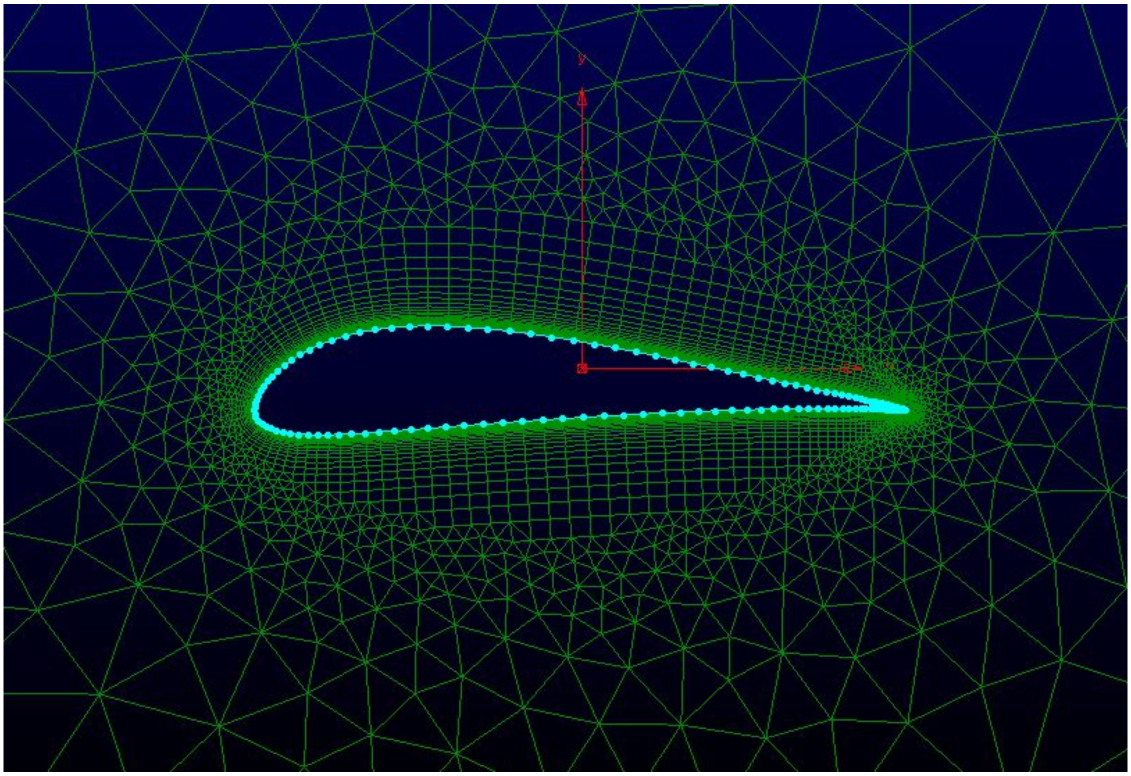


Figure 3: Nearfield

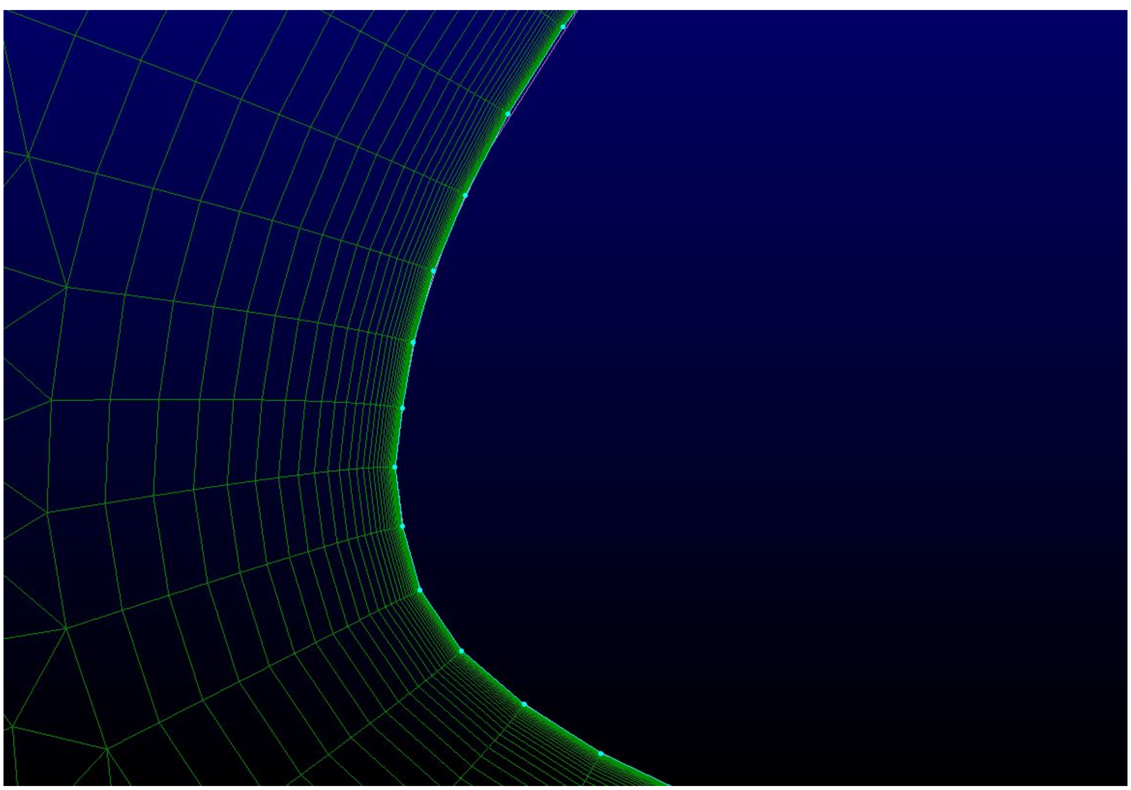


Figure 4: Leading edge

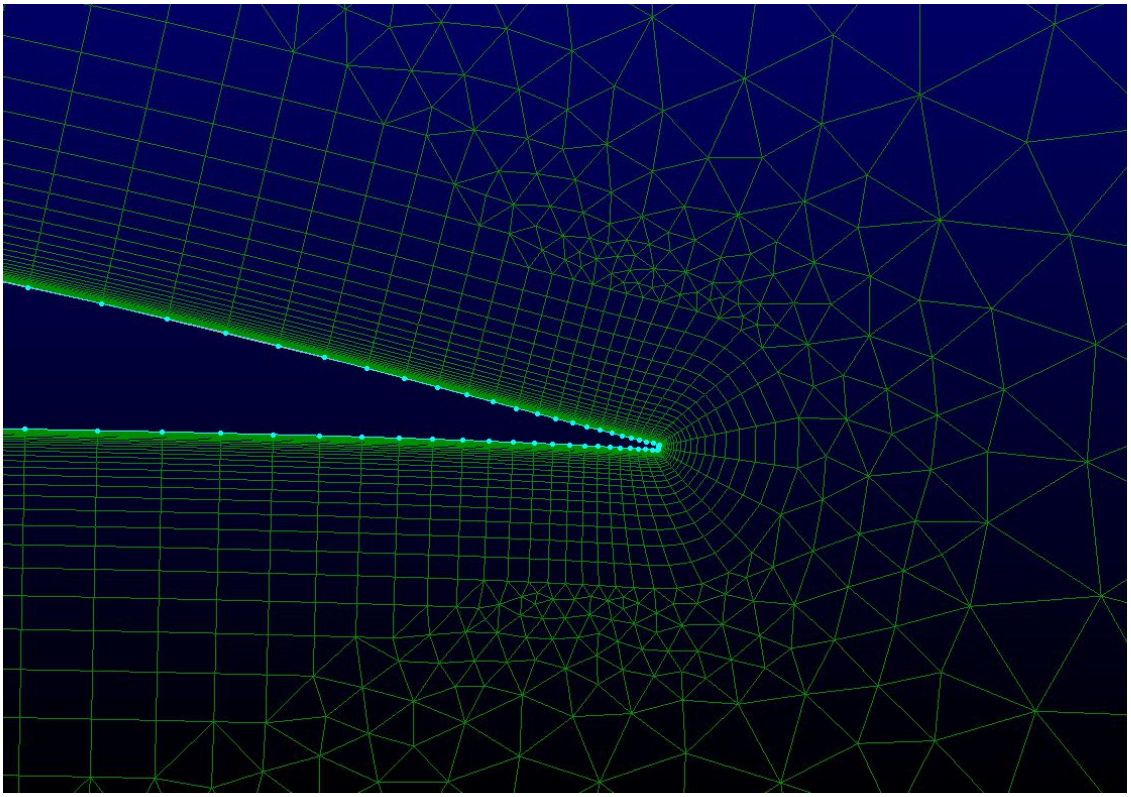


Figure 5: Trailing edge

Table 3: General grid information

	Value
Cell count	inner mesh: 11,890 outer mesh: 6204
Normal-to-wall dist	1e-5
Boundary conditions	left wall: velocity inlet right wall: pressure outlet airfoil surface: wall Upper and lower surfaces: tunnel
Reference values	Area: 1 [m^2] Density: 1.225 [kgm^{-3}] Pressure: 0 [Pa] Temperature: 290 [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 **specific dissipation rate**: first order upwind **intermittency**: first order upwind **momentum thickness Re**: first order upwind

3 Results

1. plot lift and drag coeff histories for proof of convergence history for ALL Runs (appendix)
2. Table of C_l, C_d, L/D, C_m
3. plots of the items in the table and compared against Xfoil data at the closest Re # (take directly from airfoiltools.com)
4. streamlines and pressure contours to depict flow near airfoil
   - 1 plot for each case
   - use the same contour levels
5. y+ curves (for 0° AoA case)
6. plot showing turbulent boundary layer development (0° AoA case)

3.1 Plots of convergence history for all runs

See Appendix A

Table 4: Results of CFD calculation

AoA [°]	C_l	C_d	$C_{m,c/4}$	L/D
-7	-0.247	0.013	-0.094	-19.350
-4	0.077	0.010	-0.091	7.356
-2	0.295	0.010	-0.090	28.122
0	0.516	0.011	-0.089	48.617
5	1.074	0.012	-0.088	90.362
8.5	1.436	0.017	-0.083	82.787
12	1.736	0.026	-0.073	66.487
14.5	1.847	0.038	-0.063	48.517
17	1.646	0.089	-0.074	18.489
19.5	1.390	0.164	-0.100	8.498
22	1.271	0.234	-0.126	5.431

3.2 Table of final force/moment coefficient values

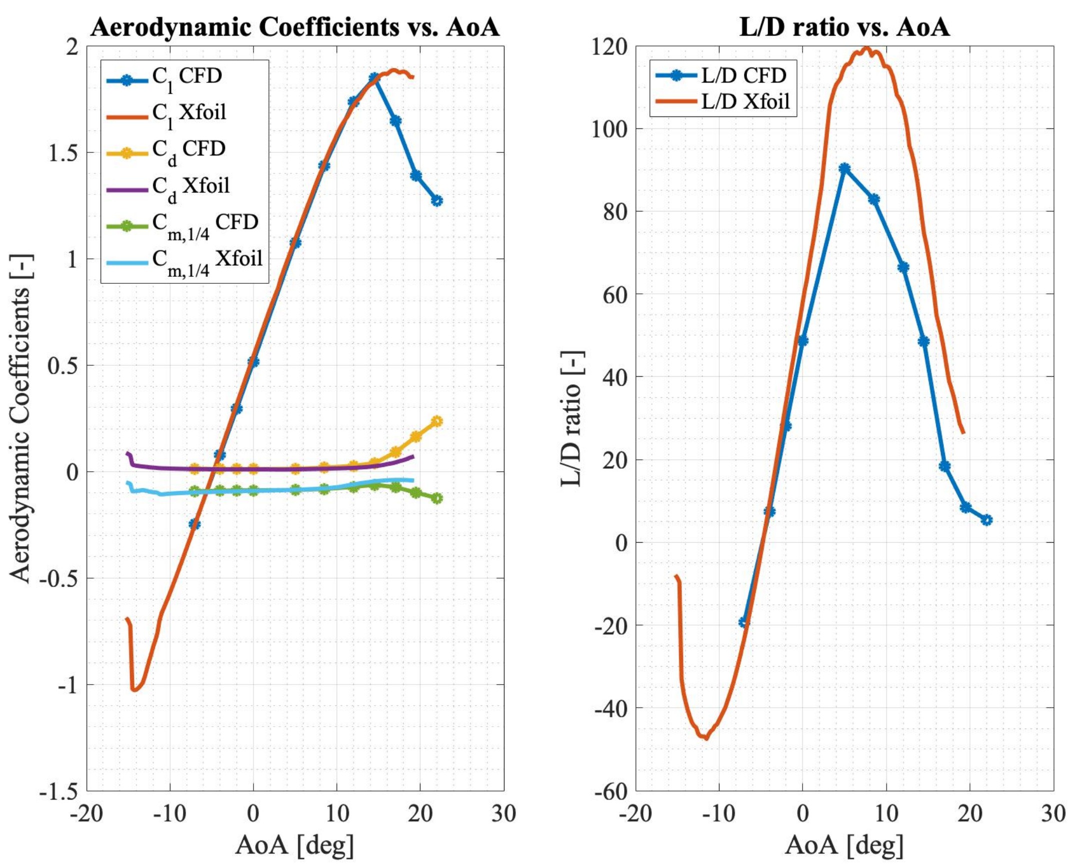


Figure 6: Comparison of aerodynamic coefficients from Xfoil and CFD

3.3 Pressure contours and streamlines

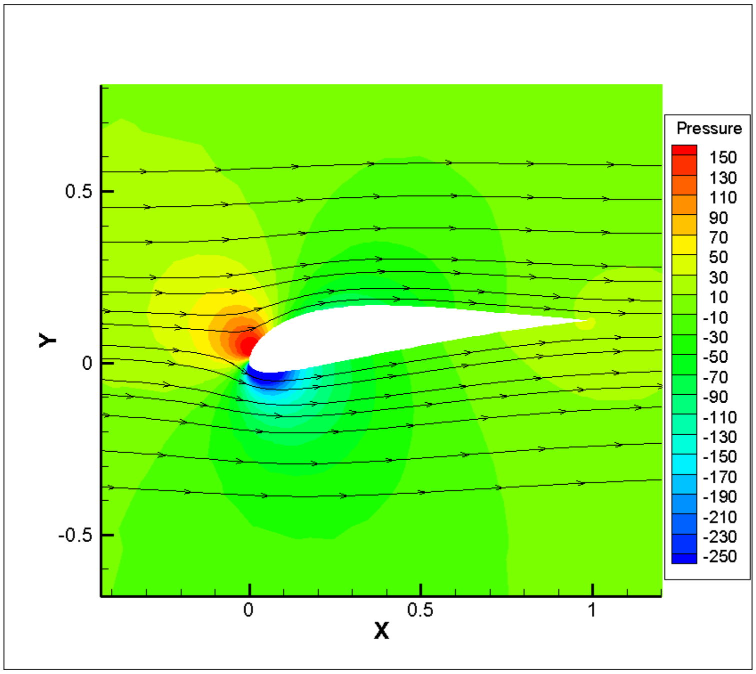


Figure 7: Pressure contours and streamlines for AoA = -7°

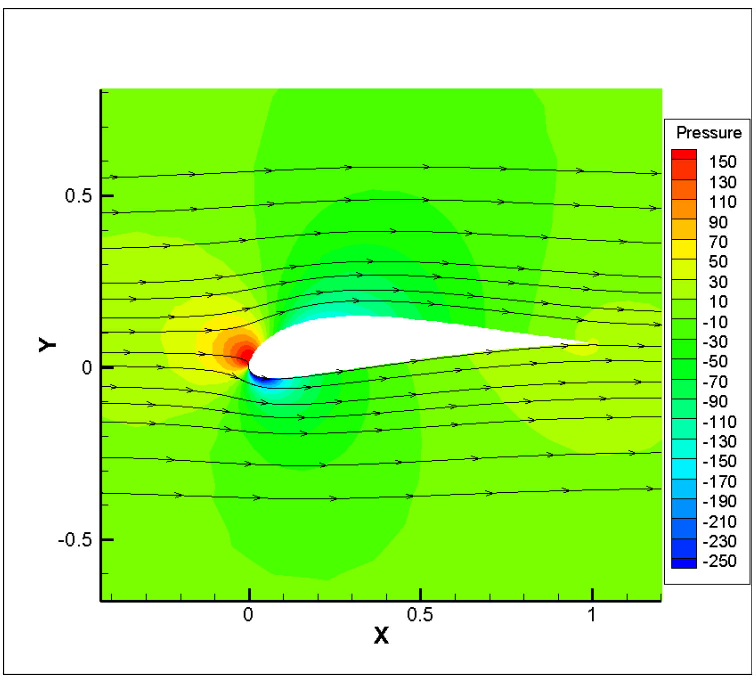


Figure 8: Pressure contours and streamlines for AoA = -4°

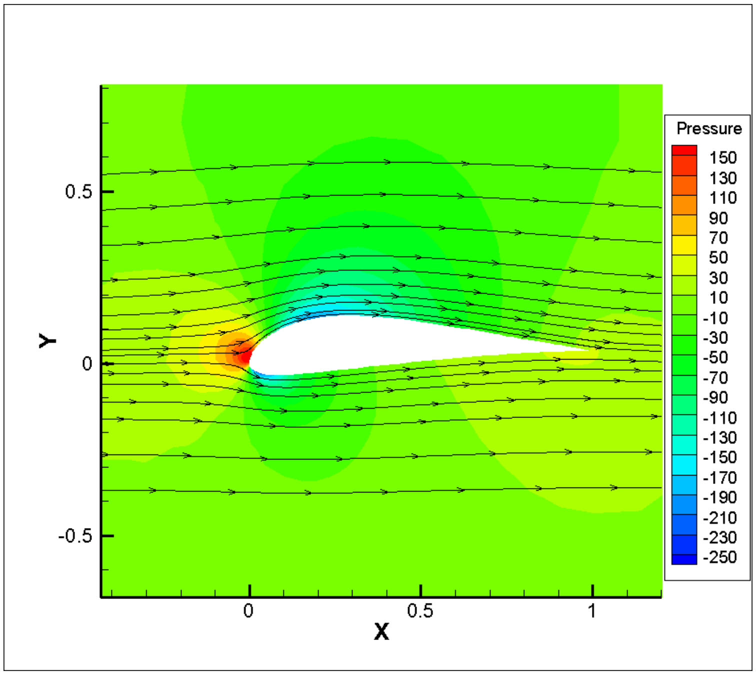


Figure 9: Pressure contours and streamlines for AoA = -2°

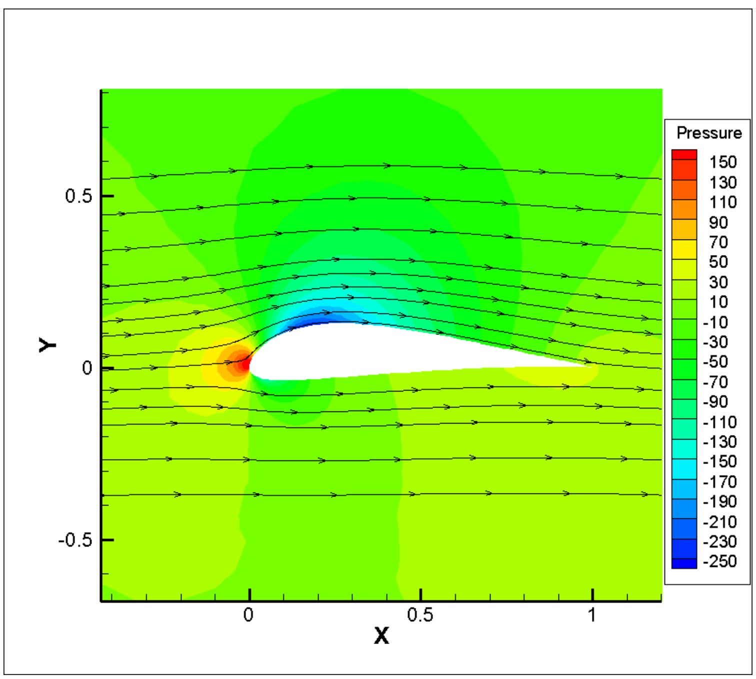


Figure 10: Pressure contours and streamlines for AoA = 0°

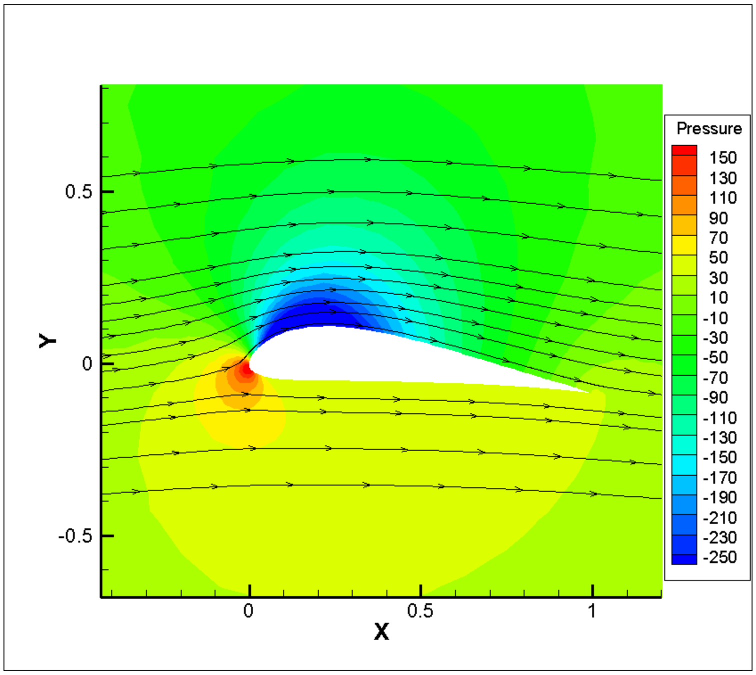


Figure 11: Pressure contours and streamlines for AoA = 5°

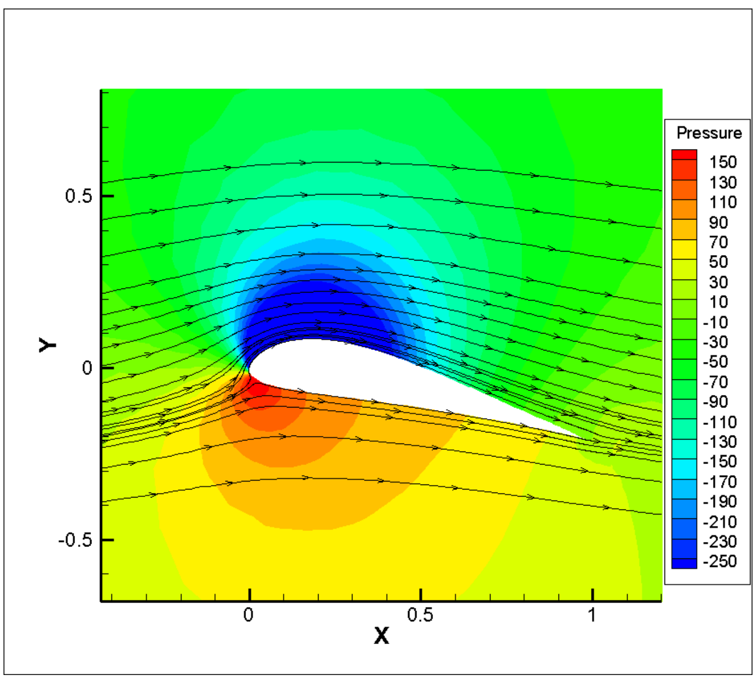


Figure 12: Pressure contours and streamlines for AoA = 12°

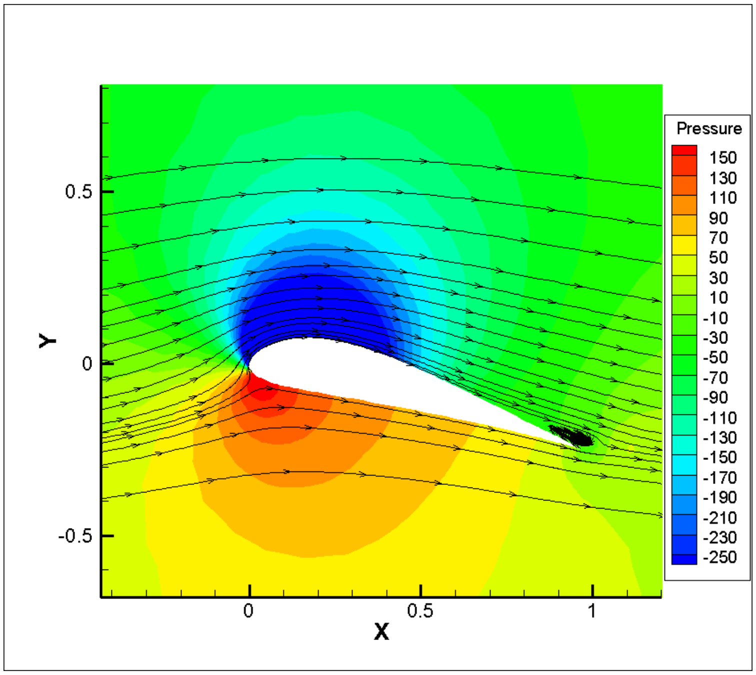


Figure 13: Pressure contours and streamlines for AoA = 14.5°

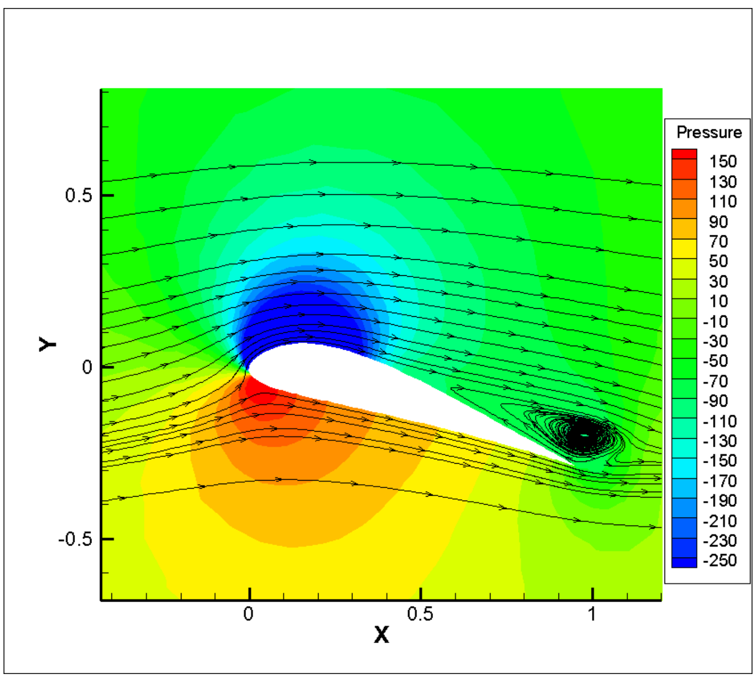


Figure 14: Pressure contours and streamlines for AoA = 17°

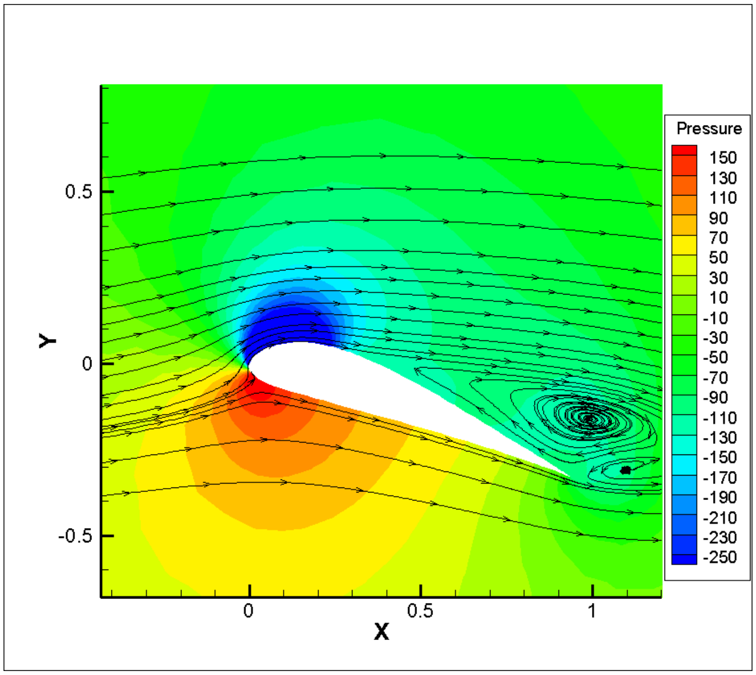


Figure 15: Pressure contours and streamlines for AoA = $19.5°$

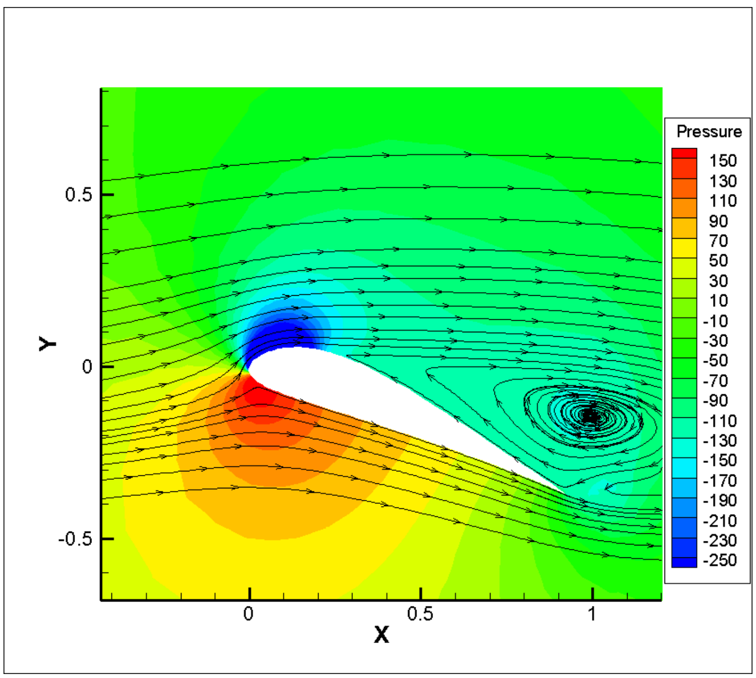


Figure 16: Pressure contours and streamlines for AoA = $22°$

3.4 y+ Curve

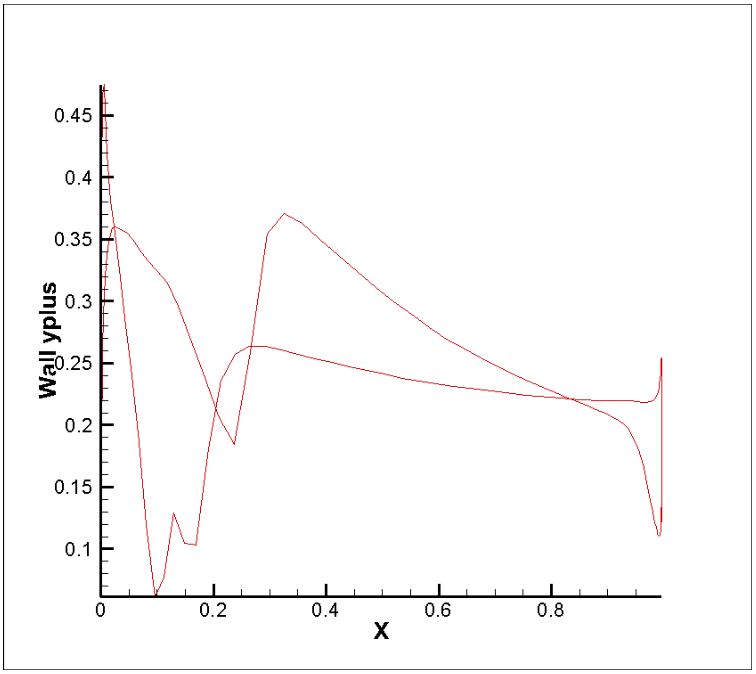


Figure 17: y plus graph

3.5 Turbulent Boundary Layer Development

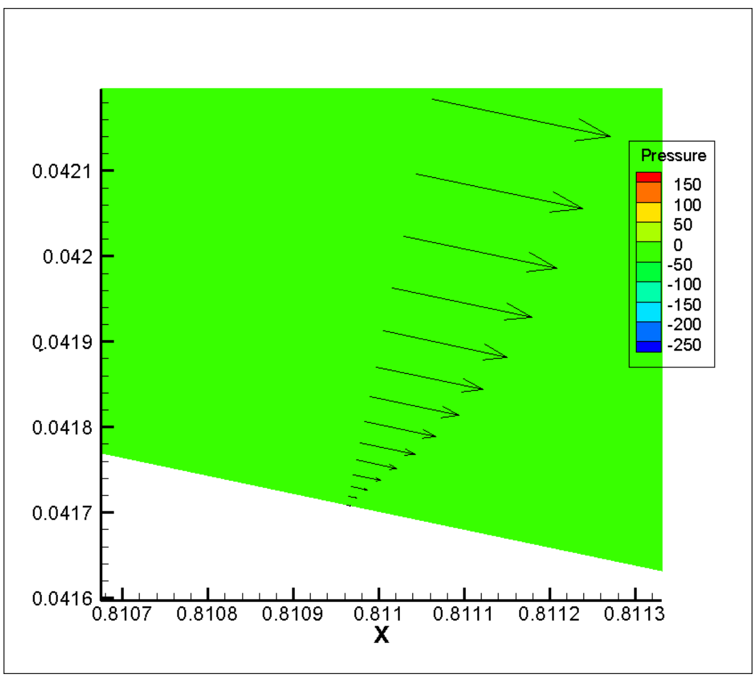


Figure 18: Boundary layer near trailing edge of wing

4 Discussion

Taking the XFoil data as "experimental," and the CFD data as numerical prediction, error bars of $\pm 10\%$ were drawn from each XFoil data point. Observing the C_l first in Fig. 19, XFoil and CFD agree very well until separation, where CFD predict its happening 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, the CFD generally overpredicted the XFoil solution as seen in Figs. 20a and 20b, zoomed-in view of the exact same same figure. The former is at small negative AoAs, where the CFD prediction is about 10% above XFoil prediction; this was as close as the two solutions ever came. Higher AoAs led to larger discrepancies, where the CFD predictions increasingly overpredicted the XFoil estimates. This discrepancy can be attributed to numerical diffusion created by second order schemes?

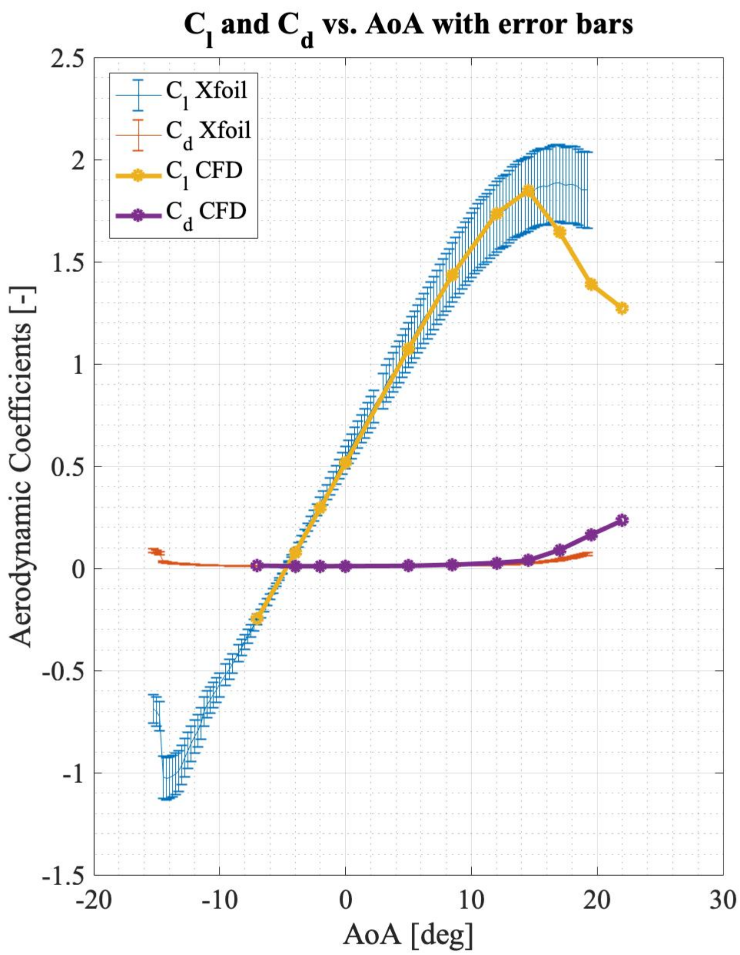
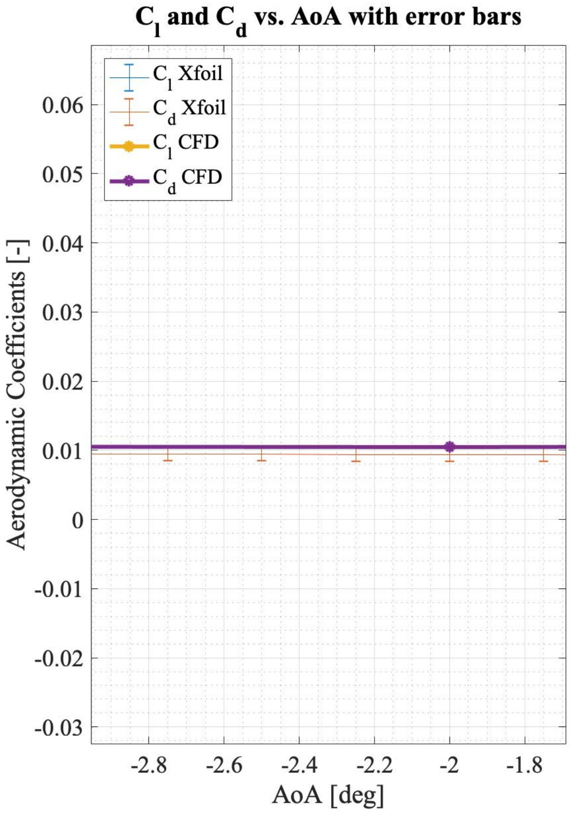
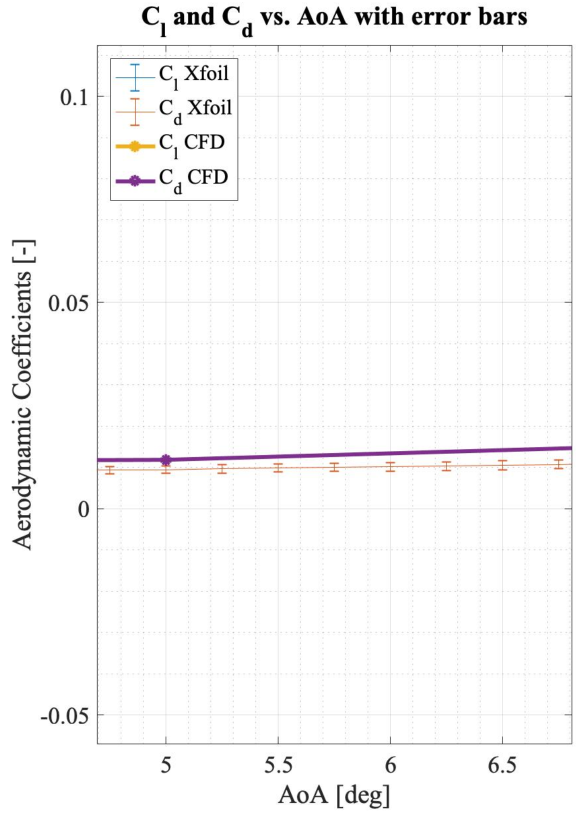


Figure 19: C_l and C_d comparisons including error bar of $\pm 10\%$



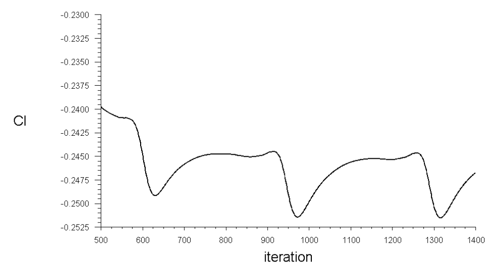
(a) Zoomed-in view of lower AoA section of C_d



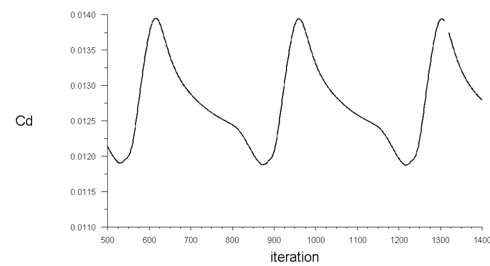
(b) Another zoomed-in view of larger AoA section of C_d

Appendix A

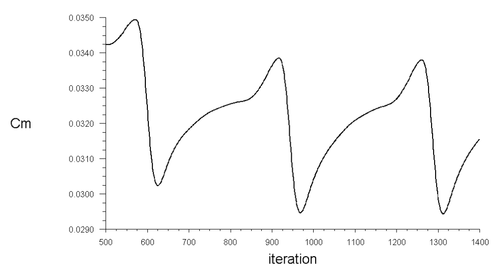
AoA = -7°



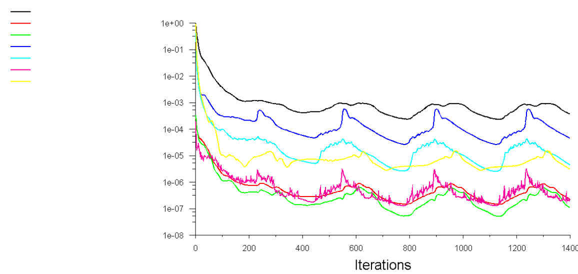
(a) C_l for AoA = -7°



(b) C_d for AoA = -7°

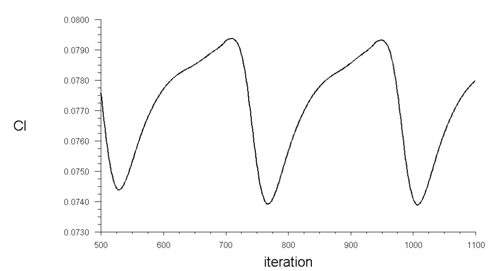


(c) C_m for AoA = -7°

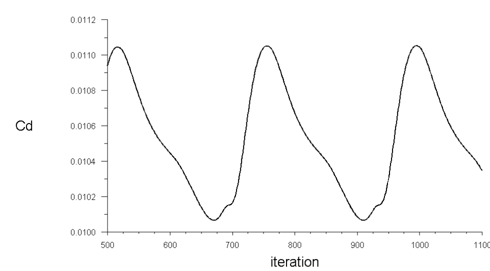


(d) Residual plot for AoA = -7°

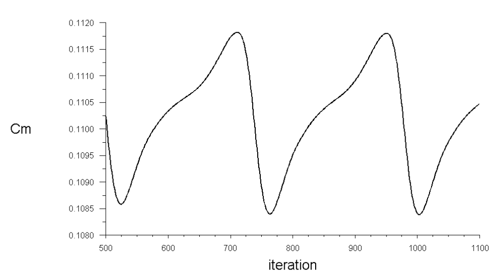
AoA = -4°



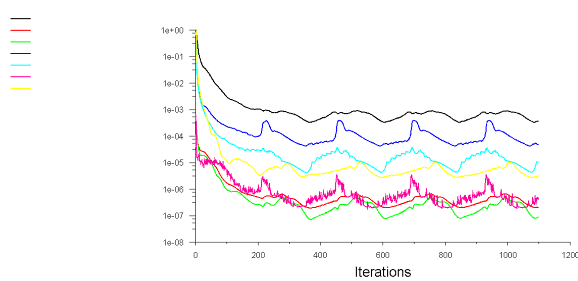
(a) C_l for AoA = -4°



(b) C_d for AoA = -4°

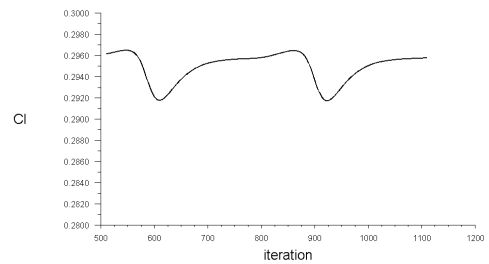


(c) C_m for AoA = -4°

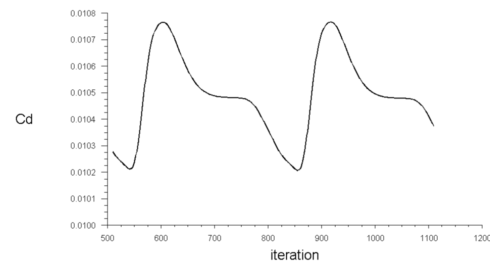


(d) Residual plot for AoA = -4°

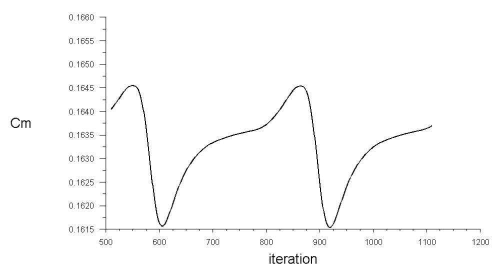
AoA = -2°



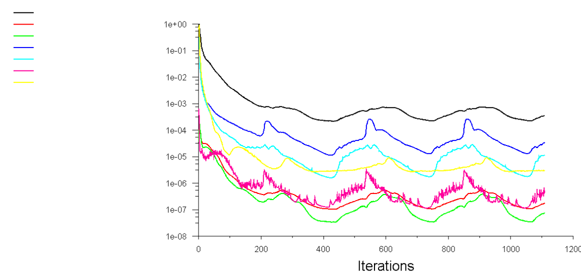
(a) C_l for AoA = -2°



(b) C_d for AoA = -2°

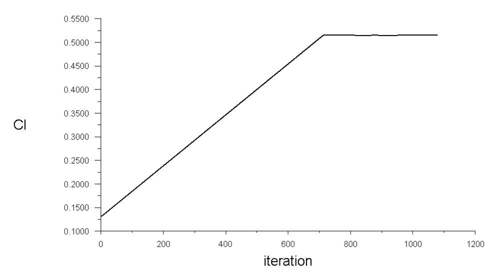


(c) C_m for AoA = -2°

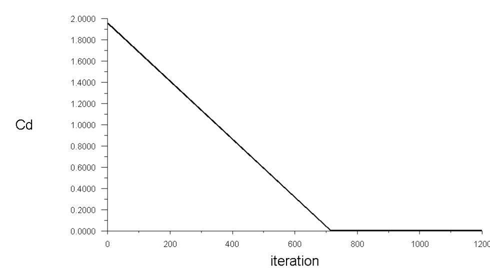


(d) Residual plot for AoA = -2°

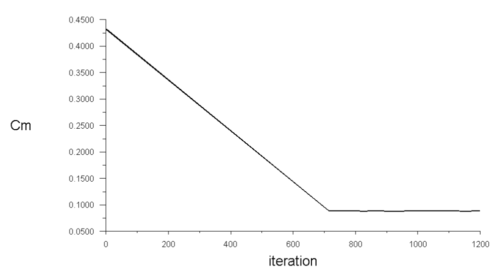
AoA = 0°



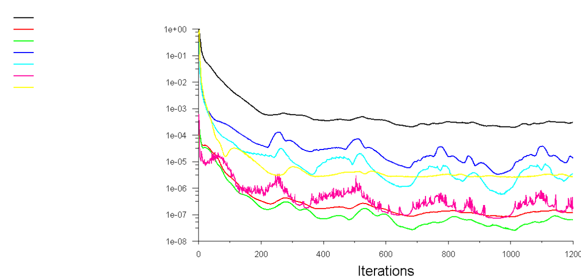
(a) C_l for AoA = 0°



(b) C_d for AoA = 0°

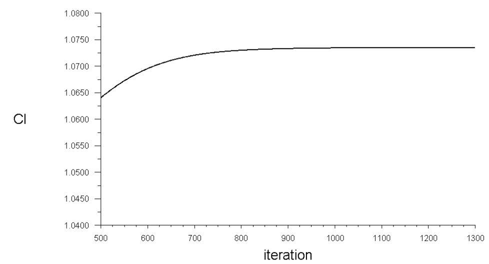


(c) C_m for AoA = 0°

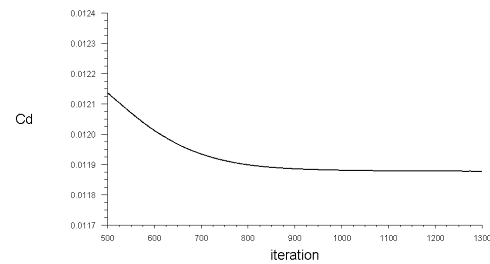


(d) Residual plot for AoA = 0°

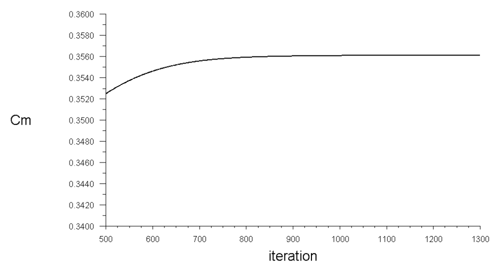
AoA $= 5°$



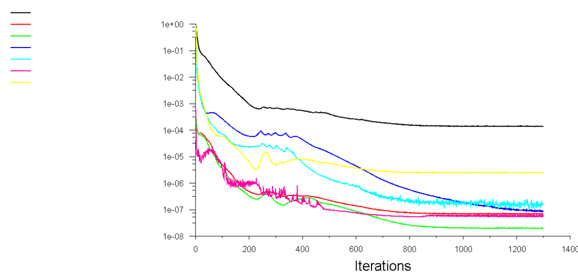
(a) C_l for AoA $= 5°$



(b) C_d for AoA $= 5°$

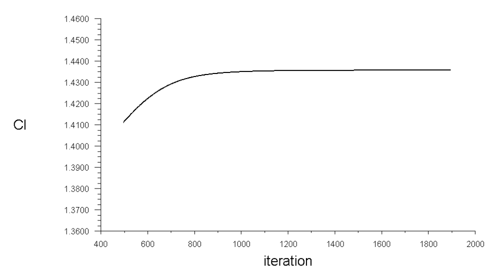


(c) C_m for AoA $= 5°$

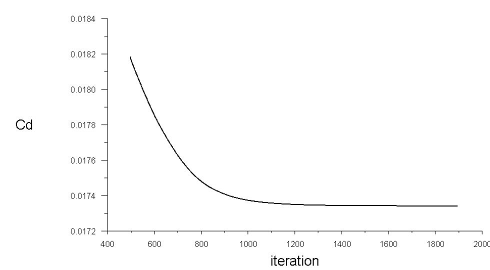


(d) Residual plot for AoA $= 5°$

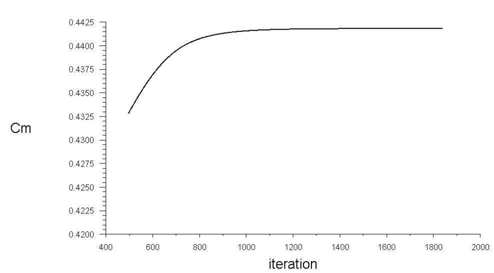
AoA $= 8.5°$



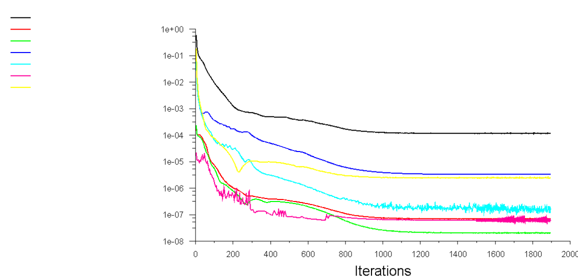
(a) C_l for AoA $= 8.5°$



(b) C_d for AoA $= 8.5°$

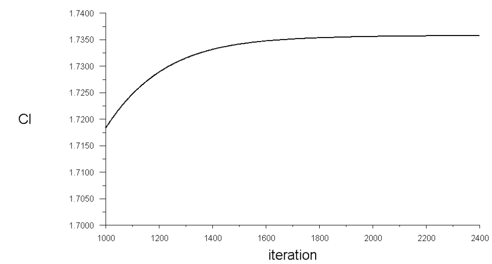


(c) C_m for AoA $= 8.5°$

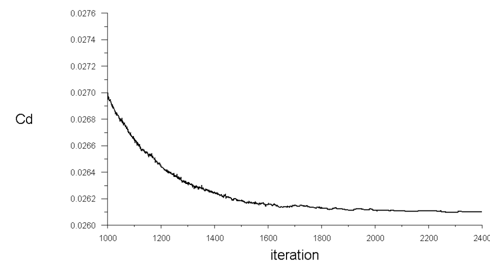


(d) Residual plot for AoA $= 8.5°$

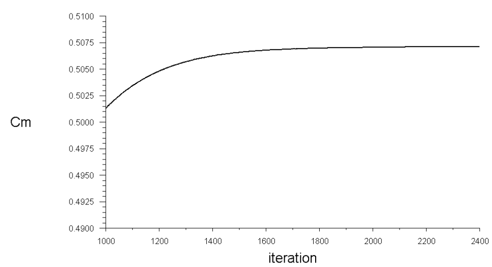
AoA $= 12°$



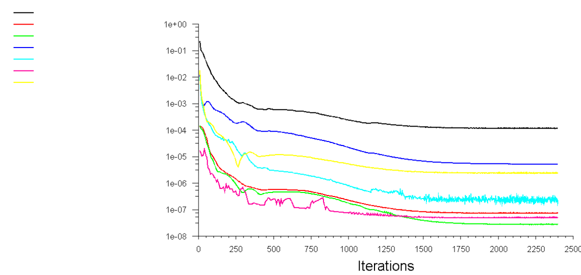
(a) C_l for AoA $= 12°$



(b) C_d for AoA $= 12°$

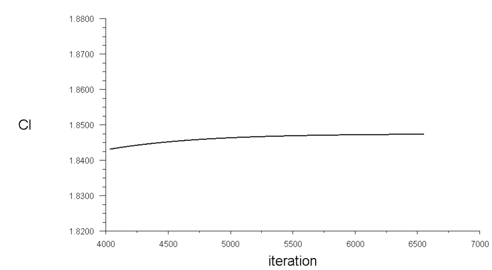


(c) C_m for AoA $= 12°$

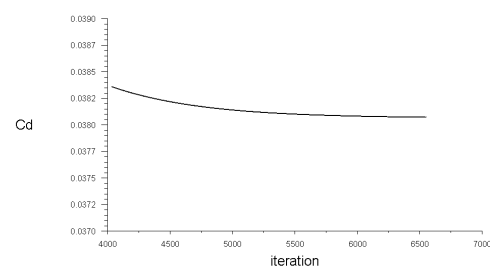


(d) Residual plot for AoA $= 12°$

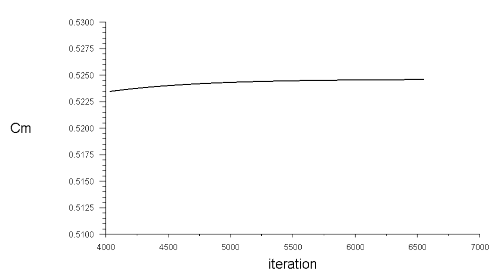
AoA $= 14.5°$



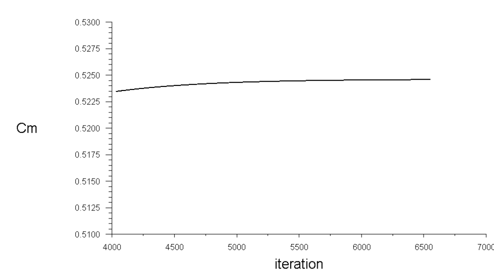
(a) C_l for AoA $= 14.5°$



(b) C_d for AoA $= 14.5°$

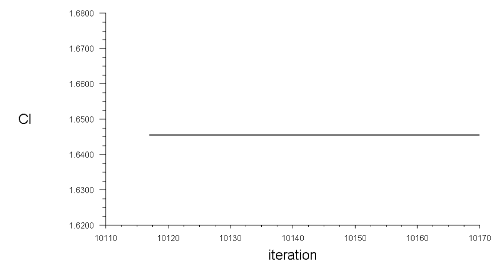


(c) C_m for AoA $= 14.5°$

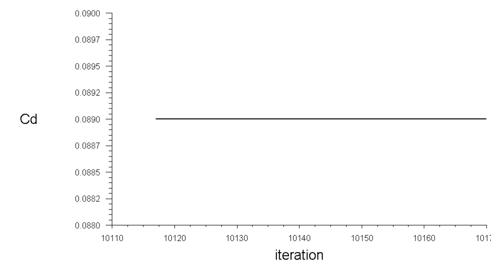


(d) Residual plot for AoA $= 14.5°$

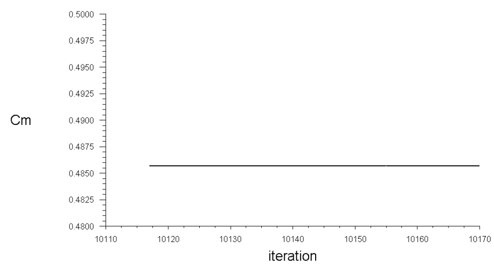
AoA $= 17^\circ$



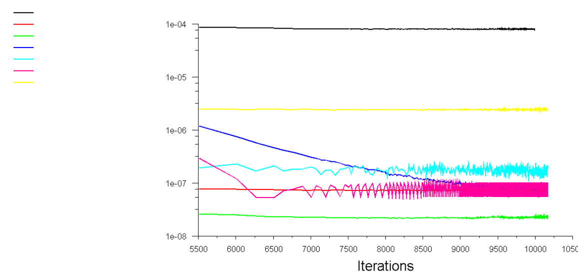
(a) C_l for AoA $= 17^\circ$



(b) C_d for AoA $= 17^\circ$

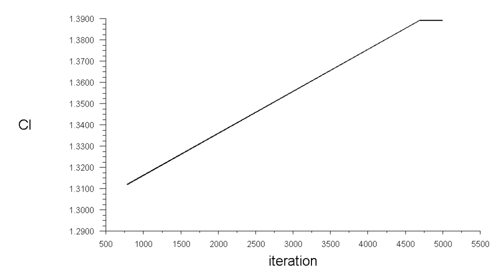


(c) C_m for AoA $= 17^\circ$

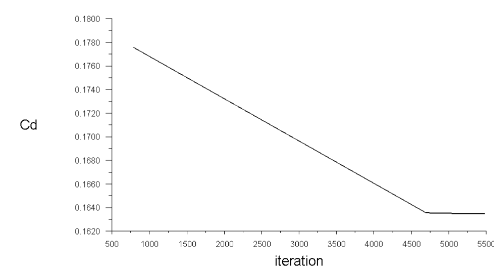


(d) Residual plot for AoA $= 17^\circ$

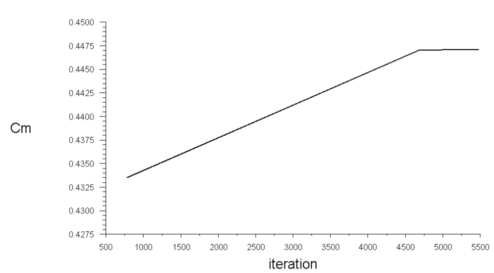
AoA $= 19.5^\circ$



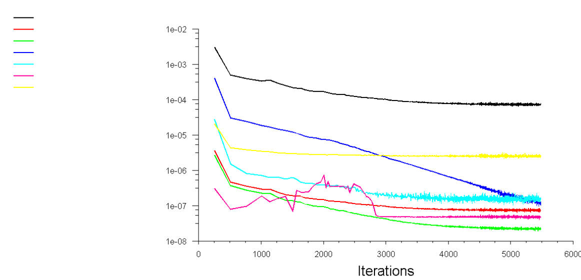
(a) C_l for AoA $= 19.5^\circ$



(b) C_d for AoA $= 19.5^\circ$

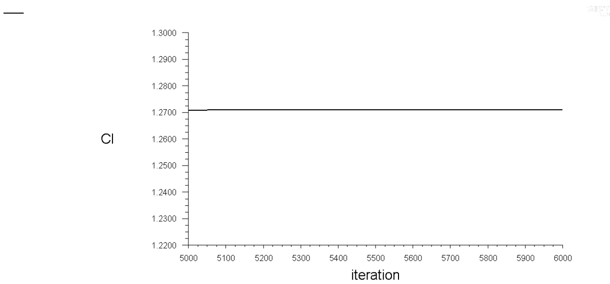


(c) C_m for AoA $= 19.5^\circ$

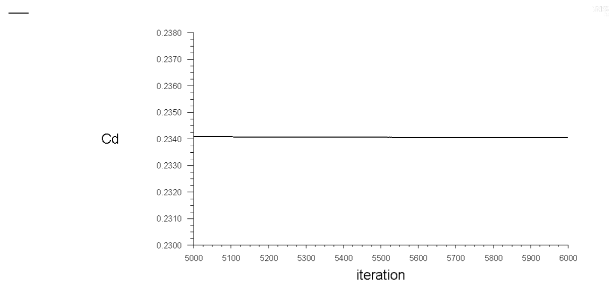


(d) Residual plot for AoA $= 19.5^\circ$

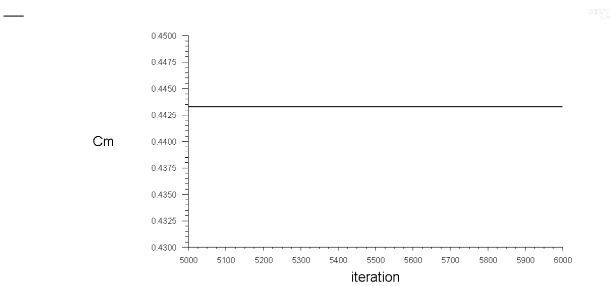
AoA $= 22^{\circ}$



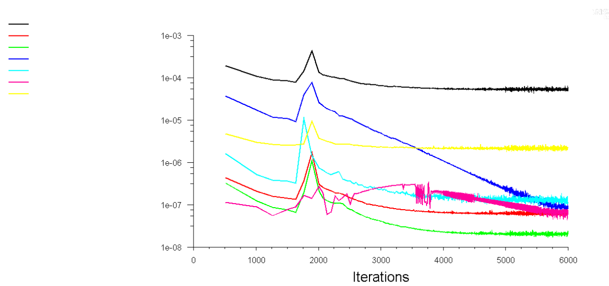
(a) C_l for AoA $= 22^{\circ}$



(b) C_d for AoA $= 22^{\circ}$



(c) C_m for AoA $= 22^{\circ}$



(d) Residual plot for AoA $= 22^{\circ}$