MECH 539: Computational Aerodynamics
Department of Mechanical Engineering, McGill University

Project #5: Investigating Subsonic Viscous Aerodynamic Flow over an Airfoil
Due 15th April, 2016

Investigate the subsonic viscous aerodynamic flow over a NACA0012 airfoil at an eight degree angle of attack. The freestream Reynolds number is 2 million, while the Mach number is 0.1. The attached data file contains the x- and y-coordinates of the entire mesh. The third through sixth columns provide the non-dimensionalized, density ρ, x-momentum ρu, y-momentum ρv, and energy ρe. The seventh and eight columns provides the dynamic viscosity, μ and the eddy viscosity, μ_T, while the last column provides the square of the normal distance from the wall, y^2. The freestream static pressure is 1.0, the ratio of specific heats, $\gamma = 1.4$. Provide the following in a written report with a thorough discussion of your observation for each of the subsequent question:

1. **Investigate the pressure distribution**. Evaluate the coefficient of pressure, c_p over the surface of the airfoil and provide a plot of both the upper and lower coefficient of pressure as a function of the x-coordinate. The vertical axis is to be plotted in reverse with the negative axis pointed upwards. Clearly mark the difference between the upper and lower coefficient of pressure distributions. Provide axis lables, titles and a legend. Describe the flow over the airfoil based on the coefficient of pressure distribution.

2. **Investigate the shear-stress distribution**. Evaluate the skin friction coefficient, c_f over the surface of the airfoil and provide a plot of both the upper and lower skin friction coefficient as a function of the x-coordinate. Note: First evaluate the wall shear stress over the surface and the employ it to compute the skin friction coefficient.

3. **Investigate the aerodynamic performance.** Evaluate the coefficient of lift, c_l, drag due to the pressure force, c_{d_p}, and the drag due to skin friction, c_{d_f}. Provide a table with listing the c_l, c_{d_p}, c_{d_f}, and the total drag coefficient, $c_d = c_{d_f} + c_{d_p}$. Discuss the magnitude of the values in relation with each other. Compare the values against experimental data. Cite the source for the experimental data. Note any discrepancies between the computational and experimental data.

4. **Investigate the boundary layer.** Using the skin-friction plot from [2.] report on whether any separation exists on the surface of the airfoil. Report on whether the boundary layer is laminar, turbulent, or both might be present at separate locations. Plot the $u+$ versus $y+$ values in each of the laminar and/or turbulent regions. If there are regions that are separated then note the point of separation and reattachment.

5. **Further investigate the turbulent boundary layer.** At $x = 0.5$, plot the $u+$ versus $y+$ for the upper surface. Also plot the analytical solutions for the $u+$ versus $y+$ in both the viscous sub-layer and the log law region of the inner boundary layer.

6. **Investigate the momentum deficit in the wake**. Plot the fluid speed profile through the wake regions at the following downstream coordinates: $1/4$-chord, $1/2$-chord, 1-chord, and 2-chords. Ensure that the complete region of the wake is observable at each downstream coordinate. Discuss how the wake evolves as it convects downstream. Report on the size, magnitude and location of the maximum deficit.