MAE 4230/5230 Homework 7

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1. Simulate the laminar boundary layer over a flat plate using FLUENT for a Reynolds number Re_L=10^5 where
$$Re_L = \frac{\rho U L}{\mu}.$$
A tutorial that shows how to solve this problem using FLUENT is available at *https://confluence.cornell.edu/x/9YxoBQ*. The Reynolds number in the tutorial problem is 10^4. Change the value of the coefficient of viscosity μ from the tutorial example to get Re_L=10^5, keeping all other parameters the same. Use the same mesh as in the tutorial. You have the option of skipping the geometry and meshing steps in the tutorial by downloading the mesh at the top of the geometry step. Students enrolled in the Tuesday section should use the mesh they generated for the section HW.

   (a) While developing boundary-layer theory, Prandtl made the following key arguments about the boundary-layer flow to simplify the Navier-Stokes equations:

      i. $u \gg v$

      ii. Steamwise velocity gradients $\ll$ Transverse velocity gradients; for instance, $\dfrac{\partial u}{\partial x} \ll \dfrac{\partial u}{\partial y}$

   Since we are solving the Navier-Stokes equations, we can use the FLUENT solution to check the validity of the above two essential features of boundary layers. Consider the solution at $x = 0.5$ and $x = 0.7$ and make plots of appropriate profiles to check the validity of these two features. Make one figure to illustrate each feature. Choose the upper limit of your abscissa (vertical axis) such that you can clearly see the variation within the boundary layer (the flow outside the boundary layer is not very interesting in this case).

   (b) For the FLUENT solution, plot the u-velocity profiles (y vs. u) at x=0.5, 0.7, and 0.9 in the same figure. Briefly comment on the change in the velocity profile with x.

   (c) Prandtl's student Blasius deduced that the velocity profiles in a flat plate boundary layer obey the similarity principle i.e. if rescaled accordingly, they should collapse to a single curve. Re-plot the profiles from part (b) in terms of the Blasius variables (η vs. $u/U(x)$) in a different figure. Also plot the corresponding values from the Blasius solution in this figure (you should have this from Homework 6). How well does the FLUENT solution obey the similarity principle?

2. Consider the steady flow past a circular cylinder at Re = 40.

(a) What is the value of the drag coefficient for this Re reported by Fonberg (1980)? This paper can be accessed at *http://www.mae.cornell.edu/swanson/mae423files.html*

(b) Simulate this flow using FLUENT. The mesh can be downloaded from the above website. The cylinder diameter is 1 m. Plot the streamlines near the cylinder. Calculate the drag coefficient from your FLUENT results and compare with Fonberg (1980).

3. Consider the unsteady flow past a circular cylinder at Re = 120.

(a) The non-dimensional frequency is called the Strouhal no. and is given by

$$St = fD/U$$

where f is dimensional frequency, D is the cylinder diameter and U is the free-stream velocity. From experiments, Williamson & Brown (1998) determined the following relationship in this Re regime: $St = 0.285 - 1.390/\sqrt{Re} + 1.806/Re$ What is the experimentally-determined St for Re = 120 ?

(b) Simulate this flow using FLUENT. Let τ be the non-dimensional time: $\tau = tU/D$. Use a non-dimensional time-step $\Delta\tau = 0.2$ until the lift coefficient becomes sinusoidal (indicating periodic vortex shedding). Then decrease $\Delta\tau$ to 0.02 and continue marching in time until the frequency and amplitude of the lift coefficient are not changing. Export your lift coefficient data to a file and estimate St for $\Delta\tau = 0.2$ and 0.02. Use at least five peaks in determining the frequency in each case. Compare these values of St to the experimental value above. Comment briefly on the effect of the time step on the computed St.