Final Exam:
Thursday, December 12, 10:30 am – 12:30 pm
LILLY 1105

The questions will be problem based, similar to the homework problems. The final exam is cumulative with approximately a quarter of the points for questions on Viscous flow.

- You can bring your 2-sided formula sheet.
- You should bring a calculator to the exam.

Suggested Study Strategy:
1) Review the homework assignments, especially the problems you may have done incorrectly. Focus on understanding solution strategies and concepts when looking at these problems.
2) Review the questions listed below
3) Review lecture notes for important points and example problems
4) Review appropriate summary sections in the book

Study Questions (in addition to questions for Exam 1 & 2):

1) Potential Flow
   a) What are the four type of fundamental potential solution that we discussed in class?
   b) Define the stream function, velocity potential, and velocity for the four fundamental potential flow solution.
   c) What is the physical meaning of Q for source flow?
   d) How do you find stagnation points?
   e) What combination of elementary flows gives a doublet?
   f) How do we compute the stagnation points for this flow?
   g) How do we determine the body shape?
   h) What is a necessary, but not sufficient condition for a closed body to exist?
   i) What do we get if we combine a uniform flow with a doublet?
   j) Is the potential solution around a cylinder physically realistic? Why?
   k) Show that Bernoulli's equation applied to potential flows results in the following expression for the pressure coefficient:
      \[ C_p = 1 - \left( \frac{V}{V_\infty} \right)^2 \]
      expression for the pressure coefficient:
   l) What is D’Alembert’s Paradox? How does it relate to potential flow?
   m) What combination of elementary potential flow solutions gives a lifting flow over a cylinder?
   n) What is Kutta-Joukowski theorem?
   o) What is Kutta condition?

2) Panel Methods
   a) What is the basis of panel methods?
b) How many equations are needed to determine a lifting flow over an airfoil using a panel method? Which equations are used?
c) What simplifications can be made to a panel method which would make hand calculations easier?

3) Overview of Viscous flow
   a) What is the velocity boundary condition for viscous flows? How is this different from the velocity boundary condition for inviscid flows?
   b) What is a boundary layer?
   c) What is separation?
   d) What is aerodynamic heating and why is it important for high speed viscous flows? (i.e. re-entry vehicles)
   e) What is transition?
   f) How does a turbulent velocity profile compare to a laminar one?
   g) Do turbulent or laminar flows have higher shear stress?
   h) In general, do turbulent flows separate earlier or later than laminar flows? Why?

4) Navier-Stokes Equations
   a) For a viscous flow what is the shear stress proportional to? (hint: in a solid the stress is proportional to the strain.)
   b) What is a Newtonian fluid? Give an example of a Newtonian and a non-Newtonian fluid.
   c) How are the 9 components of the shear stress tensor defined for a Newtonian fluid?
   d) What are the Navier-Stokes Equations for an incompressible flow?
   e) How is the viscous heating term formulated for a Newtonian fluid?
   f) What is the energy equation for viscous flows? What are some special form of the energy equation and when can they be used?
   g) Relate the Navier-Stokes Equations to the Global Conservation Equations, by explaining which terms in the Navier-Stokes Equations corresponds to the terms in the Global Conservation Equations.

5) Non-dimensionalization
   a) Why do we non-dimensionalize the governing equations?
   b) How does non-dimensionalization of the governing equations related to the Buckingham Pi Theorem?
   c) What are the important non-dimensional numbers for viscous flow? Define these non-dimensional numbers.

6) Exact Solution to the Navier-Stokes Equations
   a) Why are the Navier-Stokes Equations difficult to solve analytically?
   b) What is the process for determining an exact solution to the Navier-Stokes Equations?
   c) Give some examples of simplifying assumptions that are made to determine exact solutions?
   d) What is a self-similar solution?

7) Boundary Layers
   a) How do we define the boundary layer thickness?
   b) What is meant by displacement thickness and how is the displacement thickness related to the concept of effective body shape?
c) What is the momentum thickness and how is it related to drag?

d) How are the boundary layer equations derived? Which terms are small in the boundary layer and why? Specifically, what is \( \frac{\partial p}{\partial y} \) approximately equal to?

e) How is \( \frac{\partial p}{\partial x} \) determined for the boundary layer equations?

f) What is the response of the boundary layer to pressure gradients?
   i) Define a favorable pressure gradient. Can a boundary layer separate in a favorable pressure gradient? Justify your answer.
   ii) Define an adverse pressure gradient. Can a boundary layer separate in a favorable pressure gradient? Justify your answer.
   iii) How does separation affect the performance of a wing?

g) When can you use the Blasius boundary layer solution?

h) What is Thwaites’ method?
   i) How is the displacement thickness, momentum thickness, and wall shear stress found using Thwaites’ method?
   ii) In terms of a variable, how does Thwaites’ method define boundary layer separation?