ME351B Mid-Term
Win 2003-2004

Mechanical Engineering, Stanford University

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This is a take-home, closed books/notes mid-term.

The maximum amount of time permitted is 2 hours. There are 13 questions. So on the average you have about 9 minutes per question. Do all the questions first, then go over your answers; ebellish your answers and add clarifications when you have time.

The maximum number of points for this mid-term is 110.

Put it in a sealed manila envelop, sign your name and date and time it. Submit it in class on Tuesday.

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1. What is the Moody diagram? Sketch it, explain what is the vertical and horizontal axes, and why it is useful. (10 points)

2. What is the dimension of viscosity μ in terms of mass M, length L and time T? How is kinematic viscosity ν defined? What is the approximate (within a factor of two) numerical value of viscosity (or kinematic viscosity) of air or water under 'standard' condition? (10 points)

3. You are told that the speed of sound of a gas, 'a', is a thermodynamic state variable. From the dimensional point of view, how should 'a' be related to other thermodynamic variables such 'p' (pressure) and 'ρ' (density)? (5 points)

4. Write down, succinctly, the mathematical definitions of gradient, divergence, and curl. Define all symbols used. (15 points)

5. What is the physical meaning of the following:

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \mathbf{V} \cdot \nabla$$

where $\mathbf{V}$ is the velocity vector of the flow field. (5 points)

6. Let the viscous stress tensor be denoted by $\bar{\bar{\varepsilon}}$. How is the surface (vector) force $\mathbf{f}_s$ acting by the fluid on a surface element $d\sigma$ (with unit normal $\mathbf{n}$ computed? Give your answer in vector notation and also in index notation. What is the physical meaning of ε_{yx} (how would you say it in English?). (10 points)

7. Write down the work done on a material volume of fluid by the viscous surface force in vector notation and also in index notation. (5 points)

8. Write down the amount of conduction heat flux 'q' (a scalar) on a surface element $d\sigma$ (with unit normal $\mathbf{n}$ in vector notation and also in index notation. (5 points)

9. List the physical arguments used to arrive at the Navier-Stokes viscous stress tensor for a Newtonian fluid. (10 points)

10. In the constant property Navier-Stokes equation, the viscous term is represented by $\mu \nabla^2 \mathbf{V}$. There is no complication when you use Cartesian coordinates. Explain how you would go about handling this term in curvilinear coodinates. You are not asked to do it. Just explain what your strategy is. (10 points)

11. List your succinct summary of Prandtl's physical reasonings behind his boundary layer approximation, and list the major simplifications. Use English. For your reference, the constant property (laminar, two-dimensional) boundary layer equations are:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

and

$$\rho(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}) = -\frac{dp_e}{dx} + \mu\frac{\partial^2 u}{\partial y^2}$$

List the needed initial and boundary conditions. (20 points)

12. How would you estimate the order of magnitude of the thickness of a laminar boundary layer on a semi-infinite flat plate (how does it depend on Reynolds Number—and how is the relevant Reynolds Number defined)? (5 points)

13. Justify the conclusion that the separation of laminar boundary layers do not depend on the characteristic Reynolds Number. (5 points)