80 minutes allowed. The exam is open book to the extent of the printed version of the course lecture notes, your
own notes, homework assignments and solutions and the optional Wickert textbook only. Calculators are allowed,
but not any other electronic devices. The material covered on the exam will emphasize stresses/materials and fluid mechanics (Chapters 5 and 6) but may include Units and Scrutiny (which are always important) as well. The material covered in Chapters 5 and 6 includes

**Stresses and strains, material properties**
- Stress = (Force on a material) / (Area of material that has to withstand this force) – units force/area, like pressure
- Normal stress (σ): stress perpendicular to a particular imaginary plane drawn through a point in the material
- Shear stress (τ): stress parallel to a particular imaginary plane drawn through a point in the material
- Strain (ε): fractional amount of elongation or contraction in a material caused by a stress = ε = ΔL/L, where L = length of material without stress, ΔL = change in length due to stress
- Elastic material: a linear relationship between stress and strain, i.e., σ = εE, E is called the elastic modulus
- Elastic modulus relates more or less to the attractive force between the atoms/molecules in the material; units of E are also force/area
- Yield, ultimate, fracture stresses depend only partially on this attractive force; these stresses also depend on the grain size and structure
- Poisson’s ratio (ν), i.e. v = -(Δd/d)/(ΔL/L), Δd = change in diameter due to stress
- Relationships between normal and shear stresses (stress is actually a 3 x 3 matrix) – principal stresses
- Pressure vessels – hoop and longitudinal stress, end caps
- Bending of beams – moments, stresses
- Buckling of columns

**Fluid mechanics**
- Hydrostatic pressure \( P(z) = P(0) - \rho g z \) (if \( z \) is defined positive upward)
- Buoyant force \( F = (\rho_f - \rho_o)gV \)
- Bernoulli’s equation – relates pressure (\( P \)), velocity (\( v \)) and elevation (\( z \)) (defined positive upward in this case) for an incompressible (\( \rho = \) constant) fluid (generally, in a pipe or duct) for steady flow when viscosity is unimportant.
- Viscosity effects
  - Definition of dynamic (\( \mu \)) and kinematic (\( \nu \)) viscosity
  - Reynolds number \( Re = \frac{vL}{\nu} \) - measure of the importance of viscosity
- Lift and drag coefficients
- Navier-Stokes equations – \( \mathbf{F} = \frac{d(mv)}{dt} \) applied to a fluid
- Laminar and turbulent flow – flows are always turbulent when \( Re \) is high enough
• Drag coefficient for spheres and cylinders with laminar and turbulent flow
• Friction factor \((f)\) and pressure drop in pipes with laminar and turbulent flow
  o Moody diagram – incompressible fluid, constant diameter pipe, steady flow
• Compressible flow – when the fluid density \((\rho)\) cannot be considered constant, which really means when the Mach number \((M)\) is not << 1
  o \(M = \frac{v}{c}\), where \(c\) = sound speed = \((\gamma RT)^{1/2}\)
  o Isentropic flow equations – special case with steady flow, no friction, no shock waves

Last year’s 2\(^{nd}\) midterm (should look familiar…) (average was 60)

**Problem #1 (scrutiny) (20 points total)**

I calculated the power required to pump liquid through a new type of pipe as follows:

\[
Power = \sqrt{\frac{\rho v^5 \dot{m}^2}{\mu^2}} - \frac{1}{2f} \frac{\dot{m} v^2 d}{L} + 3.2 \text{ Watts} - 8
\]

where \(\rho\) = density, \(\mu\) = dynamic viscosity, \(v\) = fluid velocity, \(\dot{m}\) = mass flow rate, \(f\) = friction factor, \(d\) = pipe diameter and \(L\) = pipe length.

What “obvious” mistakes can you find with this formula? There are at least 6, but state only 4 of which you are most certain.

**Problem #2 (stresses and materials) (36 points total)**

Ronney Materials, Inc. has invented a new metal, called PDR™, that has all the same properties as aluminum (Al) except that its yield stress in compression is 3 times larger than Al and its yield stress in shear is 3 times smaller than Al (see table):

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield stress (\sigma_{\text{yield}}) (tension) (N/m(^2))</th>
<th>Yield stress (\sigma_{\text{yield}}) (compression) (N/m(^2))</th>
<th>Yield stress (\sigma_{\text{yield}}) (shear) (N/m(^2))</th>
<th>Elastic modulus ((E)), (N/m(^2))</th>
<th>Poisson's ratio ((\nu))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>300 x 10(^6)</td>
<td>300 x 10(^6)</td>
<td>300 x 10(^6)</td>
<td>70 x 10(^9)</td>
<td>0.32</td>
</tr>
<tr>
<td>PDR™</td>
<td>300 x 10(^6)</td>
<td>900 x 10(^6)</td>
<td>100 x 10(^6)</td>
<td>70 x 10(^9)</td>
<td>0.32</td>
</tr>
</tbody>
</table>

If PDR™ were substituted for aluminum, how would each of the following structural properties be affected? Specifically, would the property increase, decrease or remain the same, and if there is a change, is it by less than, more than or exactly a factor of 3? **No credit without explanation!**

(a) The maximum pressure \((P)\) that a cylindrical pressure vessel with the high pressure inside could withstand without the material yielding
(b) The maximum pressure \((P)\) that a cylindrical pressure vessel with the high pressure outside could withstand without the material yielding
(c) The maximum bending moment \((M_{\text{max}})\) on a point-loaded beam
(d) The maximum uniform load (w, force/length) that a beam of round cross-section could withstand without the material yielding.

(e) Maximum deflection (Δ) of a point-loaded beam of square cross-section.

(f) The maximum force that a column of circular cross-section with pinned ends can withstand without buckling.

**Problem #3 (fluid mechanics) (44 points total)**

Air at an inlet pressure of 10 atm and a temperature of 600°C flows through a steel pipe 1 inch inside diameter, 1/8 inch wall thickness and 100 feet long at a speed of 30 m/s. The kinematic viscosity (ν) of the air is 0.1 cm²/sec, the density (ρ) is 4.0 kg/m³ and the specific heat ratio (γ) is 1.35. The pipe wall is very very smooth and the pipe mass is 60 kg.

(a) (5 points) What is the Reynolds number of the air flow inside the pipe?

(b) (10 points) Compute the pressure drop in the pipe in units of lbf/in².

(c) (7 points) Suppose a small leak occurs in the wall of the pipe. What is the Mach number (M₂) of the air after expansion from the initial pressure (P₁ = 10 atm) and Mach number (M₁ ≈ 0) to ambient pressure (P₂ = 1 atm)?

(d) (7 points) What is the air temperature (T₂) after expansion?

(e) (10 points) If the pipe were dropped into water and remained horizontal, what would the pipe’s terminal velocity be?

(f) (5 points) At this terminal velocity, would the pipe be sinking or rising? Explain.