Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Cambridge, MA 02139

Unified Engineering
Fall 2004

Problem Set #9

Due Date: Tuesday, November 9, 2004 at 5pm

	Time Spent (minutes)
T11	
T12	
T13	
F1	
F2	
F3	
F4	
M8	
Study Time	

Name: ____________________

UNIFIED ENGINEERING Fall 2004

Ian A. Waitz

Problem T11 (Unified Thermodynamics)

Consider a commercial airliner flying at M=0.8 at 11km ($T_{atm} = 217K$, $p_{atm} = 22.6kPa$, $\gamma = 1.4$).

a) In the reference frame of the airplane, what are the static and stagnation (or total) temperatures, and static and stagnation (or total) pressures?

b) In the inlet of the engine, the flow is decelerated (adiabatically and quasi-statically) to about M=0.5 before passing into the compressor. Again in the reference frame of the airplane, what are the stagnation and static pressures and temperatures at the entrance to the compressor?

c) The compressor operates quasi-statically and adiabatically and increases the total pressure of the flow by a factor of 40, before delivering it to the combustor at a Mach number near zero (M= 0.03). What are the stagnation and static pressures and temperatures at the combustor inlet.

d) If the airliner were a supersonic transport flying at M=3 at 18km ($T_{atm} = 217K$, $p_{atm} = 7.5kPa$, $\gamma = 1.4$), what are the static and stagnation temperatures, and static and stagnation pressures in the reference frame of the aircraft?

e) What pressure ratio would be required for the compressor on the supersonic aircraft if the stagnation temperatures at the exit of the compressor were constrained by material limitations to be the same as those for the subsonic aircraft?

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Problem T12 (Unified Thermodynamics)

a) In problem T5 you evaluated the work obtained through three different adiabatic processes. Calculate the change in entropy for those same three processes. What is the relationship between entropy change, work and irreversibility?

b) In problem T7 you were asked to calculate the pressure and temperature at each point in the cycle for MIT's ABB Cogeneration Plant. Calculate the change in entropy of the system for each leg of the cycle and sketch the cycle on a T-s diagram.

c) On the T-s diagram, sketch how you would represent non-isentropic behavior (*e.g.* flow with friction) in the compressor and turbine . Assume that the engine still maintains the calculated pressure ratios across the two components--other properties may be different.

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Problem T13 (Unified Thermodynamics)

Write a short essay (a few paragraphs long) that explains the concepts of reversibility and irreversibility of various thermodynamic processes. Cite examples of how irreversibility would impact the performance of aerospace power and propulsion systems. The concepts should be explained at a level that is understandable by a high school senior or non-technical person.

Unified Engineering Fall 2004
Fluids Problem 1

Part A. (80%) An 8.5×11 piece of paper is sent scooting across a smooth table at a speed of $1\,\mathrm{m/s}$, on a layer of air $1\,\mathrm{mm}$ thick. See figure on page 1 of Lecture 1 notes.

a) Determine the strain rate $\dot{\theta}$ of the air layer, and corresponding shear stress τ being applied to the fluid. Air viscosity at sea level is $\mu = 1.78 \times 10^{-5}\,\mathrm{kg/m \cdot s}$.

b) On its own, the paper will decelerate from the friction. Determine the force F which would have to be applied to the paper to maintain its speed at a constant $1\,\mathrm{m/s}$.

Part B. (20% freebie if completed) Skills self-assessment.
The objective is to establish the average UE student's understanding of material taught in the prerequisite subjects. The collective results will be made available to the whole class to let you gauge your own level of understanding of the material relative to the average UE student.

Use the following scale for your responses.

1 Poor understanding, or never heard of the concept
2 Weak understanding, probably couldn't apply it properly
3 OK understanding, could apply it with considerable effort
4 Good undertanding, could apply it with little or no trouble
5 Excellent understanding, almost second nature

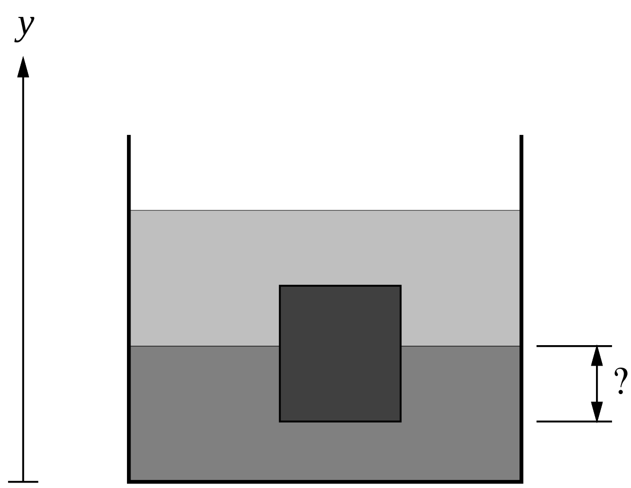
	TOPIC OR CONCEPT	UNDERSTANDING
1	Equation of state for a perfect gas $p = \rho R T$	1 2 3 4 5
2	Fluid viscosity μ	1 2 3 4 5
3	Vector addition and subtraction $\vec{u} + \vec{v}$	1 2 3 4 5
4	Scalar (Dot) product of two vectors $\vec{u} \cdot \vec{v}$	1 2 3 4 5
5	Vector (Cross) product of two vectors $\vec{u} \times \vec{v}$	1 2 3 4 5
6	Vector relations in polar coordinates r, θ	1 2 3 4 5
7	Conversion of a vector into a new coord. system $(x, y) \rightarrow (x', y')$	1 2 3 4 5
8	Normal and tangential vectors on a surface $\hat{n}$, $\hat{t}$	1 2 3 4 5
9	Gradient of a scalar field ∇p	1 2 3 4 5
10	Divergence of a vector field $\nabla \cdot \vec{v}$	1 2 3 4 5
11	Curl of a vector field $\nabla \times \vec{v}$	1 2 3 4 5
12	Stokes Theorem $\iint (\nabla \times \vec{v}) \cdot \hat{n}\, dA = \oint \vec{v} \cdot d\vec{s}$	1 2 3 4 5
13	Gauss (Divergence) Theorem $\iiint \nabla \cdot \vec{v}\, d\mathcal{V} = \oiint \vec{v} \cdot \hat{n}\, dA$	1 2 3 4 5
14	Gradient Theorem $\iiint \nabla p\, d\mathcal{V} = \oiint p\hat{n}\, dA$	1 2 3 4 5
15	Line, Surface, Volume integrals $\int \vec{v} \cdot d\vec{s}$, $\iint \vec{v} \cdot \hat{n}\, dA$, $\iiint \vec{v}\, d\mathcal{V}$	1 2 3 4 5
16	Conservation of mass	1 2 3 4 5
17	Conservation of linear momentum	1 2 3 4 5
18	Conservation of angular momentum	1 2 3 4 5

Unified Engineering Fall 2004
Fluids Problem F2

A large tank is filled half with water ($\rho = 1000\,\mathrm{kg/m^3}$), and half with oil ($\rho = 850\,\mathrm{kg/m^3}$) floating on top of the water. The water and oil depths are 1 m each.

a) Determine and sketch the pressure distribution $p(y) - p_0$ from the bottom of the water to the top of the oil. Choose any convenient p_0 you like.

b) A 1 meter cube of polypropylene ($\rho = 950\,\mathrm{kg/m^3}$) is now dropped in the tank, and comes to rest at it neutral buoyancy position. How far is the bottom of the cube from the water/oil interface?



Unified Engineering Fall 2004
Fluids Problem F3

A certain thin airfoil of chord $c = 0.5\,\mathrm{m}$ has the following linear variation of pressure on both the top and bottom surfaces when operating at $\alpha = 5°$.

$$
\begin{aligned}
p_u(x) &= p_\infty + p_{u_0}(1 - x/c) \\
p_\ell(x) &= p_\infty + p_{\ell_0}(1 - x/c)
\end{aligned}
$$

$$
\begin{aligned}
p_\infty &= 100000\,\mathrm{Pa} \\
p_{u_0} &= -1500\,\mathrm{Pa} \\
p_{\ell_0} &= 1000\,\mathrm{Pa}
\end{aligned}
$$

a) Determine the lift L', moment $M'_{c/4}$, and center of pressure x_{cp}

b) This operating condition corresponds to $c_\ell = 0.8$. What must be the airfoil's flight speed in sea level air?

Anderson Chapter 1, Problem 7. (page 82).

Unified Engineering Problem Set #9 **Unit M2.1**
Fall, 2004

9(M).1 Write out the following tensor equations in full:
(**Note:** these equations do not necessarily have any real meaning)

(a) $C_{mn} = R_{mnjk}\,\Box_j\, z_k$ (for m = 1, n = 3)

(b) $E = 1/2\ \Box_{\Box\Box}\,\Box_{\Box\Box}$

(c) $H_i = b_{\Box\Box}\,P_{\Box\Box}\,n_i$

(d) $\Box_{31} = \ell_{3m'}\,\ell_{1n'}\,\Box'_{m'n'}$

(e) $f_{pq}\,(\partial g_q / \partial t) + x_p = 0$