Massachusetts Institute of Technology
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16.001/16.002 Unified Engineering I, II
Fall 2008

Problem Set 2

Name: ______________________

Due Date: 9/19/2008

	Time Spent (min)
T4	
T5	
F2	
F3	
Study Time	

Announcements:

Unified Engineering Fall 2008
Thermodynamics & Propulsion Z. S. Spakovszky

(Add a short summary of the concepts you are using to solve the problem)

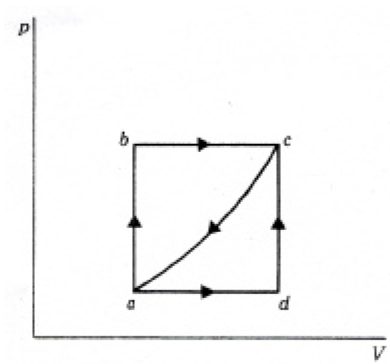
Problem T4

1) During a certain cyclic process a system receives 100 kJ of heat from a reservoir while it is discharging 60 kJ of heat to a sink. Two work quantities are noted during this process. One is an input work of 15 kJ. Find the other work quantity. Also find the net work and state if this is done on or by the system.

2) A system is capable of executing a cyclic process as indicated in the *pV* sketch; it may be executed either clockwise *abca* or counterclockwise *adca*.

   a) When going clockwise to state *c*, 80 kJ of heat flow to the system and 35 kJ of work are done by it. Returning to state *a* from *c*, 60 kJ of heat flow from the system. Find the work along the path *ca*.

   b) When going counterclockwise to state *c*, 70 kJ of heat flow to the system. Find the work during the process *adc*.



Unified Engineering Fall 2008
Thermodynamics & Propulsion Z. S. Spakovszky

(Add a short summary of the concepts you are using to solve the problem)

Problem T5

The schematic on the next page shows the pressure and temperature profiles through a modern two-spool turbofan engine. The fan, compressors and turbines can be assumed adiabatic. An animation of how a jet engine works can be found under:

http://www.rolls-royce.com/education/schools/how_things_work/journey02/flash.html

The fan (STA 2 to 2.4) is driven by the low pressure turbine (STA 5.4 to 5.5) and the core compressor (STA 2C to 3) is driven by the high pressure turbine (STA 4 to 5). The specific heat of air in the compressor and in the turbine are c_{pC} = 1000 J/kgK and c_{pT} = 1200 J/kgK respectively.

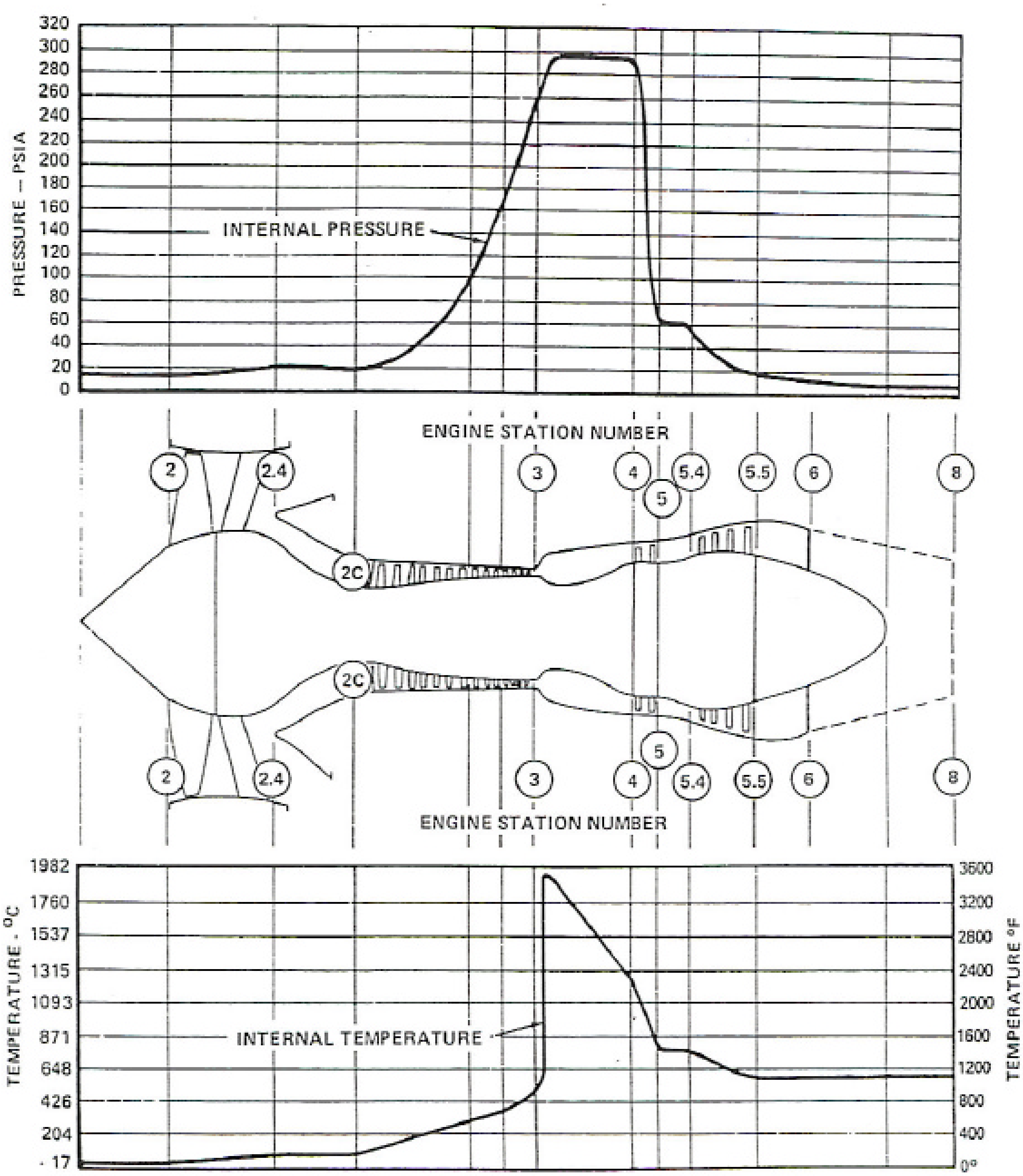
a) What is the power needed to drive the high-pressure compressor if the mass flow rate through the core is 30 kg/s?

b) How much heat is transferred to the air flow in the combustor?

c) The bypass ratio of an engine is defined as the ratio of the mass flow rate in the bypass stream to the mass flow rate through the core of the engine. Determine the bypass ratio for this engine. (Suggestion: it might help to make a schematic of the engine and its shaft arrangements.)

d) What is the power needed to drive the fan?

Problem T5 continued



Problem F2

Electrospray thrusters are little rocket engines that operate in vacuum conditions, producing a stream of very small, electrically charged, liquid droplets. Consider such a device creating droplets of radius R and electric charge Q. In this problem we will focus on the isolated situation of a single droplet. The electric charge distributes on the surface of the droplet, thus generating an electric field of magnitude,

$$E = \frac{Q}{4\pi\varepsilon_0 R^2}.$$

Since like charges repel each other, the droplet surface becomes stressed by an outward *electric pressure* of magnitude $P_E = \frac{1}{2}\varepsilon_0 E^2$, which acts normal to the droplet surface.

1. What is the maximum number of elementary charges e that such droplets can hold before *exploding* due to charge repulsion?
2. What is the maximum electric charge per unit mass of these droplets?

Use the following data for numerical evaluation:

Surface tension, $\gamma = 0.05$ J/m^2

Droplet radius, $R = 20$ nm (1 nm = 10^{-9} m)

Permittivity of vacuum, $\varepsilon_0 = 8.854\times10^{-12}$ F/m

Elementary charge, $e = 1.6\times10^{-19}$ C

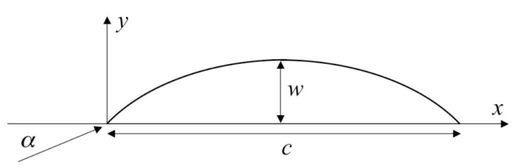
Droplet density, $\rho = 1200$ kg/m^3

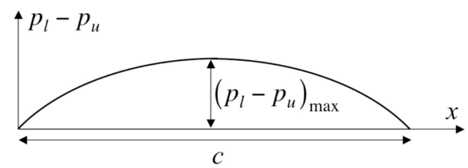
Unified Engineering Fall 2008
Fluids P. Lozano

Problem F3

Consider a parabolically shaped airfoil profile. A fluid of density ρ flows towards the airfoil with a uniform upstream speed V_∞ at an angle of attack α with respect to its chord. The pressure distribution $p_l - p_u$ is also paraboidal, with a maximum value of,

$$\left(p_l - p_u\right)_{\max} = 2\rho V_\infty^2 \left(\frac{w}{c}\right)^2. \quad \text{Assume } p_l = const = p_\infty.$$





1. Find expressions of the type $f(x) = Ax(1+Bx)$ for the airfoil shape $y(x)$ and the pressure distribution $(p_l - p_u)(x)$.
2. Neglecting shear stresses, derive equations for the local lift coefficient $c_l = L'/q_\infty c$ and the local quarter-chord moment coefficient $c_{m\,c/4} = M'_{c/4}/q_\infty c^2$.

   Note: <u>Do not</u> neglect α or y' terms for this part.
3. The following expressions, shown in class, result from neglecting α and y' terms:

$$L' \approx \int_0^c (p_l - p_u)dx \qquad M'_{c/4} \approx \int_0^c -(p_l - p_u)(x - c/4)dx$$

   Compare the local coefficients using these expressions against your results from part 2 for the cases shown in the table. Assume $p_\infty/q_\infty = 5$. <u>*Discuss your results*</u>.

α(deg)	w/c	c_l	$c_{m\,c/4}$	c_l with $\alpha = y' = 0$	$c_{m\,c/4}$ with $\alpha = y' = 0$
0	0.01				
	0.1				
	0.5				
5	0.01				
	0.1				
	0.5				
10	0.01				
	0.1				
	0.5				

Unified Engineering Problem Set 2 **Lectures: M1, M2**
Week 3 Fall, 2008 **Units: M1.1, U-A, some M1.2*(look-ahead)***

M1 (M3.1) ***(10 M-points)*** For the following structures, list key design considerations and discuss the relative importance of these considerations.

(a) business jet

(b) traffic tunnel

(c) step ladder

(d) space station

(e) 18-wheeler transport truck (including transport bin)

(f) glider

M2 (M3.2) ***(10 M-points)*** A 10 m by 10 m grid is situated in the (x-y) plane. The grid is made up of rigid rods connected at 1 m increments. The following set of forces act on this grid:

Force 1 acts at point (1,1) at an angle of 0.0° with a magnitude of 2 N
Force 2 acts at point (1,-4) at an angle of 63.4° with a magnitude of 5 N
Force 3 acts at point (2,-3) at an angle of -116.6° with a magnitude of 5 N
Force 4 acts at point (-5,-5) at an angle of 45° with a magnitude of 3 N
Force 5 acts at point (2,4) at an angle of 251.5° with a magnitude of 3 N
Force 6 acts at point (-5,5) at an angle of 315° with a magnitude of 4 N

(**Note:** Angles are measured positive counterclockwise relative to a line drawn parallel to the x-axis and through the acting point of the force.)

For this configuration:

(**NOTE:** Express the answer as a vector as appropriate.)

(a) Describe each force as a vector and neatly draw out the described configuration.

(b) Determine the total (resultant) force acting on the grid and its magnitude.

(c) Can any of the forces be expressed as a couple? If so, do so.

(d) Determine the moment acting about the origin (center) of the grid.

(e) Determine the moment acting about the upper right-hand corner of the grid.

(f) Determine the components of the moment acting about the x-axis and about the y-axis.