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

16.003/16.004 Unified Engineering III, IV
Spring 2007

Problem Set 9

Name: ________________________

Due Date: 04/18/2007

	Time Spent (min)
T12	
T13	
T14	
F17/18	
F19	
Study Time	

Announcements:

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

Problem T12

A turbojet engine on an aircraft takes in air at *static temperature* T_0 from the atmosphere and exhausts air at a *static temperature* of T_1 at its exit. The aircraft is in level steady flight at velocity u_0. The exhaust velocity of the engine, relative to the aircraft is u_1. Assume air and the combustion gas to be perfect gases with the same specific heat c_p.

a) Sketch the thermodynamic cycle in an h-s diagram and indicate work and heat transfer in each segment of the cycle.

b) What is the heat rejected to the atmosphere per unit of mass flow?

c) What is the *net heat input* to the engine per unit of mass flow?

d) What is the thermal efficiency $\eta_{thermal}$ of the engine?

e) What is the overall efficiency ($\eta_{overall} = \eta_{thermal} \times \eta_{propulsive}$) of the engine?

Express your answers in terms of the given quantities.

Unified Engineering Spring 2007
Thermodynamics & Propulsion Z. S. Spakovszky

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

Problem T13

A ramjet engine is to propel an object at an air speed of 914 m/s at an altitude of 12.8 km (Pa=0.2 bar, Ta=-51 C). We assume that there are no losses. The pressure at the nozzle exit is 0.2 bar and the heating value of fuel is 43 MJ/kg. The stagnation temperature of the gases as they enter the nozzle is 2030 C and the propulsive power at the specified speed is 7.5 MW. Air can be assumed the working fluid neglecting the effects of the fuel. Compute:

a) The stagnation temperature and pressure at the exit of the diffuser.

b) The exit speed of the gases from the nozzle relative to the ramjet.

c) The thrust force and the ramjet mass flow for the desired propulsive power.

d) The net cycle work per unit ramjet mass flow.

e) The fuel-to-air ratio and the rate of fuel flow.

f) The propulsive efficiency.

g) The overall efficiency.

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

Problem T14

Consider a blowdown thrusting system for a spacecraft, which will use hydrogen as the working fluid. The hydrogen will be stored in a high-pressure tank at 20MPa, from which it will be bled to a chamber having a regulated pressure of 1.4MPa. The system temperature will be approximately 300K. The thrusting nozzles will operate with an exit pressure of 70kPa.

a) Make a sketch of the blowdown thrusting system and indicate all system components (i.e. tank, nozzle etc.). Introduce appropriate station numbers.

b) Sketch the process in an h-s diagram, label the states (static and stagnation) and state all your assumptions.

c) What is the specific impulse?

d) What flow rate is required for a 200N thrust?

e) How large must the storage vessel be if the total thrusting requirement is 5000Ns?

Unified Engineering Spring 2007
Fluids Problems F17–F18 (worth 2 Pset Q's)

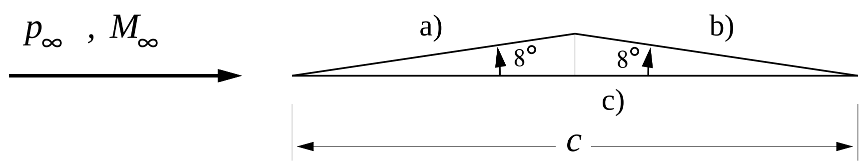
The airfoil shown is operating at $M_\infty = 1.5$. Sketch the flow pattern.

a) Determine the pressure p_a on the front upper facet.
Also obtain the surface Mach number M_a, and then p_{o_a}, which will be needed for part b).

b) Determine the pressure p_b on the rear upper facet.

c) Determine the pressure p_c on the lower surface.

d) Using the surface pressures, determine the L', D', and corresponding c_ℓ and c_d.
(Note: $\rho V^2 = \gamma p M^2$).



A water rocket built from a 2-liter water bottle, sketched below, is pumped up to 400 KPa absolute pressure (about 60 psi). There is no water in the rocket, just the pressurized air. The pumping is done slowly, so that the rocket air stays at the ambient temperature of 300 K. The atmospheric pressure is 100 KPa. The minimum nozzle area is $4\,\mathrm{cm}^2$.

a) Explain why the airflow at the nozzle is locally at $M = 1$ (and not at $M > 1$) when the rocket is launched.

b) At the instant the flow starts, with the inside pressure still nearly at its initial value, determine the following quantities at the nozzle: ρ, p, T, u.

c) Determine an absolute minimum amount of time the air flow will last.
Hint: Determine the initial mass flow through the nozzle.