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

16.001/16.002 Unified Engineering I, II
Fall 2006

Problem Set 12

Name: ________________________

Due Date: 11/28/2006

	Time Spent (min)
T11	
T12	
S5	
S6	
Study Time	

Announcements:

UNIFIED ENGINEERING

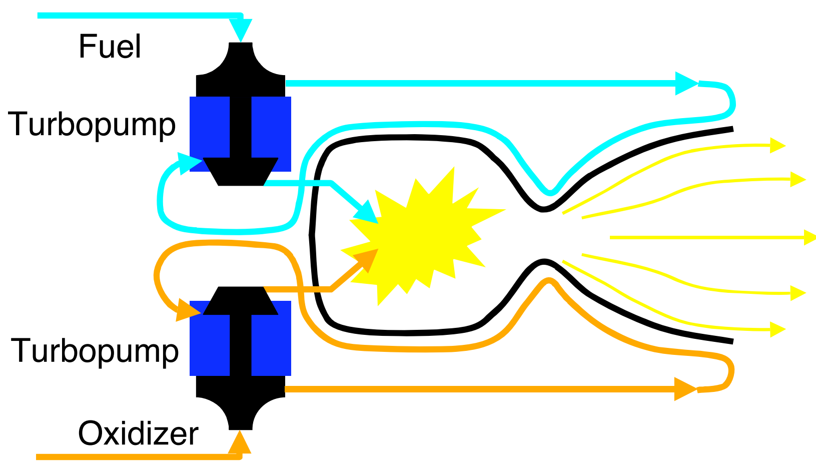
Fall 2006

Ian A. Waitz

Problem T11 (Unified Thermodynamics)

R=287 J/kg-K, c_p=1003.5 J/kg-K, and c_v = 716.5 J/kg-K. (MO# 5)

Below is a schematic diagram of a rocket engine cycle called an expander cycle. The cold liquid propellants are pumped through the walls of the rocket nozzle to cool them. In doing so, they gain energy and turn into gases. Some of the energy in these propellant gases is then extracted in a turbine. The turbine is connected by a shaft to the liquid propellant pump. After passing through the turbine, the propellant gases flow to the combustion chamber where they are ultimately responsible for producing the heat at the walls of the rocket nozzle. So it is a little like pulling yourself up by your bootstraps. As you might expect, the design of a device like this depends on a careful analysis of the thermodynamics, fluid mechanics and structural/material behavior.



To simplify the problem, we will consider only one of the propellants and assume that it is always in gaseous form and behaves as an ideal gas with constant specific heats. Assume R=260 J/kg-K, c_p= 2800 J/kg-K, and c_v = 2540 J/kg-K. (LO #4, LO#6)

a) The cold propellant enters the pump at p = 1MPa, T = 200K and c = 50 m/s. The flow rate is 100 kg/s. The flow leaves the pump at p = 5MPa and c = 50 m/s. Assuming the pump behaves adiabatically and quasi-statically, what are the conditions at the pump exit? How much shaft work and flow work were done by propellant during the pumping process?

b) Assume that 1300 kJ/kg are absorbed by the gas as it passes along the walls of the rocket nozzle. At entrance to the turbine, it is now flowing at c=100 m/s and remains at p = 5MPa. What are the thermodynamic conditions at this point of the engine. How much shaft work and flow work were done by the propellant during the heating process?

c) Assuming the turbine behaves quasi-statically and adiabatically, what are the conditions at the exit of the turbine assuming the velocity is c = 120m/s? How much shaft work and flow work were done by the propellant in the turbine?

Problem T12 (Unified Thermodynamics)

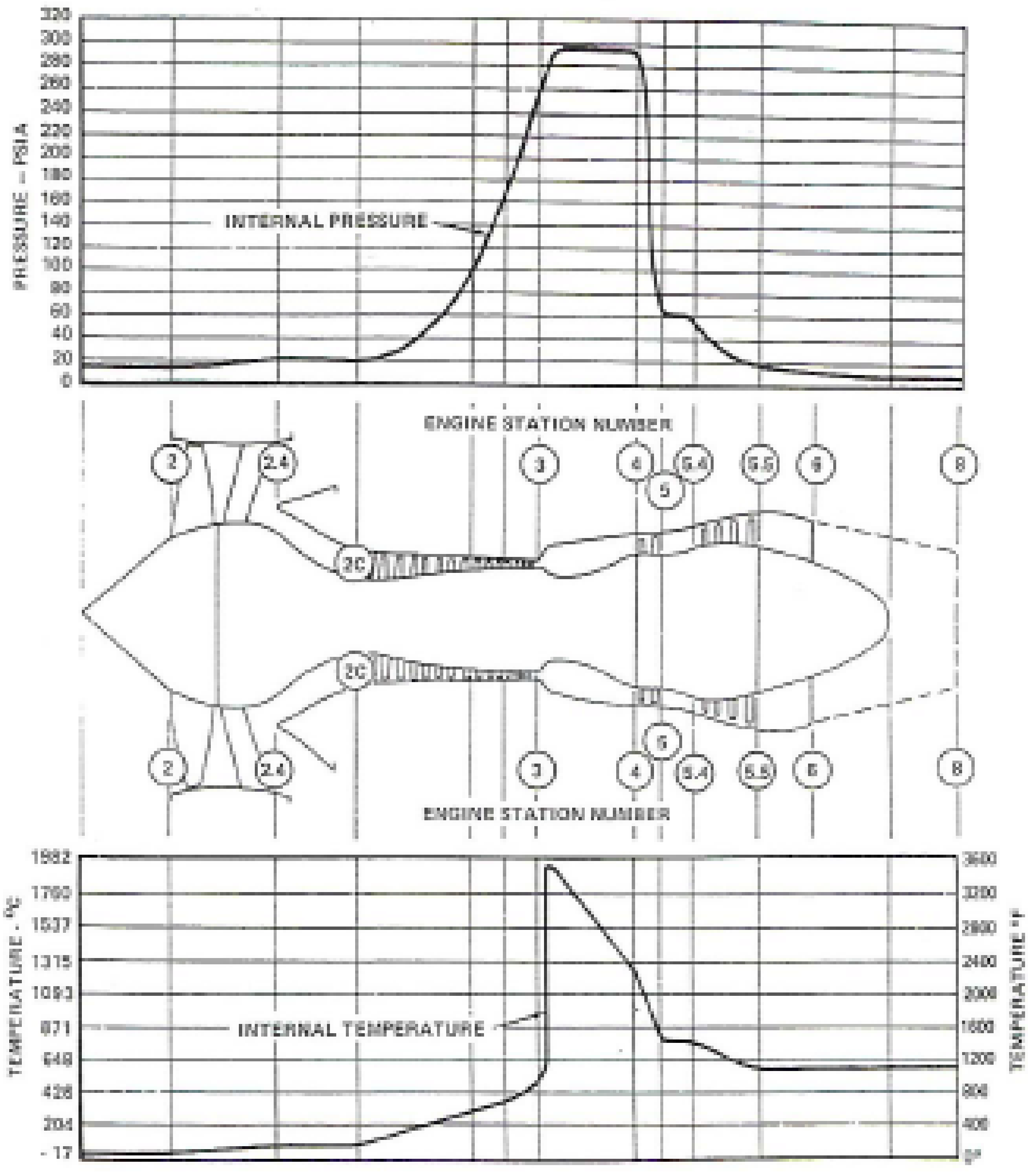
The schematic below shows the stagnation pressure and stagnation temperature profiles through a modern two-spool turbofan engine. The fan (STA 2 to 2.4) is driven by the low pressure turbine (STA 5.4 to 5.5) and the core compressor (STA 2C to 3) is driven by the high pressure turbine (STA 4 to 5). The specific heat of air in the compressor and in the turbine are c_{pC} = 1000 J/kgK and c_{pT} = 1200 J/kgK, respectively. (LO #4, LO#6)

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?

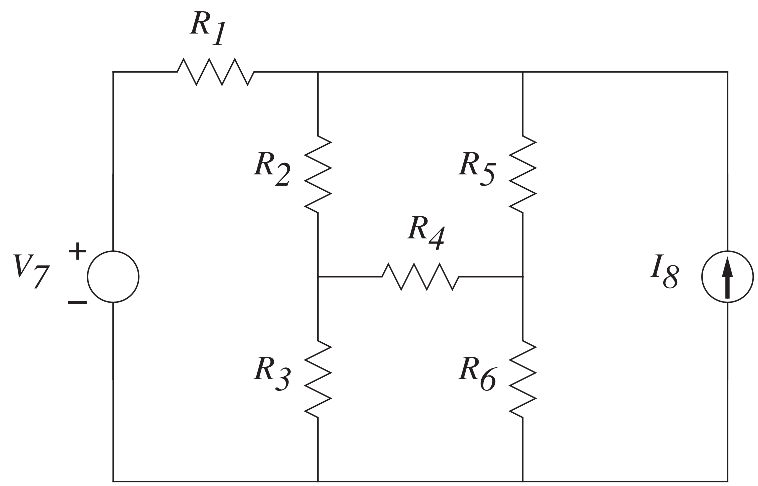
c) The bypass ratio of an engine is defined as the ratio of the mass flow rate in the bypass stream to the mass flow rate through the core of the engine. Determine the bypass ratio for this engine. (Suggestion: it might help to make a schematic of the engine and its shaft arrangements.)

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



PRESSURE – PSIA
INTERNAL PRESSURE
ENGINE STATION NUMBER
2
2.4
2C
3
4
5
5.4
5.5
6
8
INTERNAL TEMPERATURE
TEMPERATURE - °C
TEMPERATURE °F

Problem S5 (Signals and Systems)



For the circuit above, find the branch voltages and branch currents using the loop method. The component values are:

$$\begin{aligned} R_1 &= 1\ \Omega \\ R_2 &= 1\ \Omega \\ R_3 &= 4\ \Omega \\ R_4 &= 6\ \Omega \\ R_5 &= 1\ \Omega \\ R_6 &= 6\ \Omega \\ I_8 &= 3\ \text{A} \\ V_7 &= 5\ \text{V} \end{aligned}$$

Note that the circuit topology is the same as in Problem S3, but the component values are different. (R_6 is different.) Please make sure to use the values above.

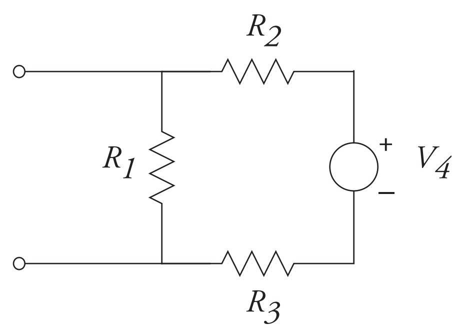
Unified Engineering I **Fall 2006**

Problem S6 (Signals and Systems)

Find the Thevinin and Norton equivalent circuits for the circuits below. Hint: Add a test current to the terminals, and then determine the voltage at the terminals as a function of the test current. You should find that the terminal voltage can be expressed as

$$v = V_T + R_T I_{\text{test}}$$

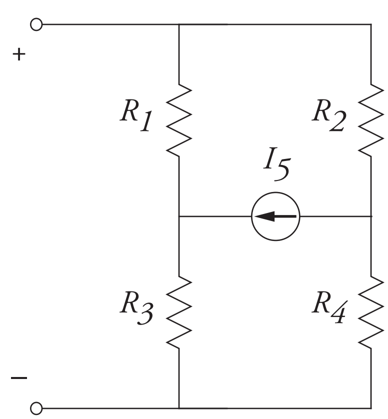
1.



where

$$R_1 = 2\ \Omega,\quad R_2 = 4\ \Omega,\quad R_3 = 3\ \Omega,\quad V_4 = 12\ V$$

2.



where

$$R_1 = 1\ \Omega,\quad R_2 = 3\ \Omega,\quad R_3 = 3\ \Omega,\quad R_4 = 1\ \Omega,\quad I_5 = 8\ \text{A}$$