ASSIGNMENT # 6
Due in class 11/05/2013

Note: All reading assignments below are from Moran and Shapiro, Fundamentals of Engineering Thermodynamics

Suggested reading: Chapter 9: Gas Turbine Power Systems (aircraft propulsion, combined cycles, compressible flow, nozzles and diffusers)

PROBLEMS

[1] (25%) Air at 22 kPa, 220 K, and 250 m/s enters a turbojet engine in flight at an altitude of 10,000 m. The pressure ratio across the compressor is 12. The turbine inlet temperature is 1400 K, and the pressure at the nozzle exit is 22 kPa. The diffuser and nozzle processes are isentropic, the compressor and turbine have isentropic efficiencies of 85 and 88%, respectively, and there is no pressure drop for flow through the combustor. On the basis of an air-standard analysis, determine

(a) The pressures and temperatures at each principal state, in kPa and K, respectively
(b) The velocity at the nozzle exit, in m/s

Neglect kinetic energy except at the diffuse inlet and the nozzle exit

[2] (25%) A combined gas turbine-vapor power plant has a net power output of 10MW. Air enters the compressor of the gas turbine at 100kPa, 300K, and is compressed to 1200 kPa. The isentropic efficiency of the compressor is 84%. The conditions at the inlet to the turbine are 1200 kPa and 1400 K. Air expands through the turbine, which has an isentropic efficiency of 88%, to the pressure of 100 kPa. The air then passes through the interconnecting heat exchanger, and is finally discharged at 480 K. Steam enters the turbine of the vapor power cycle at 8 MPa, 400 °C, and expands to the condenser pressure of 8 kPa. Water enters the pump as saturated liquid at 8 kPa. The turbine and pump have isentropic efficiencies of 90 and 80%, respectively. Determine

(a) the mass flow rates of air and steam, each in kg/s
(b) the thermal efficiency of the combined cycle

[3] (25%) A turboprop engine consists of a diffuser, compressor, combustor, turbine, and nozzle. The turbine drives a propeller as well as the compressor. Air enters the diffuser with a volumetric flow rate of 83.7 m³/s at 40 kPa, 240 K, and a velocity of 180 m/s, and decelerates essentially to
zero velocity. The compressor pressure ratio is 10 and the compressor has an isentropic
efficiency of 85%. The turbine inlet temperature is 1140 K, and its isentropic efficiency is 85%.
The turbine exit pressure is 50 kPa. Flow through the diffuser and nozzle is isentropic. Using an
air-standard analysis, determine

(a) The power delivered to the propeller, in MW
(b) The velocity at the nozzle exit, in m/s

Helium is used in a combined cycle power plant as the working fluid in a simple
closed gas turbine serving as the topping cycle for a vapor power cycle. A nuclear reactor is the
source of energy input to the helium. Helium enters the compressor of the gas turbine at 200
lbf/in$^2$, 180 °F with a mass flow rate of 8 x 10$^5$ lb/h and is compressed to 800 lbf/in$^2$. The
isentropic efficiency of the compressor is 80%. The helium then passes through the reactor with a
negligible decrease in pressure, exiting at 1400 °F. Next, the helium expands through the turbine,
which has an isentropic efficiency of 80 %, to a pressure of 200 lbf/in$^2$. The helium then passes
through the interconnecting heat exchanger before re-entering the compressor. A separate stream
of liquid water enters the heat exchanger and exits as saturated valor at 1200 lbf/in$^2$. The vapor is
superheated in a boiler before entering the turbine at 800 °F, 1200 lbf/in$^2$. The steam expands
through the turbine to 1 lbf/in$^2$ and a quality of 0.9. Saturated liquid exits the condenser at 1
lbf/in$^2$ and it is pumped back to the interconnecting heat exchanger. Cooling water passing
through the condenser experience a temperature rise from 60 °F to 90 °F. The isentropic pump
efficiency is 100%. Stray heat transfer and kinetic and potential energy effects are negligible.
Determine:

(a) The mass flow rates of the steam and the cooling water, each in lb/h
(b) The net power developed by the gas turbine and vapor cycle, each in Btu/h.
(c) The thermal efficiency of the combined cycle.