Homework #6 (group) – Thursday, March 29 by 4:00 pm

5290 exercises (individual) – Thursday, March 29 by 4:00 pm

extra credit (individual) – Tuesday, April 3 by 4:00 pm

Readings for this homework assignment and upcoming lectures

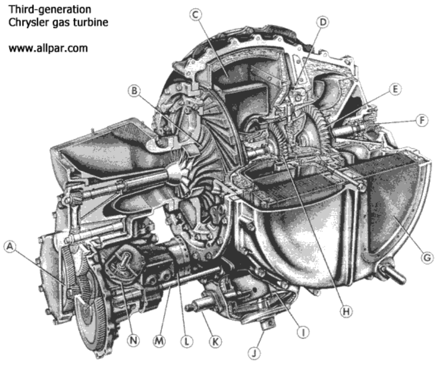
- Read Chapter 5. Gas Turbines and Jet Engines (Weston Textbook)
- Review lecture notes:
  - Part 8. Brayton Cycle

Homework Submission

- For this assignment, the 4200-portion of the homework is to be worked as a group assignment and submitted as a group in class or by dropping off at my office (room 905). If you use EES for this assignment, then print a copy of the code and solution and include with the homework.
- MEEM 5290 problems are always to be worked and submitted individually.
- Bonus problems are always to be worked and submitted individually.
- **At the end of each problem, rank your confidence in the answer from 1 to 5; 5 being very confident and 1 being ‘a guess’.**
- PLEASE include the course number (MEEM4200, MEEM5290) in the subject line of any email correspondence.

Homework #6 - due Thursday, March 29 by 4:00 pm

1. What four processes make up the simple ideal Brayton cycle?
2. Somebody claims that at very high pressure ratios, the use of regeneration actually decreases the thermal efficiency of a gas-turbine engine. Is there any truth in this claim? Explain.
3. Determine the pressure ratio required to produce a net work of 600 Btu/lbm in an ideal, simple Brayton cycle using (i) helium and (ii) air. Assume these gases are ideal with constant specific heats. The cycle has maximum and minimum temperatures of 2500 °R and 500 °R, respectively. Also, calculate the optimum pressure ratio for both gases.
4. In 1903, Aegidius Elling of Norway designed and built an 11-hp gas turbine that used steam injection between the combustion chamber and the turbine to cool the combustion gases to a safe temperature for the materials available at the time. Currently there are several gas-turbine power plants that use steam injection to augment power and improve thermal efficiency. For example, the thermal efficiency of the General Electric LM5000 gas turbine is reported to increase from 35.8% in simple-cycle operation to 43% when steam injection is used. Explain why steam injection increases the power output and the efficiency of gas turbines. Show, using a cycle diagram, how you could obtain the steam.
5. Weston 5.8
6. Weston 5.10
7. The idea of using gas turbines to power automobiles was conceived in the 1930s, and considerable research was done in the 1940s and 1950s to develop automotive gas turbines by major automobile manufacturers such as the Chrysler and Ford corporations in the United States and Rover in the United Kingdom. The worlds first gas-turbine powered automobile, the 200-hp Rover Jet 1, was built in 1950 in the United Kingdom. This was followed by the production of the Plymouth Sport Coupe by Chrysler in 1954 under the leadership of G. J. Huebner. Several hundred gas turbine-powered Plymouth cars were built in the early 1960s for demonstration purposes and were loaned to a select group of people to gather field experience. The users had no complaints other than slow acceleration. But the cars were never mass-produced because of the high production (especially material) costs and the failure to satisfy the provisions of the 1966 Clean Air Act.



MAIN COMPONENTS OF THE TWIN-REGENERATOR GAS TURBINE: (A) accessory drive; (B) compressor; (C) right regenerator rotor; (D) variable nozzle unit; (E) power turbine; (F) reduction gear; (G) left regenerator rotor; (H) gas generator turbine; (I) burner; (J) fuel nozzle; (K) igniter; (L) starter-generator; (M) regenerator drive shaft; (N) ignition unit.

http://www.allpar.com/mopar/turbine.html

   A gas-turbine-powered Plymouth car built in 1960 had a turbine inlet temperature of 1700 °F, a pressure ratio of 4, and a regenerator effectiveness of 0.9. Using isentropic efficiencies of 0.80 for both the compressor and the turbine, determine the thermal efficiency of this car. Also, determine the mass flow rate of air for a net power output of 95 hp. Assume the ambient air to be at 540 °R and 14.5 psia.

8. An open Brayton cycle operates with a compressor-pressure ratio of 5.0, an inlet temperature of 27 °C, and a turbine-inlet temperature of 980 °C, and produces a total of 50 MW_m of mechanical power. For the following systems, find the thermal efficiency, the air mass flow rate, and the total compressor and turbine powers, in kW, assuming that the isentropic compressor and turbine efficiencies are 90%.
    (a) A simple Brayton cycle.
    (b) A regenerative Brayton cycle with a regenerator effectiveness of 80%.
    (c) A reheat Brayton cycle with a reheat at 310 kPa to 955 °C.
    (d) A Brayton cycle with 3 stages of compression with 2 intercoolers that cool the gas back to 27 °C.
    (e) A system that uses the regenerator of part (b) and the reheater of part (c).
    (f) A system that uses the intercoolers of part (d) and the regenerator of (b).

    Homework #6 – 5290 only

9. Weston 5.12
10. Weston 5.19
11. Weston 5.24
12. Weston 5.50

extra credit (individual) – Tuesday, April 3 by 4:00 pm

13. Weston 5.23

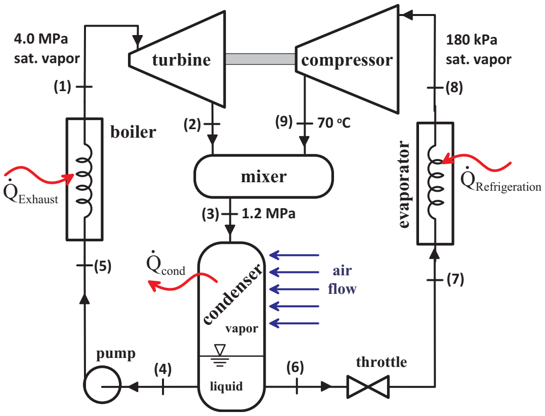
14. Weston 5.30

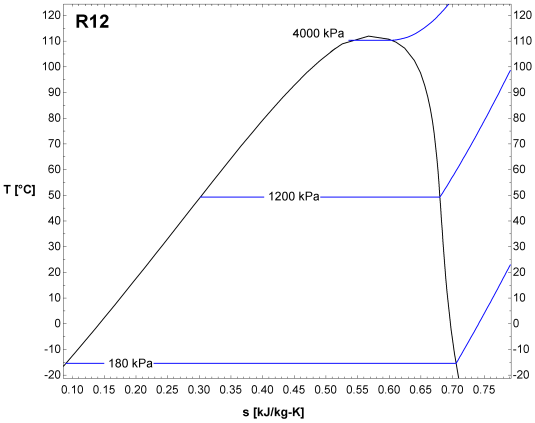
15. You are tasked with designing a combined power-refrigeration cycle for a unique hybrid truck in which waste thermal energy from the engine exhaust is used to cool the cargo hold. The working fluid for both halves of the cycle is Freon-12 (R12). The exhaust gas boils the freon which then expands through a turbine. All of the turbine work is used to power the compressor. Freon from the power cycle mixes with the freon from the refrigeration cycle before condensing in an air-cooled radiator.

    Saturated vapor enters the turbine at 4.0 MPa (1). The low-pressure leg of the refrigeration cycle is at 180 kPa also with saturated vapor entering the compressor (8). The temperature of the freon exiting the compressor is 70 °C (9) and the condenser pressure is maintained at 1.2 MPa (3). The isentropic turbine efficiency is $\eta_t = 0.80$. The pressure drop from turbine-compressor through mixer into the condenser is negligible. Likewise the pressure drops through the heat exchangers are negligible.

    (a) Determine the mass flow ratio of the power cycle to the refrigeration cycle, $\dot{m}_{\text{turbine}}/\dot{m}_{\text{compressor}}$,
    (b) If the thermal energy harvested from the exhaust is $\dot{Q}_{\text{Exhaust}} = 15\,\text{kW}$, and the pump work is negligible, what is the thermal power extracted from the cargo hold, $\dot{Q}_{\text{Refrigeration}}$?
    (c) Sketch the combined cycle on the T-s diagram using the state points shown in the cycle diagram.

    Bonus: What is the compressor efficiency?





16. A high-temperature gas-cooled reactor (HTGR) is coupled to a gas turbine as a closed, direct cycle with helium as the working fluid. Helium serves a dual purpose of cooling the reactor and producing expansion work in the turbine. The helium flow rate is 145,000 kg/hr. The gas enters the turbine at 730 °C and 2500 kPa and is discharged at 450 °C and 980 kPa. The regenerator effectiveness is 86%. At the inlet to the first stage of the three-stage compressor, the pressure is 952 kPa and the inlet and exit temperatures for all three compressor stages are 16 °C and 66 °C, respectively. The discharge pressure from the third compression stage is 2550 kPa. Find:
    (a) The pressure and temperature across each component in the cycle.
    (b) The reactor power in thermal megawatts.
    (c) The fuel cost in \$/kW$_e$hr, if the fuel cost is \$0.75 per million Btu.
    (d) The thermal efficiency and heat rate of the cycle.