Turbomachinery Problem Sheet 1

1. The desk fan discussed in the lecture had a rotational speed to 200 rpm and a diameter of 30 cm, air enters the fan at 3 m/s parallel to the axis of rotation.
   1. Sketch the meridional and cascade views.
   2. Calculate the relative velocity at the fan tip.
   3. Calculate the relative velocity at the fan hub given that the hub diameter is 10 cm.
   4. Can you explain why most desk fans have twisted blades?
2. Explain why a bicycle pump is not classified as a turbomachine.
3. Sketch the meridional view of the turbojet engine shown below.
4. Draw the cascade view of the last stage compressor and the first stage turbine.

General Electric J85-GE-17A turbojet engine¹.

---

¹: Source: http://en.wikipedia.org/wiki/File:J85_ge_17a_turbojet_engine.jpg This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.
Turbomachinery Problem Sheet 3

1. Using the blade heights calculated for the industrial gas turbine in the lecture, draw to scale the meridional view with:
   1. a constant mean radius of 0.4 m.
   2. a constant outer diameter (useful if you wish to minimise cross sectional area) of 1.05 m

   The turbine is an industrial gas turbine operating at an 8.8:1 pressure ratio and a massflow of 77 kg/s. The exhaust temperature is at 437 degrees centigrade and the inlet temperature to the machine is around 1000 degrees centigrade. The machine is to be designed for a constant axial velocity of 200 m/s.

   This data is based on the Rolls-Royce Avon, an engine that dates from the 1950s but is still used as low efficiency high reliability engine for stationary power such as pipeline pumping.

2. This question is the first that requires you to start drawing complex velocity triangles.

   Consider an axial compressor rotor blade row. The inlet velocity is 150 m/s and is in the axial direction. The blade speed is 180 m/s and the relative outlet angle is -30° to the axial. The axial velocity is constant across the row. Calculate the relative flow angle at inlet and the absolute swirl (or tangential) velocity at exit and the absolute flow angle. Calculate also the specific work output. (Answers: -50.2°; 93.4 m/s, +31.9°, 16.8 kJ/kg)

Turbomachinery Problem Sheet 4

1. The flow at exit from a turbine stator row has a velocity of 100 m/s at an angle (α₂) of 70° to the axial direction. Calculate the swirl and axial velocity components. The rotor row is moving with a velocity of 50 m/s. Calculate the velocity magnitude relative to the rotor blades at inlet and the relative inlet flow angle (β₂). At exit from the rotor row the relative flow angle (β₃) is -60°. Assuming that the axial velocity is constant across the row, what is the absolute exit velocity magnitude and direction? (Answers: 94.0 m/s, 34.2 m/s; 55.7 m/s, 52.1°; 35.4 m/s, -15.1°)

2. For the turbine above, assuming that the relative flow at exit from the rotor row is unchanged, calculate the blade speed that would give absolute axial flow at exit (i.e. no swirl). Calculate also the specific work output if the exit flow is axial. (Answers: 59.2 m/s, 4.7 kJ/kg)
1. Write down the equations for the total to total and total to static efficiency of a compressor.

2. The rotor blades of Q3, problem sheet 3 are followed by a set of stator blades to form a complete stage. The stators turn the flow back to the axial direction and the axial velocity is constant across the whole stage. If the total-to-total efficiency is 90%, calculate the total pressure at outlet from the stage. Assume air properties with inlet stagnation conditions of 25°C and 1.0 bar. (Answer: 1.187 bar)

3. You may wish to wait until after all the lectures to attempt this part. Calculate the Reaction of the stage in Q2. (Answer: 0.74)

4. The flow at exit from a turbine stator row has a velocity of 100 m/s at an angle ($\alpha_2$) of 70° to the axial direction. Calculate the swirl and axial velocity components. The rotor row is moving with a velocity of 50 m/s. Calculate the velocity magnitude relative to the rotor blades at inlet and the relative inlet flow angle ($\beta_2$). At exit from the rotor row the relative flow angle ($\beta_3$) is -60°.

(This is from Problem Sheet 4, Q1 you might want to use your answers from that sheet)

Calculate the power output for a flow rate of 4 kg/s. Calculate the total pressure drop across the stage if the total-to-total efficiency is 90% and the fluid density is constant at 1.2 kg/m³. Calculate also the static pressure drop. What is the total-to-static efficiency? You may wish to wait until after all the lectures to attempt this part but you could also calculate the stage reaction? (Answers: 20.6 kW, 6.88 kPa, 6.93 kPa, 81.1%, 0.154)

Turbomachinery Problem Sheet 6

1. The last stage of a multi-stage gas turbine is designed with the following data:
   - Axial velocity constant = 150 m/s
   - Inlet and exit velocities for the stage are axial
   - Stator exit angle, $\alpha_2$ = 70°
   - Mean radius = 0.7 m
   - Rotational speed = 5000 rev/min

   a) Draw the velocity triangles at stator exit/rotor inlet and at rotor exit. Calculate the relative flow angles at rotor inlet and exit.
   b) Calculate the reaction for the stage.

   (Answers: a) $\beta_2 = 16.9^\circ, \ beta_3 = -67.7^\circ$  b) $R = 0.438$)

2. The turbine stage in Q1 is designed to produce 25 MW of power. The inlet stagnation conditions are $T_{01} = 550$ K, $p_{01} = 4.5$ bar. The exit static pressure, $p_3 = 1$ bar. Calculate:
   a) The mass flow of gas
   b) The blade height at exit
   c) The total-to-static and total-to-total efficiencies

   Sketch the process on the T-s diagram. For the gas, $c_p = 1.10$ kJ/kgK, $\gamma = 1.33$

   (Answers: a) 165.5 kg/s  b) 0.276 m  c) $TS = 0.801, TT = 0.849$)
1. The compressor operates with an axial inlet flow velocity of 250 m/s at 3000 rpm. The rotor relative exit angle is set at -34 degrees at a mean radius of 0.75 m. Draw the velocity triangle for the first stage rotor exit and hence estimate the specific work output.

2. The turbine operates with an axial inlet velocity of 300 m/s. The axial velocity is kept constant through the stage. The stator blades have an absolute exit angle of 60 degrees and the rotor blades have a relative exit angle of -30 degrees. Calculate the specific work output and calculate the stage loading coefficient for the turbine at a mean radius of 0.75m.

3. Compare the stage loading coefficient of the turbine and the compressor. Why is the turbine stage loading coefficient higher than that of the compressor? What limits compressor loading?

(Answers: 1) 15.8 kJ/kg, 2) \( w_x = 107.7 \text{ kJ/kg, } \psi_{\text{turbine}} = 1.94 \) 3) \( \psi_{\text{comp}} = 0.28 \) This is an extract from a 2007 exam in Durham)