Due: 28 Nov 2007

Assignment 7

Turbomachinery Problems

**Work in groups of ONE or TWO (not three), submit problem 1 & 2 please work 3 & 4
Problems 3 and 4 can be submitted for extra credit (10 points each)**

1. An axial compressor stage is to be designed using a repeating stage with no inlet guide vane (C_A=C_1=C_3). The inlet pressure and temperature are standard day sea level values and the velocity at the face of the compressor is 492 ft/sec. The machine spins at 6000 RPM and has a hub and tip diameter of 20 in and 24 in respectively. The air is turned 30 degrees in the rotor. Assuming constant gas (air) properties find the following:

   a. Draw the velocity triangles
   b. Sketch the rotor and stator blades by using the flow angles
   c. Compressor mass flow (hint: annulus flow area)
   d. Power required for the first stage
   e. Stage total to total pressure ratio assuming a polytropic efficiency of 0.9
   f. Degree of reaction
   g. For a pressure ratio of 10, how many stages are required?

2. A single stage turbine is to be designed for small inexpensive turbojet engine. The mass flow of the engine is 20 kg/sec with a turbine inlet temperature and pressure of 1100 K and 4 bar respectively, a temperature drop across the turbine of 145 K. The pressure ratio will be 0.533 with an isentropic efficiency of 0.9. The wheel speed is 15,000 RPM and the mean blade speed is 340 m/sec. Assume that α_1 = 10 (pre-swirl) degrees and C_1= C_3.

   a. Determine all unknown absolute and relative flow angles
   b. What are C_A and C_2 (m/sec)
   c. Determine the degree of reaction
   d. Sketch the turbine stator/nozzle and rotor blades
   e. Estimate the annulus area and size the turbine rotor (hub, tip and mean radius)
   f. What are the static temperature and pressure at the stage exit (T_3 and P_3)?
   g. Check the work/power calculated from the velocity triangles with the thermodynamic work/power prescribed.

3. The SR-30 turbine drives the compressor and requires an estimated 55 HP (41.2 kW). Using the following data fully evaluate the velocity triangles for the SR-30:

Thermodynamic:

ηc = 0.64 (Total-to-Total Isentropic)
ηt = 0.75 ((Total-to-Total Isentropic)
Burner exit total temperature and pressure: 950 K, 290 kPa
Burner exit velocity and Mach number: 114 m/sec, 0.19
Mass flow approximately 0.26 kg/sec (see geometry below)

Geometry:

D_{hub} = 64 mm, D_{tip} = 88.9 mm
Max thickness of blades: 3 mm
Number of rotor and stator blades: 26 and 21
Use mean diameter for U with rotational speed as 80,000 RPMs

a. Given this power requirement and assuming a mean line (mean radius) approach, estimate the blade (flow) angles in the SR-30 turbine. Find:
   1) Determine all unknown absolute and relative flow angles
   2) What are C_A and C_2 (m/sec)
   3) Determine the degree of reaction
   4) Sketch the turbine stator/nozzle and rotor blades
   5) What are the static temperature and pressure at the stage exit (T_3 and P_3)?
   6) Check the work/power calculated from the velocity triangles with the thermodynamic work/power prescribed.

b. If we assume the compressor and turbine isentropic efficiency stated above and a mechanical efficiency of 0.98, how many turbine stages are required to more than double the engine pressure ratio from 2.8 to 6?

4. You are stuck on a deserted island in the South Pacific and your aircraft is out of fuel. You discover a large fuel storage tank at the bottom of a ravine. It is about 100 feet below a tank truck parked at the edge of the deserted airstrip. Carrying the amount of fuel (S.G. = 0.8, kinematic viscosity of 2.8e-5 ft^2/sec) required by hand will take too long and the dangerous creatures of indescribable terror and unspeakable horror are making their way through the jungle even as you read this problem! Assuming a 250 foot, 6 inch I.D. galvanized iron pipe is available to pump from the large reservoir to the tank truck and the piping system has 2 globe valves and 2 gate valves at either end find the pump power required in HP if the best pump efficiency available is 65% and the flow rate is 100 gal/min. Can the rusted out 3.5 HP motor drive the pump?

For incompressible flow we can write:

$$\frac{P_1 g_c}{\rho g} + \frac{V_1^2}{2g} + z_1 + H_{pump} = \frac{P_2 g_c}{\rho g} + \frac{V_2^2}{2g} + z_2 + H_{losses}$$

Where the loss terms are defined as follows:

$$H_{losses} = \frac{f L_e V^2}{2Dg}$$

and where the friction coefficient for smooth pipe is defined as follows:

$$f = \left\{ \begin{array}{ll} \dfrac{64}{\mathrm{Re}_D}, \mathrm{Re}_D \le 2300 & \\ \dfrac{1.325}{\left(\ln\left(\dfrac{\varepsilon/D}{3.7} + \dfrac{5.74}{\mathrm{Re}_D^{0.9}}\right)\right)^2}, & \begin{array}{l} 5000 \le \mathrm{Re}_D \le 10^3 \\ 10^{-6} \le \varepsilon \le 10^{-2} \end{array} \end{array} \right\}$$

ε/D is the relative roughness L_e is the equivalent length of pipe given by the following table below:

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Table 3.9
Typical Equivalent Lengths of Schedule 40 Straight Pipe
For Steel Fittings and Valves

(For any fluid in turbulent flow)

Equivalent Length, ft

Fitting Type	Pipe Size* 1"	2"	4"	6"	(flanged pipe) 8"
Standard Radius 90° Elbow	5.2	8.5	13.0	8.9	12.0
Long Radius 90° Elbow	2.7	3.6	4.6	5.7	7.0
Regular 45° Elbow	1.3	2.7	5.5	5.6	7.7
Tee, flow through line (run)	3.2	7.7	17.0	3.8	4.7
Tee, flow through stem	6.6	12.0	21.0	18.0	24.0
180° Return Bend	5.2	8.5	13.0	8.9	12.0
Globe Valve, open	29.0	54.0	110.0	190.0	260.0
Gate Valve, open	.84	1.5	2.5	3.2	3.2
Angle Valve, open	17.0	18.0	18.0	63.0	90.0
Swing Check Valve	11.0	19.0	38.0	63.0	90.0
Coupling or Union	.29	.45	.65	—	—

*Screwed pipe and fittings unless flanged indicated.

Of course the friction factor can also be found using the Moody diagram for which the turbulent equation above is an approximation.

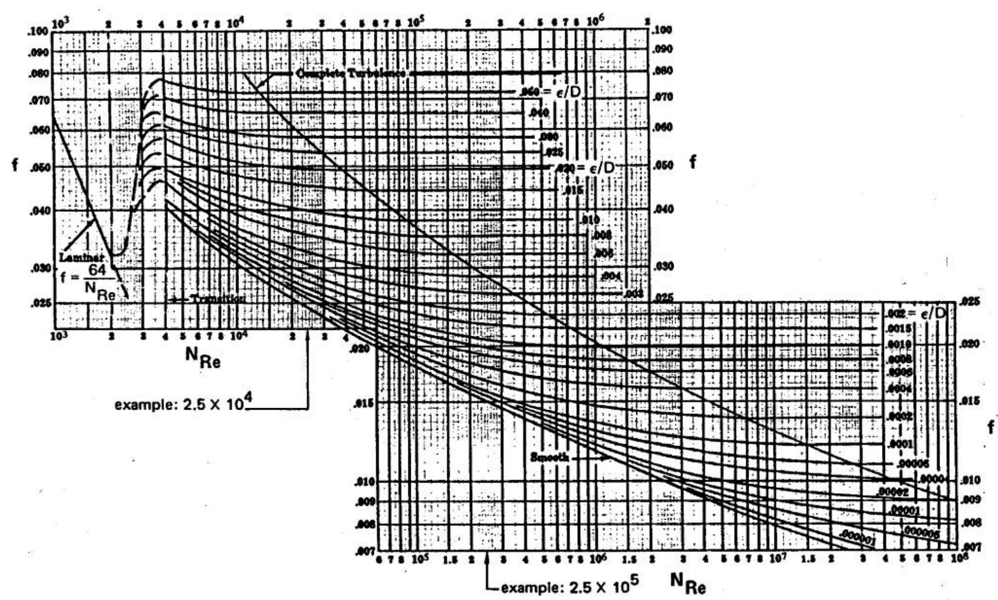

Figure 3.13 Moody Friction Factor Chart

Table 3.8
Specific Roughness and Hazen-Williams Constants for Various Pipe Materials

	ε(ft)		C		
Type of pipe or surface	Range	Design	Range	Clean	Design
STEEL					
welded and seamless	.0001–.0003	.0002	150–80	140	100
interior riveted, no projecting rivets				139	100
projecting girth rivets				130	100
projecting girth and horizontal rivets				115	100
vitrified, spiral-riveted, flow with lap				110	100
vitrified, spiral-riveted, flow against lap				100	90
corrugated				60	60
MINERAL					
concrete	.001–.01	.004	152–85	120	100
cement-asbestos			160–140	150	140
vitrified clays					110
brick sewer					100
IRON					
cast, plain	.0004–.002	.0008	150–80	130	100
cast, tar (asphalt) coated	.0002–.0006	.0004	145–50	130	100
cast, cement lined	.000008	.000008		150	140
cast, bituminous lined	.000008	.000008	160–130	148	140
cast, centrifugally spun	.00001	.00001			
galvanized, plain	.0002–.0008	.0005			
wrought, plain	.0001–.0003	.0002	150–80	130	100
MISCELLANEOUS					
fiber				150	140
copper and brass	.000005	.000005	150–120	140	130
wood stave	.0006–.003	.002	145–110	120	110
transite	.000008	.000008			
lead, tin, glass		.000005	150–120	140	130
plastic (ABS, PVC, etc.)		.000005	150–120	140	130