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

16.003/16.004 Unified Engineering III, IV
Spring 2007

Problem Set 2

Name: ________________________

Due Date: 02/20/2007

	Time Spent (min)
F2	
F3&4	
T3	
T4	
T5	
T6	
Study Time	

Announcements:

(Add a short summary of the concepts you are using to solve the problem)

Problem T3

Consider an ideal gas for which $C_v = 5/2\,R$ J/K and $C_p = 7/2\,R$ J/K. The initial state is 1 bar and 20 ^oC.

a) 1 kg is heated at constant volume to 80 ^oC. Calculate ΔU, ΔH, ΔS, Q, and W.

b) 1 kg is heated at constant pressure to 80 ^oC. Calculate ΔU, ΔH, ΔS, Q, and W if the process is reversible.

c) 1 kg is changed from its initial state to a final state of 10 bar and 80 ^oC by several different reversible processes. Which of the following quantities are the same for all processes: ΔU, ΔH, ΔS, Q, and W?

d) Repeat part c) for irreversible processes.

Problem T4

A compressor operates reversibly and isothermally. The fluid medium is an ideal gas with constant specific heats and the kinetic energy at the inlet and outlet station can be neglected. The stagnation pressure ratio (Pt_{exit}/Pt_{inlet}) is *PR*.

a) What is the entropy change of the fluid, inlet to exit, per unit mass?

b) What amount of heat transfer per unit mass flow rate must occur? Indicate whether the heat transfer is to or from the compressor.

c) What is the shaft work per unit mass flow rate?

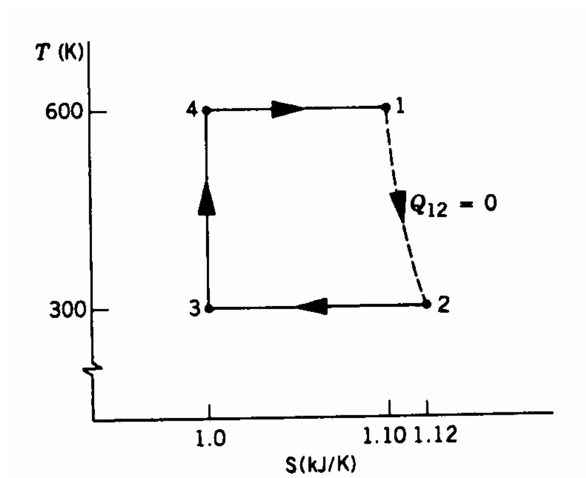
Unified Engineering Spring 2007

Thermodynamics & Propulsion Z. S. Spakovszky

(Add a short summary of the concepts you are using to solve the problem)

Problem T5

The figure below depicts the temperature-entropy diagram for a closed system undergoing a power cycle. Internal irreversibilities are present during the adiabatic process from state 1 to state 2. All other processes are internally reversible.



a) What is the net work done by the cycle?

b) What is the thermal efficiency of the cycle?

Suppose there were no internal irreversibilities. What would be the

c) Heat rejected by the cycle at T=300K?

d) Heat absorbed by the cycle at T=600K?

e) Net work done by the cycle?

f) Thermal efficiency of the cycle?

(Add a short summary of the concepts you are using to solve the problem)

Problem T6

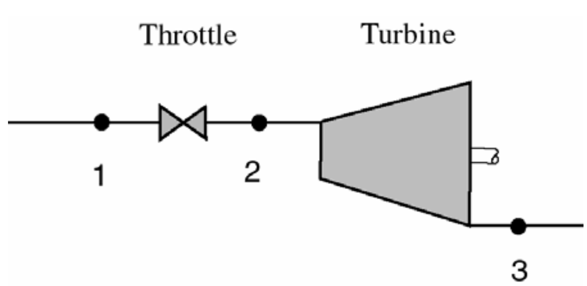
Air flows through an insulated throttle before it enters an ideal turbine as sketched in the figure below. There is a stagnation pressure drop, ΔP_t, across the throttle. The air enters the throttle at a stagnation pressure P_{t1} = 10 bar and a stagnation temperature T_{t1} = 600 C. The turbine exit stagnation pressure is P_{t3} = 1 bar.

a) Sketch the throttling process from state 1 to state 2 in an *h-s* diagram. Explain the rationale behind your sketch (one to two sentences are needed, possibly with an equation)

b) The throttle (think of a valve) can be operated over a range of conditions. If it is fully opened there is no stagnation pressure drop, $P_{t1} = P_{t2}$. If it is closed as far as possible there is only a small leakage flow so the stagnation pressure change across the turbine is negligible and $P_{t2} = P_{t3}$. Sketch the stagnation states in these two "limiting cases" for the expansion through the overall *throttle-turbine combination* on an *h-s* diagram.

c) Assuming that the throttle is fully open ($P_{t1} = P_{t2}$) what is the shaft work, per unit mass flow, produced in the turbine? The gas can be considered to have a specific heat of c_p = 1000 J/kgK and a ratio of specific heats of γ = 1.4.

d) Assuming that the throttle is closed as far as possible so that $P_{t2} = P_{t3}$ what is the change in entropy across the throttle *between stations 1 and 2*?

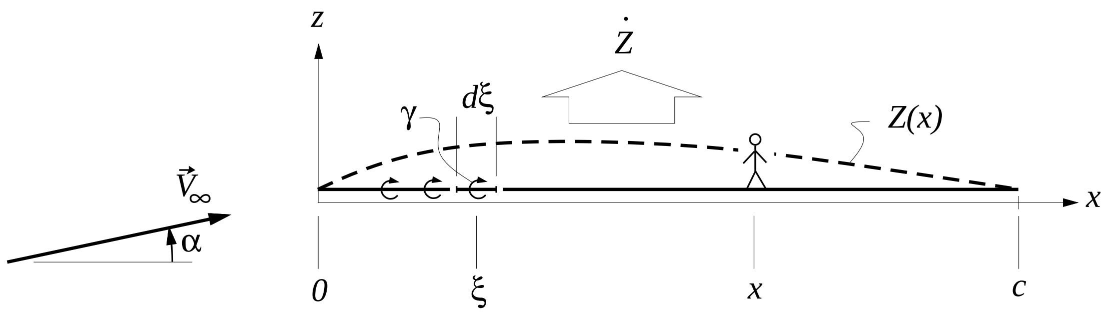


Unified Engineering Spring 2007
Fluids Problem 2

As given in the notes, the total $\vec{V}(x)$ velocity at some location x on an airfoil is given by equation (1) in the F02 notes. The corresponding $\vec{V} \cdot \hat{n} = 0$ flow-tangency condition on the airfoil's $Z(x)$ camberline reduces to

$$V_\infty \left(\alpha - \frac{dZ}{dx} \right) - \int_0^c \frac{\gamma(\xi)\, d\xi}{2\pi(x-\xi)} \; = \; 0 \qquad \text{(for } 0 < x < c\text{)} \qquad (3)$$

which is equation (3) in the notes. Consider now a case where the airfoil is translating upward at some velocity $\dot{Z}$.



1) Determine the total apparent velocity vector $\vec{V}_{\rm app}(x)$ seen by an observer sitting on the airfoil at some location x.

2) The physically correct boundary condition on the airfoil is now $\vec{V}_{\rm app} \cdot \hat{n} = 0$. Modify the equation (3) above so that it accounts for the airfoil velocity $\dot{Z}$.

3) TAT predicts that $\partial c_\ell / \partial \alpha = 2\pi$. Determine $\partial c_\ell / \partial \dot{Z}$.
Hint: It may be easiest to first define an apparent α as seen by the observer.

Unified Engineering Spring 2007
Fluids Problem 3+4 (worth 2 Pset Q's)

1) Anderson problem 4.6 p. 389 (p. 349 in 3rd Edition).

2) Anderson problem 4.7 (follows from 4.6).

3a) Compare the TAT results of 1) and 2) with inviscid results from XFOIL for the following airfoils:
– NACA 4412
– NACA 4407
– NACA 4402
All these airfoils have the same camberline $Z(x)$, so that they are equivalent as far as TAT is concerned. So your results from 1) and 2) apply to all three.

3b) Comment on the accuracy of TAT compared to the "exact" results from XFOIL.

Note: XFOIL computes the flow about airfoils using the panel method. For the inviscid flows considered here, it is nearly exact. XFOIL is available on Athena — see the "XFOIL Instructions" link on the UE Fluids web page. A Linux or Windows version can also be downloaded at `http://raphael.mit.edu/xfoil/`