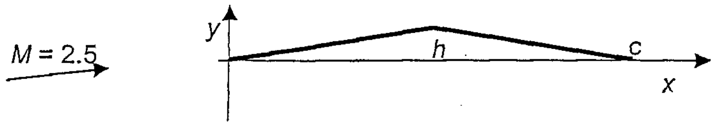
Delft University of Technology DEPARTMENT OF AEROSPACE ENGINEERING	
Course: Thermodynamics and compressible aerodynamics; Code AE2-125	Course year: 2
Date: Tuesday 19th August 2008	Time: 14 – 17

Problem 1-a

Consider a thin airfoil with zero thickness is immersed in a uniform supersonic stream at $M_\infty = 2.5$ at incidence $\alpha = 4.2$ degrees. The airfoil camber to cord ratio is $h/c = 0.12$.



(i) Draw the pattern of shock waves expansion waves and streamlines around the airfoil
(ii) Determine the airfoil drag coefficient
(iii) Determine the flow direction behind the airfoil trailing edge

Problem 1-b

A probe for planetary exploration is designed to enter Mars atmosphere at a travelling speed of 6 km/s. Mars atmosphere is mostly composed of Carbon dioxide and assume a temperature of 150 K and pressure of 10 Pa.

(i) Determine the entry Mach number and the temperature of the gas at the stagnation point for ideal gas behaviour
(ii) Explain what is the effect of the large temperature increase on the gas specific heat ratio and on the flow stagnation temperature.

Problem 2-a

Air flows through a convergent-divergent nozzle with an exit section $A_e = 2.5$ m^2. The convergent is connected to a reservoir at $P_0 = 5.5\times10^5$ Pa and $T_0 = 290$ K and discharges in an ambient at $P_a = 1.013\times10^5$ Pa.

(i) Determine the throat cross section A_t such that a normal shock wave stands at the nozzle exit
(ii) Calculate the mass flow for the determined value of the throat to exit area ratio
(iii) Determine the exit Mach number when the stagnation pressure is reduced to $P_0 = 1.5\times10^5$ Pa

Problem 2-b

The linearized theory for compressible flows around airfoils represents an approximation to the exact flow theory.

(i) Under which hypotheses is the linearized velocity potential equation valid?
(ii) Describe the relationship between the pressure coefficient Cp and the Mach number M according to linearized theory, at subsonic and supersonic speed

Problem 3-a

Consider a piston-cylinder device containing 0.5 kg of water. The initial volume and pressure are 0.1 m^3 and 400 kPa respectively. The water is heated at constant pressure until a final temperature of 300 °C is reached. Given the properties of water in the tables below, answer the following questions:

(i) Under which phase is the water at the beginning and at the end of the transformation? Motivate your answer

(ii) Draw the evolution of the transformation in the (T, v) plane

(iii) Determine the amount of heat transferred to the water

(iv) Evaluate the accuracy of the perfect gas model to predict the specific volume of water at the end of the heating process

Table 1 – water properties as a function of pressure

T [K]	Psat [MPa]	v_l [m^3/Mg]	v_g	H_l [kJ/kg]	h_g	s_l [kJ/kg K]	s_g
553,15	6,419	1,332	30,11	1237	2779	3,068	5,856
573,15	8,592	1,404	21,62	1346	2749	3,256	5,704
603,15	12,86	1,562	12,96	1528	2665	3,555	5,441

Table 2 – water properties as a function of temperature

Tsat [K]	P [MPa]	v [m^3/Mg]	h [kJ/kg]	s [kJ/kg K]
133,5	0,3	875	3069	7,703
143,6	0,4	655	3067	7,567
151,8	0,5	522,6	3064	7,461

Table 3 – Superheated water properties at 300 °C

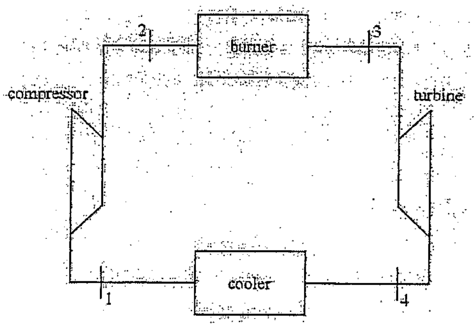
P [MPa]	Tsat [K]	v_l [m^3/Mg]	v_g	h_l [kJ/kg]	h_g	s_l [kJ/kg K]	s_g
0,38	414,9	1,082	485,3	596	2736	1,758	6,914
0,4	416,8	1,084	462,4	604,8	2739	1,777	6,897
0,44	418,5	1,086	441,7	612,3	2741	1,795	6,880

Note : 1 Mg = 10^3 kg

Problem 3-b

Consider the power plant depicted in the figure. Assume that:

a) the working gas is air behaving like a perfect gas
b) the transformation in the compressor is polytropic with exponent n =1.3
f) the turbine has an isentropic efficiency of 1
g) the transformations in the burner and the cooler take place at constant pressure
h) p_1 = 200 kPa; T_1 = 310 K; p_2/p_1 = 4; T_3 = 1800 K
i) the cold and hot source temperatures equals T_1 and T_3 respectively



Answer the following questions:

(i) Depict the evolution of the cycle in the T-s plane (verify a posteriori the correspondence between the graphical representation and the numerical values of the state variables)

(ii) Determine the net work per unit mass produced by the power plant

(iii) Determine the Carnot efficiency of the power plant and discuss the difference with respect to the actual thermal efficiency of the power plant

Appendix

Universal gas constant: R_0 = 8314 J/Kmol K, specific heat of air: C_p = 1004 J/Kg K