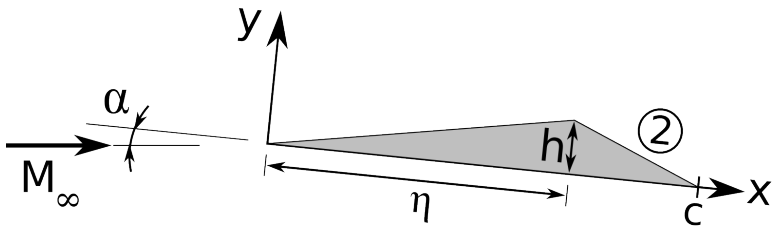
Delft University of Technology **DEPARTMENT OF AEROSPACE ENGINEERING**		
Course: Aerodynamics 2;	Code: AE2210	Course year: 2
Date: Wednesday 3 July 2013		Time: 14:00 – 17:00
On the top of <u>each</u> answer sheet write: initials, name, student number, sheet number/total number of sheets **This exam consists of 4 questions.**		

Problem 1

An airfoil is immersed in a supersonic flow at a free stream Mach number $M_\infty = 2.0$. The airfoil geometry is shown in the figure below. The angle of attack is $\alpha = 2^o$, $h = 0.04c$ and $\eta = 0.6c$.



i. Give a clear and accurate sketch of the flow over the airfoil. In your drawing indicate: shock waves, expansion waves, streamlines and sliplines.
ii. Use the linearized theory to determine c_d.
iii. Use shock expansion theory to compute the pressure coefficient in region 2 and compare its value with the one obtained from linear theory.

Problem 2

i. Use a control volume approach and apply conservation of mass and momentum over a soundwave to derive that $a^2 = {\partial p}/{\partial \rho}$, furthermore show that for a perfect gas this can be reduced to $a = \sqrt{\gamma RT}$
ii. The temperature in the reservoir of a supersonic wind tunnel is 400 K. In the test section the air flow velocity is 700 m/s. Compute the Mach number M and characteristic Mach number M^* in the test section.
iii. Repeat question 2ii. in case Helium is used instead of air (μ_{He} = 4 g/mol).

Problem 3

Air flows from a large reservoir to the ambient through a convergent-divergent channel. The throat area is $A_t = 0.2$ m^2 and the exit area is $A_e = 0.5$ m^2. The total pressure in the reservoir is p_0 and the total temperature is $T_0 = 300$ K. The ambient pressure is $p_a = 100$ kPa. Three operating regimes are considered.

1) $p_o = 102$ kPa
2) $p_0 = 170$ kPa
3) $p_0 = 10000$ kPa

i. For all cases determine the exit Mach number and the mass flow $\dot{m}$
ii. Identify the case(s) in which the flow is *overexpanded* or *underexpanded*
iii. A second throat is added to the channel, what is its minimum size such that a supersonic flow can be still be established in the original convergent-divergent channel

Problem 4

The theoretical lift coefficient for a thin, symmetric airfoil in an incompressible flow is $c_l = 2\pi\alpha$.

i. Calculate the lift coefficient at $\alpha = 2^o$ for $M_\infty = 0.7$ and $M_\infty = 2.3$
ii. Give the definition of the critical Mach number for a given airfoil
iii. Sketch qualitatively and discuss the diagram of the drag coefficient c_d for a given airfoil as a function of the free stream Mach number M_∞

Values of gas properties

Universal gas constant: $R_0 = 8314$ J/Kmol K; Air gas constant: $R_{air} = 287$ J/Kg K;
Specific heat of air: $C_p = 1004$ J/Kg K