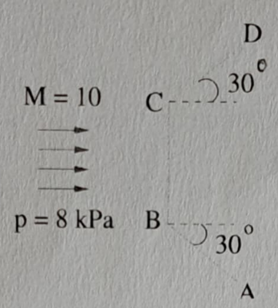
AE 339: High-speed aerodynamics
End-semester examination
November 12, 2024

Duration: 180 minutes **Maximum Marks: 45**

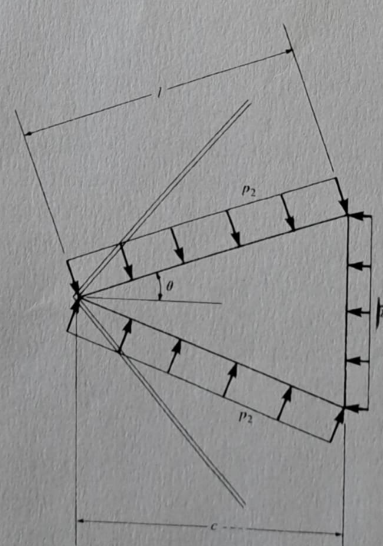
The questions are not difficult. Take some time to read the questions.
Answer briefly and to the point. All the best!

1. Consider a two-dimensional flow past a body as shown in the figure. The freestream pressure and the Mach number are 8 kPa and 10, respectively. By using Newtonian flow model, find the pressure distribution (not just C_p) on the body.



2. Consider a reservoir with an internal volume of 30 m^3. As air is pumped into the reservoir, air pressure inside continually increases with time. Consider the instant during charging process when the reservoir pressure is 10 atm. Assume the air temperature inside the reservoir is held constant at 300 K by means of a heat exchanger. Air is pumped into the reservoir at a rate of 1 kg/s. Calculate the time rate of increase of pressure in the reservoir at this instant. If the pumping rate of 1 kg/s were maintained constant throughout the charging process, how long will it take to increase the reservoir pressure from 10 to 20 atm? (6

3. Consider a wedge with a 15^0 half angle in a Mach 5 flow, as sketched in figure. Calculate the drag coefficient for this wedge. (Assume that the pressure over the base is equal to freestream static pressure.) (6)



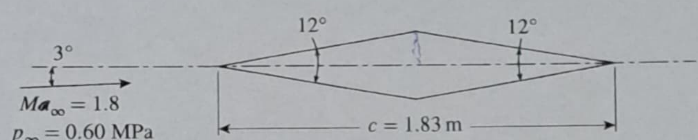
$y = mx + c$

$y = -0.07x + 0.5133$

4. Consider a normal shock wave in a supersonic airstream where the pressure upstream of the shock is 1 atm. Calculate the loss of total pressure across the shock wave when the upstream Mach number is (a) $M_1 = 2$, and (b) $M_1 = 4$. (6)

5. A flow of air with a temperature of 20^0C and a speed of 450 m/s is made to move along a wall which has a 20^0 inclination away from the flow direction. Calculate the pressure reduction ratio and the Mach number after the bending point. If the air flows in an imaginary two-dimensional tunnel with a width of 0.1 m, what will be the width of this tunnel after the bend? Also calculate the "fan" angle. (6)

6. A symmetrical diamond-shaped airfoil is shown in the figure. (9)
a) Present a sketch with the waves preceding the first surfaces on the top and bottom with the correct angles marked.
b) At what angle of attack will there be no compression waves on the first upper surface?
c) Calculate the total lift and drag and drag on the airfoil section with the shown information.



(d) Using the formulation for the pressure coefficient from Ackeret theory, calculate the pressure coefficient for the first set of waves. Compare the results with that obtained from shock expansion theory.

7. An equation for the thrust of a jet-propulsion device can be derived by applying the integral form of the momentum equation for a steady inviscid flow to a control volume wrapped around the jet engine. The resulting thrust equation for a rocket engine is (9)

$$T = \dot{m}u_e + (p_e - p_\infty)$$

where T is the thrust, $\dot{m}$ is the mass flow through the engine, u_e is the gas velocity at the nozzle exit, p_e is the gas pressure at the nozzle exit, p_∞ is the surrounding ambient atmospheric pressure, and Ae is the area of the exit. Consider a rocket engine similar to that shown in Figure 10.1. Liquid hydrogen and oxygen are burned in the combustion chamber producing a combustion gas pressure and temperature of 30 atm and 3500 K, respectively. The area of the rocket nozzle throat is 0.4 m^2. The area of the exit is designed so that the exit pressure exactly equals the ambient atmospheric pressure at a standard altitude of 20 km (0.055293 bar). Assume an isentropic flow through the rocket engine nozzle with an effective value of the ratio of specific heats $\gamma = 1.22$, and a constant value of the specific gas constant $R = 520\ J/kg \cdot K$.
(a) Using the given equation, calculate the thrust of the rocket engine.
(b) Calculate the area of the nozzle exit.

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{(\gamma+1)/(\gamma-1)}$$