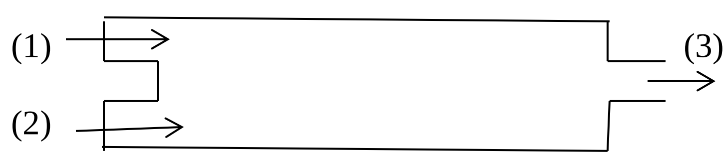
Practice problems # 1 (15th Jan 2020)

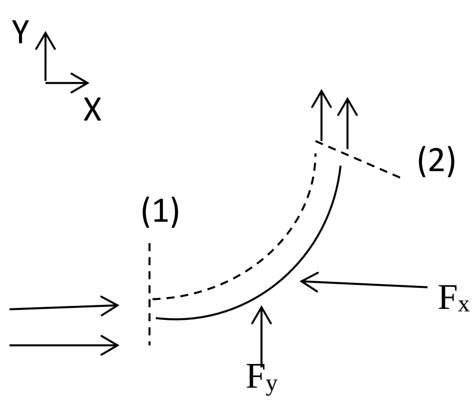
1. Derive the continuity, momentum, energy equations using RTT.
2. (i) Assume that a substance has uniform properties in all directions with $V = L_x L_y L_z$. Show that volume expansivity $\alpha_p = 3\delta_T$.

   (ii) Soft rubber is used as part of a motor mounting. It's adiabatic bulk modulus is $B_s = 2.82 \times 10^6\ kPa$, and the volume expansivity is $\alpha_p = 4.86 \times 10^{-4}\ K^{-1}$. What is the speed of sound vibrations through the rubber, and what is the relative volume change for a pressure change of *1MPa*? Use density of rubber 1100 kg/m^3.

3. Consider the control volume shown. There are two inlets and one-exit boundaries where flow crosses the control volume. Assuming the flow is steady and uniform; calculate the exit flow rate from the known inlet conditions. Given that: u_1=25 m/s, A_1=0.25 m^2, ρ_1=1.2 Kg/m^3, u_2=225 m/s, A_2=0.1 m^2, ρ_2=0.2 Kg/m^3



4. In placing a curved plate in front of a garden hose with a water flow rate of 0.1 kg/s, we have to exert an axial force on the plate, as shown, to hold it in place. Estimate the axial and lateral forces, F_x and F_y, respectively, that are needed to support the plate. (Note: u and v are x- and y-component of velocity, respectively). Given that: u_1=2 m/s, v_1=0 m/2, u_2=1.0 m/s, v_2=1.73 m/s



5. Air is compressed isentropically in a centrifugal compressor from a pressure of 1.0×10^5 Pa to a pressure of 6.0×10^5 Pa. The initial temperature is 290K. Calculate (a) the change in temperature, (b) the change in internal energy, (c) the work imparted to the air, neglecting the velocity change.

6. Air is flowing through a frictionless diffuser. At a station in the diffuser the temperature, pressure, and velocity are 0^oC, 140 kPa and 900 m/s, respectively. At a downstream station the velocity decreases to 300 m/s. Assuming the flow to be adiabatic, calculate the increase in pressure and temperature of the flow between these stations.

7. A rocket nozzle has to generate 9 kN thrust at an altitude of 16 km above the earth, with its chamber pressure and temperature of 15 atm and 2600^oC, respectively. Calculate its exit and throat areas the velocity and temperature at the nozzle exit. Take $\gamma=1.4$, R=287 J/(kgK). Assume the nozzle to operate at adapted condition.

8. Air stream at 80 kPa and 5^oC enters an adiabatic diffuser of circular cross-section with an entrance area of 0.2 m^2 at 200 m/s. If the semi-divergence angle of the diffuser is 8^oC, find the dp/dx, dV/dx and $d\rho/dx$, where x is the axial direction of the diffuser, assuming the flow to be (a) incompressible and (b) compressible.

9. Air at 700 kPa and 530 K from a storage is expanded through a frictionless convergent-divergent duct of throat area 5 cm^2 and exit area 12.5 cm^2. The backpressure is 350 kPa. There is normal shock in the divergent portion, and the Mach number just upstream of the shock is 2.32. Determine (a) the cross-sectional area at the shock location, (b) the exit Mach number, (c) the backpressure required for the flow to be isentropic throughout the duct.

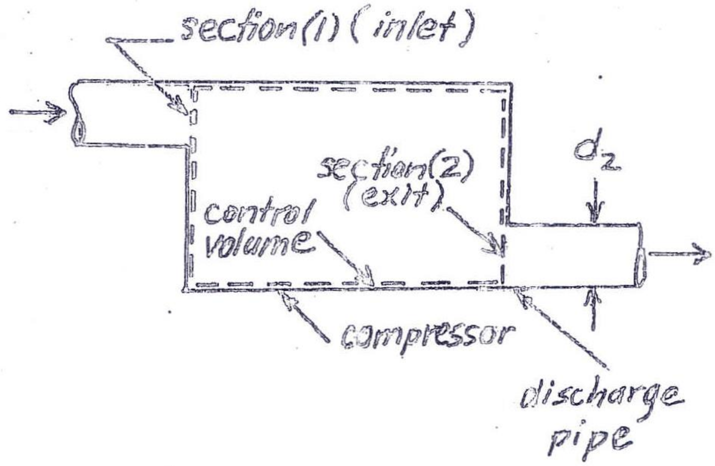
10. A convergent-divergent nozzle connects two air reservoirs at pressure 5 atm and 3.6 atm. If a normal shock has to stand at the nozzle exit, find the backpressure required.

11. A horizontal tube contains stationary air at 1 atm and 300 K. The left end of the tube is closed by a movable piston, which at time $t=0$ is moved impulsively at a speed of V_p=100 m/s to the right. Find the wave speed and pressure on the face of the piston.

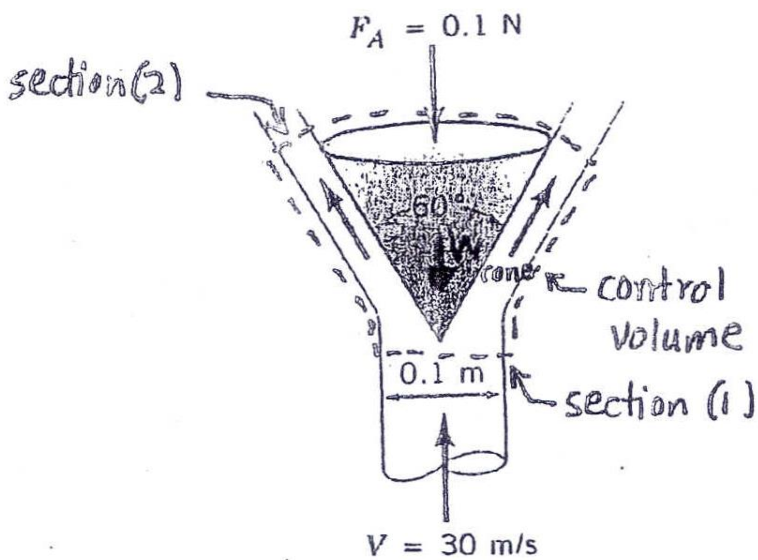
12. Consider a pipe in which air at 300 K and 1.50×10^5 N/m^2 flows uniformly with a speed of 150 m/s. The end of pipe is suddenly closed by a valve, and a shock wave is propagated back into pipe. Compute the speed of the wave and the pressure and temperature of the air which has been brought to rest.

13. Air at standard atmospheric conditions is drawn into a compressor at the steady rate of 30 m^3/min. The compressor pressure ratio, P_{exit}/P_{inlet} is 10 to 1. Through the compressor P/ρ^n remains constant with n= 1.4. If the average velocity in the

compressor discharge pipe is not to exceed 30 m/s, calculate the minimum discharge pipe diameter required.



14. A vertical, circular cross section jet of air strikes a conical deflector as indicated in figure below. A vertical anchoring force of 0.1N is required to hold the deflector in place. Determine the mass (Kg) of the deflector. The magnitude of velocity of the air remains constant.



15. A the infinitesimal neighborhood surrounding a point in an inviscid flow, the small change in pressure, *dp*, that correspond to a small change in velocity, *dV*,

is given by the differential relation $dp = - \rho\ VdV$ (This equation is called Euler's equation)

a) Using this relation, derive a differential relation for the fractional change in density, $d\rho/\rho$, as a function of the fractional change in velocity, dV/V, with the compressibility τ as a coefficient.
b) The velocity at a point in an isentropic flow of air is 10 m/s (a low speed flow), and the density and pressure are 1.23 Kg/m^3 and 1.01 X 10^5 N/m^2 respectively (corresponding to standard sea level conditions). The fractional change in velocity at the point is 0.01. Calculate the fractional change in density.
c) Repeat part (b) except for a local velocity at the point of 1000m/s (a high speed flow). Compare this result with that from part (b), and comment on the differences.

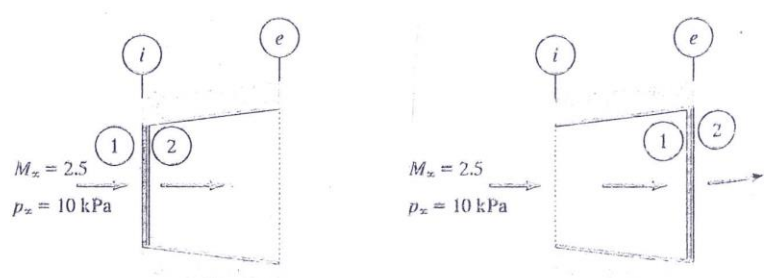
16. (A) Consider a Pitot static tube mounted on the nose of an experiment airplane. A Pitot tube measures the total pressure at the tip of the probe (hence sometime called the Pitot pressure), and a Pilot static tube combines this with a simultaneous measurement of the free-stream static pressure. The Pitot and stream Mach number at which the airplane is flying for each of the three different conditions:

(i) Pitot pressure = 1.22 X 10^5 N/m^2 , static pressure = 1.01 X 10^5 N/m^2

(ii) Pitot pressure = 7222 lb/ft^2 , static pressure = 2116 lb/ft^2

(iii) Pitot pressure = 13107 lb/ft^2 , static pressure = 1020 lb/ft^2

(B) A normal shock occurs at the inlet to a supersonic diffuser as shown in Figure below; A_e/A_i is equal to 3.0. Find M_e, P_e and the loss in stagnation pressure ($P_{0i} - P_{0e}$). Repeat for a shock at the exit. Assume $\Upsilon = 1.4$



17. Air expands from a storage tank through a converging-diverging nozzle (see Figure below). Under certain conditions, it is found that a normal shock exist in the diverging section of the nozzle at an area equal to twice the throat area, with the exit area of the nozzle equal to four times the throat area. Assuming isentropic flow except for the shockwaves, that the air behaves as perfect gas with constant Υ = 1.4, and that the storage tank pressure and temperature are 200kPa and 300K, respectively, determine the following:

(a) A^* for flow from inlet to shock

(b) A^* for flow from shock to exit

(c) The mach number at the nozzle exit plane

(d) The stagnation pressure at the nozzle exit plane

(e) The exit plane static pressure, and