AS – 5680 High Temperature Gas Dynamics
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Assignment – 2, Weightage: 20%, Due date: May 17, 2020 5pm.

Assignments must be submitted electronically to murgi@ae.iitm.ac.in *and the reports must contain:*

1. Only the results in the form of plots and discussions related to them. If there are no interpretations, there will be no scores. If submitted late, there will be negative points of -2% of grade every one hour. (need not submit after 7.5 hrs!)
2. Appendix which must include the codes used or the procedures/algorithms used if no softwares used. The codes will be checked for its running ability during evaluation. If codes don't give the plots presented, score will be zero.

Assume the fluid used to be air with composition of N_2 79% and O_2 21% by volume, if not specified.

1. Imagine a steady 2D Poiseuille flow. This is a flow thru an infinite channel between two parallel plates due to a constant pressure gradient P' in the x direction. Start with Navier stokes equations (only mass and momentum), and then reduce the differential equations to the form relevant to this problem. Then solve the problem for the velocity profile. Neglect end effects (assume a 2D problem, fully developed). Solve the velocity profile for (a) no slip condition, (b) a slip at the wall based on mean free path. $u_{slip}=\lambda(du/dy$ @wall). Compare the volume flow rate for the two cases and explain the difference. [15]

2. There exists two nozzles (linear and parabolic) both 1D rocket nozzle with same inlet and exit areas. The gas flowing from settling chamber is N_2. The convergent part of the nozzles is at 45 degree angle linear nozzle of length 25cm. The divergent nozzle is a straight line nozzle of 1m long, reaching the exit area which is 10 times throat area. The parabolic nozzle has a zero slope at the exit. Assume that the pressure ratio across the nozzle is such that the nozzle will be fully supersonic for all the cases. Now, we need to **find the thrust produced for different Tos in [500:500:5000K] by** (a) frozen flow through the nozzle (γ=1.4), (b) frozen flow with γ=1.35, (c) partly frozen flow with jump in γ. The jump in γ case is done with starting γ as 1.35, then calculate the location where the flow has flow time=vibrational relaxation time and then assume γ=1.4, which is like vibration freezes at that location onwards and downstream. **Explain the differences** in the thrusts. Find the thrust in normalised form, i.e., **Th/(Po A*)**. [25]

[Bonus] Solve the Q1 if one wall is moving with a velocity V in the x-direction, with respect to the other wall. Dont worry about the volume flow rate calculations. [8]

Formulae that may be required.

Equations of motion of fluid are given in one of the recorded video lectures from recent classes.

For the isentropic supersonic flow of air through nozzle, Use the formulae in the next page. Know that these formulae are for constant entropy and specific heats.

$$T_0 = T_0^* = \text{constant} \qquad ...(3.1)$$

$$\frac{T}{T_0} = \frac{1}{1+\frac{\gamma-1}{2}M^2} \qquad ...(3.2)$$

$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{\frac{\gamma}{\gamma-1}} = \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{1-\gamma}} \qquad ...(3.3)$$

$$\frac{\rho}{\rho_0} = \left(\frac{T}{T_0}\right)^{\frac{1}{\gamma-1}} = \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{1}{1-\gamma}} \qquad ...(3.4)$$

$$M^* = \frac{c}{c^*} = \sqrt{\frac{\frac{\gamma+1}{2}M^2}{1+\frac{\gamma-1}{2}M^2}} \qquad ...(3.5)$$

$$\frac{A}{A^*} = \frac{1}{M}\left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}} \qquad ...(3.6)$$

The required data for finding vibration relaxation times (from Millikan and White paper) are:

$$p\tau_v = \exp[A(T^{-\frac{1}{3}} - 0.015\mu^{\frac{1}{4}}) - 18.42], \qquad (2)$$

T^-(1/3) is not clear in the scan, but can be inferred from the paper.

TABLE I. Molecular data for vibrational relaxation.

System	μ	θ (°K)	A-Eq. (2)	$c\times10^3$
N_2	14	3395	220	1.15