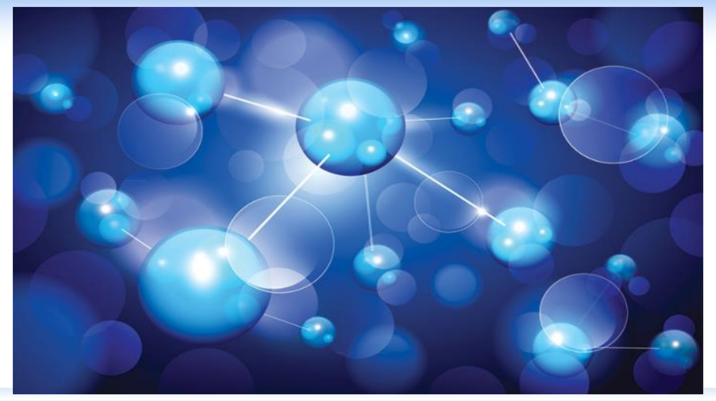
THEORY OF NEO's AERODYNAMIC HEATING USING MOLECULAR COLLISION ANALYSIS



Dr. Karthik shastri[1], Akash G M[1].

1. R.V. College of engineering, Bengaluru - 560059

INTRODUCTION

Molecular collision analysis is one of the niche area where scientists are looking into for more developments, To obtain more accurate solutions of aerodynamic heating at hypersonic speeds unsteady naiver stokes equations are widely used. However to date the precise computation of the heat transfer between flow and a selected object is till difficult to achieve. In order to find the values the intrinsic mechanism and accurate prediction of aerodynamic heating is required. The important well known nanoscale effects are velocity slip and temperature jump at the solid flow interface

To make it easier Chelyabinsk event is taken into account and the assumptions is made that during interaction of the body practically all the initial mass was evaporated

METHODS

To derive the relationship between the rising temperature of a flying object and it's flying speed a silicon cube is considered with velocity v in monoatomic gas environment along the z-direction. Where the velocity probability density of the gas should obey maxwell's distribution where the final equation after deriving will be:

$$f(v_z) = \left(\frac{m}{2\pi k_B T_G}\right)^{1/2} \exp\left(-\frac{m(v_z - v)^2}{2k_B T_G}\right)$$

The speed < Vz+ > denotes the average relative speed of monoatomic gas colliding head on with the moving cube

$$\langle v_{z+}\rangle = \int_0^{\infty} v_z \left(\frac{m}{2\pi k_B T_G}\right)^{1/2} \exp\left(-\frac{m(v_z - v)^2}{2k_B T_G}\right) \mathrm{d}v_z = \sqrt{\frac{k_B T_G}{2\pi m}} \exp\left(-\frac{m v_z^2}{2k_B T_G}\right) + \frac{1}{2} v \cdot erfc\left(-\sqrt{\frac{m}{2k_B T_G}}\, v\right)$$

While < Vz- > denotes the average relative speed of monoatomic gas colliding with the moving cube from behind:

METHODS(contd.)

$$\langle v_{z-}\rangle = \int_0^{\infty} v_z \left(\frac{m}{2\pi k_B T_G}\right)^{1/2} \exp\left(-\frac{m(v_z + v)^2}{2k_B T_G}\right) \mathrm{d}v_z = \sqrt{\frac{k_B T_G}{2\pi m}} \exp\left(-\frac{m v^2}{2k_B T_G}\right) - \frac{1}{2} v \cdot erfc\left(\sqrt{\frac{m}{2k_B T_G}}\, v\right)$$

The frequency in which the gas atoms collide head on with the front wall of the moving cube is expressed as:

$$g_f = knvS$$

Considering a static cube the energy transferring per time can be considered as the heat flux flowing from the cube to the gas atoms. Thus the heat flux per area can be expressed as :

$$q = h(T - T_G) = \frac{3}{2} n \langle v_z\rangle k_B (T - T_G) e$$

Where h is the thermal conductance between the static cube and the gas, which can be estimated using MD simulations or empirical formulas. Then e can be estimated as follows:

$$e = \frac{2h}{3n\langle v_z\rangle k_B} = \frac{2h}{3nk_B}\sqrt{\frac{2\pi m}{k_B T_G}}$$

By deriving the total energy by equipartition theorem and solving the equation with initial condition that temperature equals Ts at the very beginning the temperature of the cube as a function of time can be expressed as:

$$T = \frac{g_f(mv^2 + 2k_B T_G) + 3gk_B T_G}{3g_f k_B + 3gk_B} + \left(T_S - \frac{g_f(mv^2 + 2k_B T_G) + 3gk_B T_G}{3g_f k_B + 3gk_B}\right) \exp\left(-\frac{g_f + g}{N_S} et\right)$$

Now with time lapse the final equilibrium temperature is obtained as:

$$T_{eq} = \frac{g_f(mv^2 + 2k_B T_G) + 3gk_B T_G}{3g_f k_B + 3gk_B}$$

RESULTS

Simulation was performed for with NS model and theoretical model as well as NEMD the obtained graph is shown below:

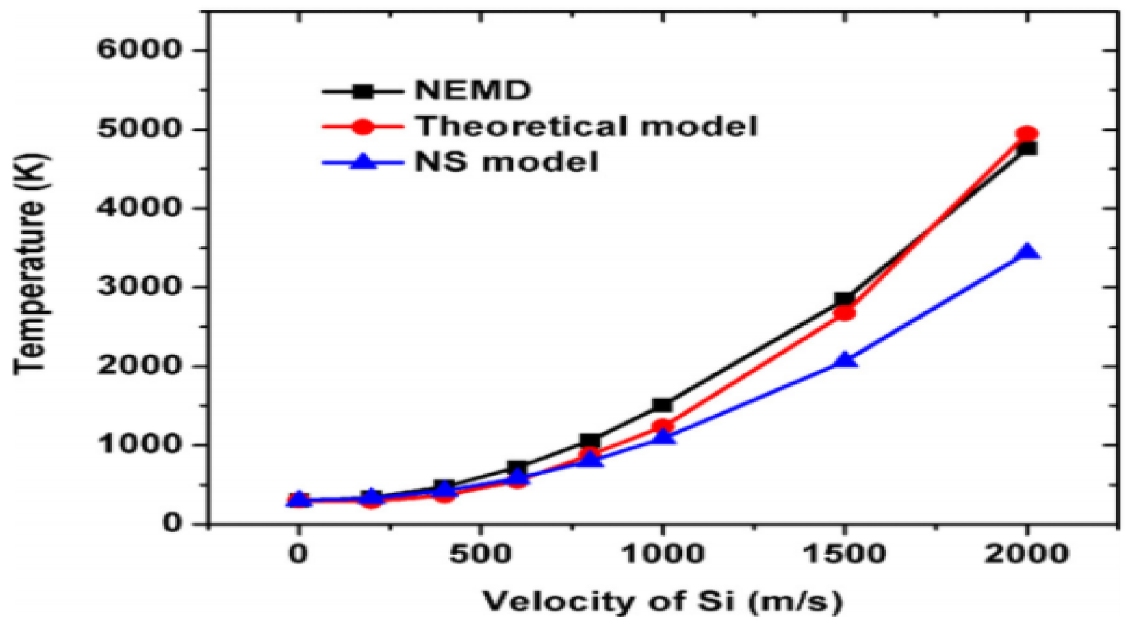


Fig. 1. The final equilibrium temperature of a silicon cube a function of the flying speed when the relative atomic mass of gas is 39.948.

It is known that VDOS will measure the distribution of vibration modes at different frequency, is proportional to kinetic energy and temperature contributed by corresponding vibration modes.

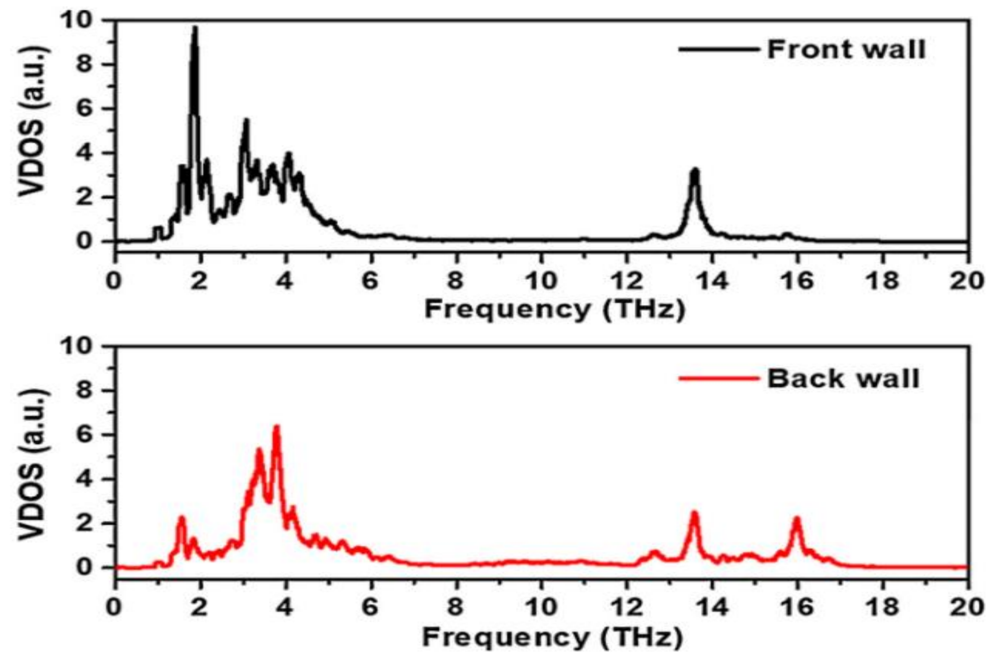


Fig. 2. VDOS of atoms at the front wall and back wall of the silicon with the gas atoms when the speed of silicon cube is 1000m/s. Each wall consists of monolayer silicon with 32 atoms.

RESULTS

By using disintegration equations of cosmic bodies after entering into earth's atmosphere and assuming values for coefficient of drag, the classical equations are converted into statistical equation by substituting values of V in the prior equation.

Primary equations:

$$\frac{dV}{dt} = -\frac{C_D \rho_a A V^2}{M} + g sin\alpha$$

$$\frac{dM}{dt} = -\frac{1}{2}\frac{C_H \rho_a A V^3}{\varsigma}$$

$$\frac{dZ}{dt} = -V sin\alpha$$

Derivation of V to statistical level

$$V = M\sqrt{\gamma RT}$$

Substituting Teq equation at T

$$V = M\gamma^2 R^2 \sqrt{\frac{g_f(mv^2 + 2k_B T_G) + 3gk_B T_G}{3g_f k_B + 3gk_B}}$$

$$V = M\sqrt{\frac{\gamma R g_f\left(m\left(M\sqrt{\gamma RT}\right)^2 + 2k_B T_G\right) + 3gk_B T_G}{3g_f k_B + 3gk_B}}$$

Primary equations turn into statistical equations as :

$$\frac{dV}{dt} = -C_D \rho_a A M \frac{\gamma R g_f\left(m\left(M\sqrt{\gamma RT}\right)^2 + 2k_B T_G\right) + 3gk_B T_G}{3g_f k_B + 3gk_B} + g sin\alpha$$

$$\frac{dM}{dt} = -\frac{1}{2}\frac{C_H \rho_a A}{\varsigma}\left(M\sqrt{\frac{\gamma R g_f\left(m\left(M\sqrt{\gamma RT}\right)^2 + 2k_B T_G\right) + 3gk_B T_G}{3g_f k_B + 3gk_B}}\right)^3$$

$$\frac{dZ}{dt} = -M sin\alpha\sqrt{\frac{\gamma R g_f\left(m\left(M\sqrt{\gamma RT}\right)^2 + 2k_B T_G\right) + 3gk_B T_G}{3g_f k_B + 3gk_B}}$$

CONCLUSION

A Theoretical model was derived to predict the temperature rise of a hypersonic flying object due to aerodynamic heating is rigorously derived from molecular collision analysis and compared with NS model where the theoretical model has presented more accurate values of the process of aerodynamic heating and it is well verified with NEMD simulations. Disintegration equations of the cosmic body equations were took as per the assumptions made by the prior paper and were converted to molecular level i.e., statistical level which will yield better results and more accurate solutions of a near earth object disintegration with respect to it's environment.

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