AE 330: Aerospace Propulsion – Tutorial 4
Heat Transfer

1. Radiation heat transfer is significant in rocket combustion chamber and nozzle flows. Let the convective heat transfer from the hot gases to the chamber walls be modelled as $q''_c = h_g\left(T_{0g} - T_{w_h}\right)$, where h_g is the heat transfer coefficient, T_{0g} is the stagnation temperature of the hot gas flow, and T_{w_h} is the wall temperature on the hot gas side. In addition to convective heat transfer from the hot gases to the chamber walls, let there also be a radiation heat transfer q''_r. Let the wall conductivity be κ_w, and thickness be t_w. If the coolant has a convection heat transfer coefficient of h_c, and a temperature of T_c, show that the total heat flux from the hot gases to the coolant is

$$q'' = \frac{T_{0g} - T_c + q''_r/h_g}{1/h_g + t_w/\kappa_w + 1/h_c}$$

2. An experimental rocket thrust chamber has an outside wall temperature of $400K$ at the throat, with a $3200K$ chamber temperature (hot gas stagnation temperature). The local heat transfer rate is measured to be $15MW/m^2$, of which 25% may be assumed to be due to radiation. If the wall is of stainless steel $2.5mm$ thick with $\kappa = 26W/m - K$, and if the coolant surface area is the same as the hot-gas surface area,

   (a) what is the inner wall temperature?

   (b) It is expected that this temperature will cause failure in the actual application. The throat is to be lined with a ceramic of conductivity $\kappa_c = 8W/m - K$ to protect the metal. Assuming that the fraction of heat transfer by radiation is unchanged and that all gas properties are unchanged, what ceramic thickness is necessary to revue the peak metal temperature to $1370K$ while the coolant side remains at $400K$?

   Note: Coolant properties are not relevant for this problem.

3. An early rocket design using a propellant at $3000K$ is limited by wall-cooling problems t o a chamber pressure of $2MPa$. Under these conditions a hot-side wall temperature , T_{w_h}, of $1100K$ is observed at the throat. A new material will allow an increase of T_{w_h} to $1300K$. What new combustion chamber pressure p_0 will be allowed by this new material if you assume that its resistance to heat transfer t_w/κ_w is about the same as the old, and that the coolant side temperature T_c and film coefficient h_c do not change. The fraction of total heat transfer due to radiation may also be assumed to be unchanged.
   Consider, $T_c = 300K$, $T_{0g} = 3300K$, $t_w = 3.8mm$, $\kappa_w = 22W/m - K$, $h_c = 0.78MW/m^2 - K$.

4. Show that for a thick-walled rocket nozzle the overall resistance to heat transfer $(m^2 - K/W)$ can be written as

$$R_T = \frac{1}{h_g} + \frac{A_g t_w}{A_w \kappa_w} + \frac{A_g}{A_c h_c}$$

   where, A_g, A_w, A_c are the areas normal to heat transfer on gas side, in the wall (on average) and on the coolant side.