

Problem 1  $\text{CH}_6\text{N}_2 - \text{N}_2\text{O}_4$  engine.  $p_0 = 70 \text{ bar} = 7 \times 10^5 \text{ Pa}$

$$A_t = 0.0036 \text{ m}^2 \quad T_f = 298 \text{ K}$$

1a)  $r = 2$   $T_{\text{ad6}} = T_2 = T_0 = 3363 \text{ K}$ , composition in table.  
Isentropic frozen flow,  $T_e = 700 \text{ K}$ ,  $p_e = p_a$ . Find  $J$

To find  $\gamma_m$ ,  $\bar{m}_m$ :

$$\gamma_m = \frac{\bar{c}_{p,m}}{\bar{c}_{v,m}}, \quad \bar{c}_{p,m} = \sum_i x_i \bar{c}_{p,i}$$

$$\bar{c}_{v,m} = \sum_i x_i \bar{c}_{v,i} \quad \text{where } \bar{c}_{v,i} = \bar{c}_{p,i} - \bar{R}$$

$$\bar{m}_m = \sum_i x_i \bar{m}_i$$

→ solve in python

→  $\gamma_m \approx 1.222$ , etc. → in table

→ Real combustion w/ dissociation followed by  
frozen flow

$\gamma, \bar{m}$  frozen @ end of CC values

$$u_e = \sqrt{\frac{2 \gamma_m \bar{R}}{(\gamma_m - 1) \bar{m}_m} T_{02} \left[ 1 - \left( \frac{p_e}{p_{02}} \right)^{\frac{\gamma_m - 1}{\gamma_m}} \right]}$$

$$\rightarrow u_e = 3308.62 \text{ m/s}$$

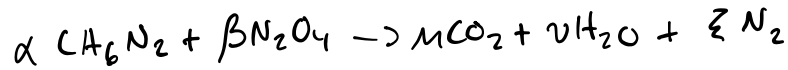
$$J = \dot{m} u_e \quad (p_e = p_a)$$

$$\dot{m} = p_e \underbrace{m_e \sqrt{\frac{\gamma_m \bar{R} T_e}{\bar{m}_m}}}_{\text{should} = u_e} A_e$$

$$p_e = \frac{p_a}{R T_e}$$

$$\rightarrow J = (14.67 \text{ kg/s})(3308.6 \text{ M/s}) = 48.5 \text{ kN} = J$$

16) complete ideal batch.



i) Find  $\beta, \mu, \nu, \xi$  in terms of  $\alpha$  & min. value of  $\alpha$

$$\text{C: } \alpha = \mu$$

$$\text{H: } 6\alpha = 2\nu$$

$$\text{N: } 2\alpha + 2\beta = 2\xi$$

$$\text{O: } 4\beta = 2\mu + \nu$$

$$\rightarrow \begin{cases} \mu = \alpha \\ \nu = 3\alpha \end{cases}$$

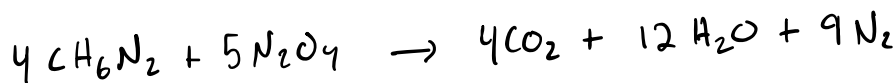
$$4\beta = 2(\alpha) + (3\alpha)$$

$$\rightarrow \beta = \frac{5}{4}\alpha$$

$$2\alpha + 2\left(\frac{5}{4}\alpha\right) = 2\xi$$

$$\rightarrow \xi = \frac{9}{4}\alpha$$

$$\Rightarrow \alpha = 4$$



$$\text{ii) OFR mole ratio} = \frac{n_{\text{N}_2\text{O}_4}}{n_{\text{CH}_6\text{N}_2}} = 1.25$$

$$\text{OFR mass ratio} = \frac{5(92.011)}{4(46.07)} = 2.5 = r$$

iii) same  $P_o, P_a, A_c/A^*,$  Find  $T_{ad}$  &  $J$

$$\dot{Q} = \dot{Q}_L + \dot{Q}_2 = 0 \rightarrow \dot{Q}_2 = -\dot{Q}_L$$

$$\dot{Q}_L = \dot{H}_{\text{ref}} = \sum_j (n_j \bar{h}_f)_{\text{prod}} - \sum_i (n_i \bar{h}_f)_{\text{reac}}$$

$$\dot{Q}_2 = \sum_j n_j (\bar{h} - \bar{h}_o) = \sum_j n_j \bar{c}_p (T_2 - T_F)$$

→ solve in python →  $Q_R = 5.11 \text{e}^9$

why is  $Q_R$  not normalized but

in the equations  $Q_R$  is per mass (same notation?)

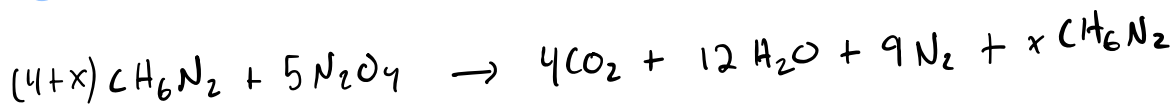
Same as: 
$$u_e = \sqrt{\frac{2 \gamma_m \bar{R}}{(\gamma_m - 1) \bar{M}_m} T_{02} \left[ 1 - \left( \frac{P_e}{P_{02}} \right)^{\frac{\gamma_m - 1}{\gamma_m}} \right]}$$

$$T_{02} = T_{01} + \frac{Q_R}{c_p} = \frac{Q_R}{\mu \cdot c_p} = 4344 \text{ K} = T_{02}$$

→ solve for  $u_e$  &  $J$

→  $u_e = 3580.9 \text{ m/s}$ ,  $J = 52.7 \text{ kN}$

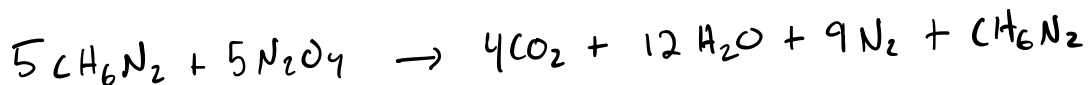
(c)  $r = 2$ , excess  $\text{NH}_4$



$$r = 2 = \frac{5(92.011)}{(4+x)(46.07)} = (4+x) = \frac{5(92.011)}{2 \cdot (46.07)}$$

$$\rightarrow x \approx 1$$

→



→ same code:  $T_{02} = 3832 \text{ K}$

→  $u_e = 3360 \text{ m/s}$ ,  $J = 49.58 \text{ kN}$

1d) See table

1e) We see clearly that case b is the highest temperature since no energy is lost to either dissociation (case a) or heating non-stoichiometric products (case c).

case b has to heat the least amount of products and retains the most of the combustion heat.

Because of this, case b has high exhaust velocity and mass flow rate, and thus highest thrust.