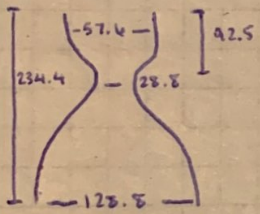
Name: Veronica Loomis

Given: $P_c = 700$ psi
$c^* = 7800$ ft/s
$O/F = 6.0$
$\gamma = 1.2$

Find: a) Total engine propellant flow rate [lbm/s]
b) Sea level thrust [lbf]
c) Vacuum thrust [lbf]
d) Sea level and vacuum Isp
e) If engine tested at SL, determine area ratio in exit ($P_{sep}/P_a = 0.333$)

Schematic:



Assumptions:
$P_{sep}/P_a = 1/3$
Purdue lookup tables
No flow sep at SL

Basic Equations:

$$\dot{m} = \frac{g_c P_c A_t}{c^*}$$

$$F = C_F A_t P_c$$

$$I_{sp} = F/\dot{m}g = \frac{C_F c^*}{g}$$

$$C_F = C_{F vac} - (P_a/P_c)\,\epsilon$$

Analysis:

a) Total Propellant Flow Rate

$$\dot{m} = \frac{g_e P_c A_t}{c^*} \quad \left[P_c = 700\,lbf/in^2,\ A_t = \pi\frac{(28.8)^2}{4} = 651.44\,in^2,\ c^* = 7800\,ft/s\right]$$

$$\dot{m} = \frac{(700\,\frac{lbf}{in^2})(651.44\,in^2)}{7800\,ft/s} \times \frac{32.2\,lbm\,ft}{lbf\,s^2}$$

$$\boxed{\dot{m} = 1882.49\ lbm/s}$$

b) Sea level thrust (no flow sep)

$\varepsilon = (128.8/28.8)^2 = 20$

Given $\gamma = 1.2$

Purdue table → $C_{Fv} = 1.82047$, [illegible]

$C_{F,SL} = C_{Fv} - (P_a/P_c)\varepsilon$

$C_{F,SL} = 1.82047 - (14.696/700)(20)$

$C_{F,SL} = 1.40$

$F_{SL} = C_F A_t P_c$

$F_{SL} = (1.40)(651.44\,in^2)(700\,lbf/in^2)$

$$\boxed{F_{SL} = 638411.2\ lbf}$$

c) Vacuum Thrust

$F_v = C_{Fv} A_t P_c$

$F_v = (1.8205)(651.44)(700)$

$$\boxed{F_v = 830162.56\ lbf}$$

d) Sea level & vacuum Isp

$$I_{sp\,SL} = \frac{C_{FSL}\,c^*}{g} = \frac{(1.4)(7800\,ft/s)}{32.2\,ft/s^2} = \boxed{339.13\,sec = I_{sp,SL}}$$

$$I_{sp,v} = \frac{(1.8205)(7800\,ft/s)}{32.2\,ft/s^2} = \boxed{441\,sec = I_{sp,v}}$$

e) ε if $P_{sep}/P_a = 1/3$

$P_{e,sep} = \frac{1}{3}(14.696\,lbf/in^2) = 4.9\,lbf/in^2$

$P_{e,sep}/P_c = 0.007$ ⟶ purdue table $\gamma = 1.2$ interpolate

$$\boxed{\varepsilon = 15.6}$$

Comment: $F_{SL}(b) \gg F_{if\ P_{sep}/P_a}$. Since area ratio is much smaller

Name: Veronica Loomis

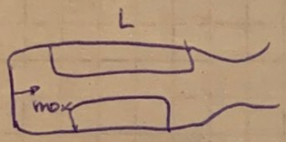
Given ρ_f, R_i, L, $\dot{m}_{ox}$, $c^* = \alpha + \beta(O/F) + \gamma(O/F)^2$, $r = aG_{ox}^n$

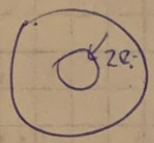
Find: a) initial P_c as $f(O/F)$

b) Eqn of O/F as $f(t)$

c) $\alpha = 2515$, $\beta = 3075$, $\gamma = -690$ calc O/F of max c^* and max c^*

Schem





Assume

Basic Eqns

$P_c = (\dot{m}_{ox} + \dot{m}_f)\, c^* / A_t$

$\dot{m}_f = r \rho_f A_b$

$G_{ox} = \dot{m}_{ox} / A_p$

Analysis

a) Initial P_c as $f(O/F)$

$r = a(G_{ox})^n \qquad G_{ox} = \frac{\dot{m}}{A_p} \qquad C^* = \frac{P_c A_t}{(\dot{m}_{ox} + \dot{m}_f)} \qquad \dot{m}_f = \rho_f A_b r$

$P_c = \frac{c^*(\dot{m}_{ox} + \dot{m}_f)}{A_t} \qquad c^* = \alpha + \beta(O/F) + \gamma(O/F)^2$

$\dot{m}_f = \rho_f A_b r = \rho_f(2\pi R L)\left(a\left(\frac{\dot{m}_{ox}}{\pi R^2}\right)^n\right)$

$$\boxed{P_c = \frac{(\alpha + \beta(O/F) + \gamma(O/F)^2)\left(\dot{m}_{ox} + 2\pi R L \rho_f a\left(\frac{\dot{m}_{ox}}{\pi R^2}\right)^n\right)}{A_t}}$$

b) O/F as $f(t)$

$O/F = \frac{\dot{m}_{ox}}{\dot{m}_f}$

$\int R^{2n} dR = \int a\left(\frac{\dot{m}_{ox}}{\pi}\right)^n dt$

$R(t) = \left[a(2n+1)\left(\frac{\dot{m}_{ox}}{\pi}\right)^n t + R_i^{2n+1}\right]^{1/2n+1}$

$$\boxed{O/F = \frac{\dot{m}_{ox}}{2\rho_f \pi L a \dot{m}_{ox}^n\left[a(2n+1)\left(\frac{\dot{m}_{ox}}{\pi}\right)^n t + R_i^{2n+1}\right]^{(1-2n)/1+2n}}}$$

c) $c^* = 2515 + 3075(O/F) - 690(O/F)^2$

derive

$c^{*\prime} = 3075 - 1380(O/F) = 0$

$\boxed{(O/F)_{max} = 2.228}$

$c^*(2.228) = 2515 + 3075(2.228) - 690(2.228)^2$

$\boxed{C^*_{max} = 5940.95 \text{ ft/s}}$

Comment: Since O/F is a function of time

c^* is also a function of time

Name - Veronica Loomis

Given - $H_2 + 4F_2 \longrightarrow aHF + bF_2 + cF$

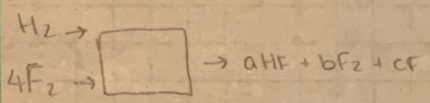
$T = 298\,K$, $P = 100$ atm

$F_2 \rightleftharpoons 2F$

Find -
a) O/F
b) c as f(b)
c) eq for K_p
d) enthalpy balance if C_p does not change w/ temp
e) " if C_p changes w/ temp
f) If P doubled, more or less diss. of F_2?

~~Basic Equations~~

Schematic



Assumptions:
const P combustion
$F_2 \rightleftharpoons 2F$
Steady state
adiabatic combustion

Basic Eqs:

$O/F = {m_{ox}}/{m_f}$

$C_p = a + b(T/1000) + c(T/1000)^2 + d(T/1000)^3$ if $C_p(T)$

Analysis:

a) O/F

H_2: (1.008)(2)

$4F_2$: (18.998)(8)

$O/F = 151.984 / 2.016$

$\boxed{O/F = 75.389}$

b) H: $2 = a$

F: $8 = a + 2b + c$

$8 = 2 + 2b + c$

$\boxed{c = 6 - 2b}$

c) $k_p = \frac{(X_F)^2}{(X_{F_2})^1} P^{2-1} = \frac{(X_F)^2}{X_{F_2}} P$

$X_F = c/n \qquad X_{F_2} = b/n$

$n = a+b+c = 2+b+(6-2b) = 8-b$

$k_p = \frac{\left(\frac{6-2b}{8-b}\right)^2}{\left(\frac{b}{8-b}\right)} P = \boxed{\frac{(6-2b)^2}{b(8-b)} P = k_p}$

d) $H_{prod} - H_{reac} = a\bar{h}_{HF} + b\bar{h}_{F_2} + c\bar{h}_F - \bar{h}_{H_2} - 4\bar{h}_{F_2} = 0$

$\bar{h} = \int_T^T C_p dT + h_f^\circ$ & since we're assuming const C_p

$\bar{h} = C_p(T_2 - T_0) + h_f^\circ$

Reactants $\bar{h} = 0$

$$\boxed{0 = 2\left[C_p(T_2 - T_0) + h_f^\circ\right]_{HF} + b\left[C_p(T_2 - T_0) + h_f^\circ\right]_{F_2} + (6-2b)\left[C_p(T_2 - T_0) + h_f^\circ\right]_F}$$

e) Now $C_p = a + b(T/1000) + c(T/1000)^2 + d(T/1000)^3$

$$\boxed{\begin{aligned} 0 = & \ 2\left[aT + \tfrac{bT}{2}(T/1000) + \tfrac{cT}{3}(T/1000)^2 + \tfrac{dT}{4}(T/1000)^3\right]_{T_0}^{T_2} + h_f^\circ (HF) \\ & + b\left[aT + \tfrac{bT}{2}(T/1000) + \tfrac{cT}{3}(T/1000)^2 + \tfrac{dT}{4}(T/1000)^3\right]_{T_0}^{T_2} + h_f^\circ (F_2) \\ & + (6-2b)\left[aT + \tfrac{bT}{2}(T/1000) + \tfrac{cT}{3}(T/1000)^2 + \tfrac{dT}{4}(T/1000)^3\right]_{T_0}^{T_2} \end{aligned}}$$

f) $\boxed{\text{If } P\uparrow,\ T\downarrow,\ \text{less dissociation}}$

Comments:

C_p as constant is much easier, but also less accurate