AE19B038
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AS2520 Endsem

Q1 Apparatus

a). Burn rate measurement in solid rocket
- Crawford Bomb
- Pressure transducer
- DC supply
- Pressure Gauge
- Pressure regulator
- Electrodes
- Propellant
- Propellant holder.
- Heat exchanger
- DAS (~~Data~~ acquisition system

b) Ramjet
- Ramjet model
- Sequential timer
- Rotameter
- Pressure Gauge
- Air compressor
- ignitor battery
- Data Acquisition system.

c) · Propellar + piston engine
- slider mechanism
- Engine
- Thrust load cell
- Fuel weight load cell.
- DAS.
- motors arduino
- PC.

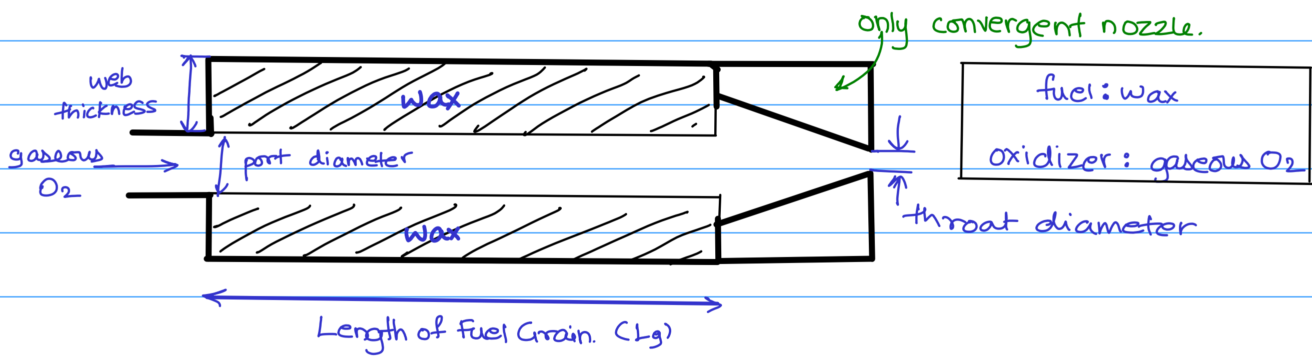
d) Hybrid Rocket

- oxidizer
- Valve control
- pressure transducer and indicator
- settling chamber
- Hybrid rocker
- Ignitor cable / battery

e) Diffusion flame height

- bunsen burner
- fuel
- Rotameter
- Needle value
- height measurement device

Q2



Data

$\dot{r} = 0.116\ G_{ox}^{0.62}$ ($\dot{r}$ in mm/s and G_{ox} in kg/m²s)

$\dot{m}_o = 0.030$ kg/s

$\rho_f = 900$ kg/m³

$L_g = 0.134$m

initial port diameter = 0.009m

web thickness = 0.022m

throat diameter = 0.008m

chamber Temp (T_c) = 3400K

burnt gases
- ↳ M = 22
- ↳ γ = 1.2

Relations

regression rate $\dot{r} = 0.116\ G_{ox}^{0.62}$ ——— (1)

oxygen mass flow rate ✓ $\dot{m}_o = A_p \cdot G_{ox}$. ——— (2)

Average port area $A_p = \frac{\pi}{4}\left(\frac{d_i + d_f}{2}\right)^2$ ——— (3)

fuel mass flow rate $\dot{m}_f = A_b \cdot \rho_f \cdot \dot{r}$ ——— (4)

A_b : combustion port surface area. (taking equal to the average port area).

$$\boxed{\text{conservation of mass.} \quad d_f^2 = \frac{4 \cdot (\Delta m)}{\pi\, \rho_f \cdot L_g} + d_i^2 \quad \text{——— (5)}}$$

To solve the given question we first need to find $\dot{m}_f$ at different times. we have to take 5 such intervals where we calculate it.

- having decided the diameter intervals, we use (3) to find A_p,
- using $\dot{m}_o$ and A_p, we calculate G_{ox} using (2)
- from G_{ox} we find $\dot{r}$, using (1)
- from $\dot{r}$ we find $\dot{m}_f$ in that time interval, using (4)

$d_{i_0} = 0.009m$

$d_{max} = d_{i_0} + (\text{web thickness})^* 2$
$= 0.009m + 0.044$
$= 0.053\,m.$

*To carry out calculations at 5 evenly spaced intervals, we will take them as the following intervals.

0.009m (d_{i_0}) — ① — 0.017m — ② — 0.025m — ③ — 0.033m — ④ — 0.041m — ⑤ — 0.049m — 0.053m (d_{max})

$\dot{m}_o = 0.030$ kg/s

Following the above mentioned steps, we have.... $O/F = \dot{m}_o/\dot{m}_f$

Int.	initial diameter (in m)	final diameter (in m)	Avg. port area (in m^2)	G_{ox} (in kg/m^2s)	$\dot{r}$ (in mm/s)	$\dot{m}_f$ (in kg/s)	O/F
1	0.009	0.017	13.273 e-5	226.01885	3.342 e-3	0.39925 e-3	75.141
2	0.017	0.025	34.636 e-5	86.615	1.844 e-3	0.57483 e-3	52.1897
3.	0.025	0.033	66.052 e-5	45.41877	1.236 e-3	0.73464 e-3	40.8365
4.	0.033	0.041	107.521 e-5	27.90152	0.9136 e-3	0.88406 e-3	33.93424
5.	0.041	0.049	159.043 e-5	18.8628	0.7167 e-3	1.02587 e-3	29.24354

from initial and final diameter, we can even find Δm, using (5)

Int.	initial diameter (in m)	final diameter (in m)	Δm (in kg)
1	0.009	0.017	0.0197
2	0.017	0.025	0.0318
3.	0.025	0.033	0.04395
4.	0.033	0.041	0.05607
5.	0.041	0.049	0.06819

$\dot{m} = \frac{\Delta m}{\Delta t}$ $\therefore$ Δt for interval, found using $\Delta m/\dot{m}$

Int.	Δm (in kg)	$\dot{m}_f$ (in kg/s)	Δt (in s)
1	0.0197	0.39925 e-3	49.3462
2	0.0318	0.57483 e-3	55.3659
3.	0.04395	0.73464 e-3	59.82502
4.	0.05607	0.88406 e-3	63.42723
5.	0.06819	1.02587 e-3	66.47806

characteristic velocity (c^*)

$$c^* = \frac{\sqrt{\dfrac{\gamma R T}{M}}}{\gamma\sqrt{\dfrac{2}{\gamma-1}}}$$

for our system

$T = 3400K$, $M = 22 g/mole$ $\gamma = 1.2$, $R = 8.314 \frac{J}{mol K}$.

for MW = 22

$\boxed{\text{or } \frac{R^*}{MW} = 377.9}$

$$c^* = 327.222 \ m/s$$

chamber pressure (P_c)

$$P_c = \frac{c^* (\dot{m}_f + \dot{m}_o)}{A_t} + P_b$$

back pressure

usually = ambient pressure

throat area

$\dot{m}_o = 0.030 \ kg/s$

Int.	$\dot{m}_f$ (in kg/s)	P_c (atm)
1	0.39925 e-3	2.9531
2	0.57483 e-3	2.9644
3	0.73464 e-3	2.9746
4.	0.88406 e-3	2.9842
5.	1.02587 e-3	2.9933

throat diameter = 0.008 m

throat area = $\frac{\pi}{4} d^2$

$= 50.265e-6$

$P_b = 1 atm = 101325 \ Pa$

we then calculate exit pressure using

$$\frac{A_e}{A_t} = \frac{\sqrt{\gamma}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}}{\left(\frac{P_e}{P_c}\right)^{1/\gamma}\sqrt{\frac{2\gamma}{(\gamma-1)}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}}$$

$\because$ only converging nozzle used $\therefore A_e = A_t$

$$\left(\frac{P_e}{P_c}\right)^{1/\gamma} \cdot \sqrt{\frac{2\gamma}{(\gamma-1)}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right]} = \sqrt{\gamma}\cdot\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

taking $\left(\frac{P_e}{P_c}\right)^{1/\gamma} = x$

$$x\sqrt{(12)\left(1-x^{\gamma-1}\right)} = \sqrt{1.2}\left[\left(\frac{10}{11}\right)^{\frac{2.2\cdot 11}{2}}\cdot\frac{1}{0.2}\right]$$

$$x\sqrt{12\left(1-x^{0.2}\right)} = \sqrt{1.2}\cdot\left(\frac{10}{11}\right)^{11/2}$$

$$x^2\left(1-x^{0.2}\right) \doteq 0.035049389$$

$\therefore$ +ve $x = 0.6209$

$$\left(\frac{P_e}{P_c}\right)^{1/\gamma} = 0.6209$$

$$P_e = (0.564450668)\,P_c$$

Int.	$\dot{m}_f$ (in kg/s)	P_c (atm)	P_e (atm)
1	0.39925 e-3	2.9531	1.66686
2	0.57483e-3	2.9644	1.67323
3	0.73464 e-3	2.9746	1.67903
4.	0.88406 e-3	2.9842	1.68445
5.	1.02587 e-3	2.9933	1.68959

similarly.

Thrust coefficient

$$C_F = \underbrace{\sqrt{\gamma}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}}_{0.64853117}\ \underbrace{\sqrt{\frac{2\gamma}{\gamma-1}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}}_{\frac{0.64853117}{(0.6209)^{1/\gamma}} = 0.9647456} + \left(\overset{0.6209}{\frac{P_e}{P_c}} + \overset{1\text{atm}}{\frac{P_b}{P_c}}\right)\cdot\frac{A_e}{A_t} \leftarrow 1$$

$$C_F = 0.6256676 + \left(0.6209 + \frac{1}{P_c}\right)$$

$$^{*}\ C_F = 1.2465676 + \frac{1}{P_c}$$

Int.	$\dot{m}_f$ (in kg/s)	P_c (atm)	P_e (atm)	C_F
1	0.39925 e-3	2.9531	1.66686	1.5851976
2	0.57483e-3	2.9644	1.67323	1.5839090
3	0.73464 e-3	2.9746	1.67903	1.5827446
4.	0.88406 e-3	2.9842	1.68445	1.5816632
5.	1.02587 e-3	2.9933	1.68959	1.5806432

and further

$$\text{Thrust}(F) = \overset{m/s}{c^*}\ \overset{kg/s}{(\dot{m}_f + \dot{m}_o)} \cdot \overset{\text{unitless}}{C_F} \quad \ldots\ N$$

Int.	$\dot{m}_f$ (in kg/s)	P_c (atm)	P_e (atm)	C_F	Thrust (N)
1	0.39925 e-3	2.9531	1.66686	1.5851976	15.768446
2	0.57483e-3	2.9644	1.67323	1.5839090	15.8466264
3	0.73464 e-3	2.9746	1.67903	1.5827446	15.917744
4.	0.88406 e-3	2.9842	1.68445	1.5816632	15.984204
5.	1.02587 e-3	2.9933	1.68959	1.5806432	16.0472413

Q2 Answer

SL. no.	Time(s)	$\dot{m}_f$ (kg/s)	O/F	P_c (atm)	Thrust(N)
1	49.3462	0.39925 e-3	75.141	1.66686	15.768446
2	104.7121	0.57483 e-3	52.1897	1.67323	15.84663
3	164.53712	0.73464 e-3	40.8365	1.67903	15.917744
4	227.96435	0.88406 e-3	33.93424	1.68445	15.984204
5	294.44241	1.02587 e-3	29.24354	1.68959	16.0472413

as fuel is used, the port diameter inc $\therefore A_p \uparrow$

$\because \dot{m}_o$ is constant, $G_{ox} \downarrow$ $\quad \therefore \dot{r} \downarrow$

$$\dot{m}_f = A_b \uparrow \cdot \rho_f \cdot \dot{r} \downarrow$$

with $n = 0.5$ i.e. n less than 0.62,

then the correlation of $G_{ox} \downarrow$ and $\dot{r} \downarrow$ will be lesser

at $n = 0$,

$\dot{r}$ will be independent of any change in G_{ox}

and will keep on increasing as $A_b \uparrow$.