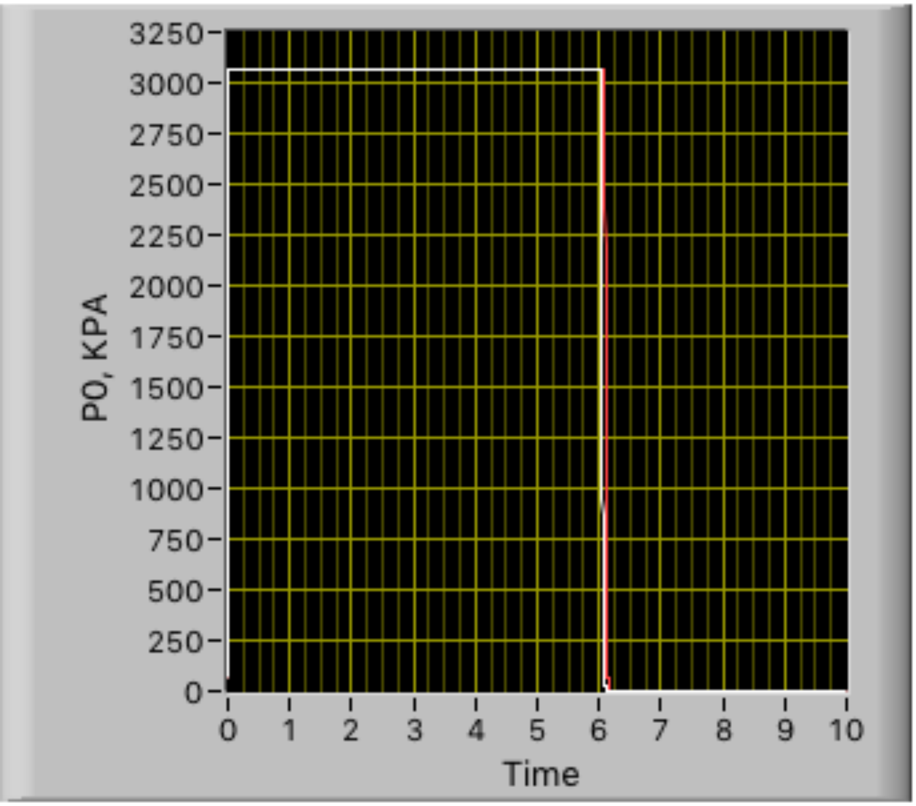
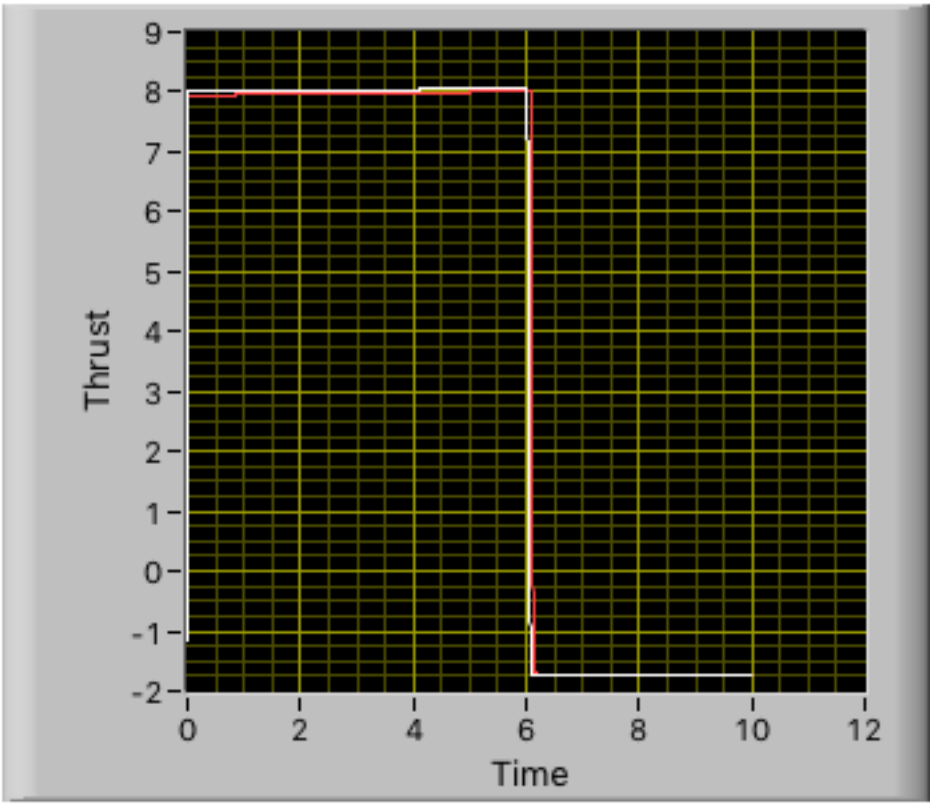
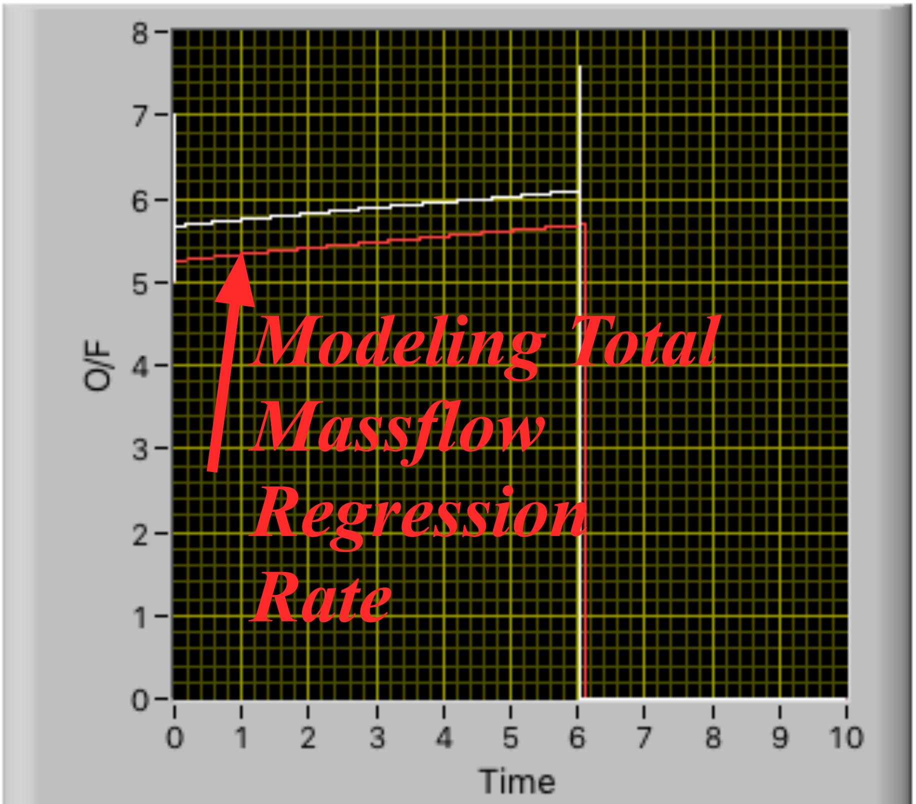
BURNER PRESSURE



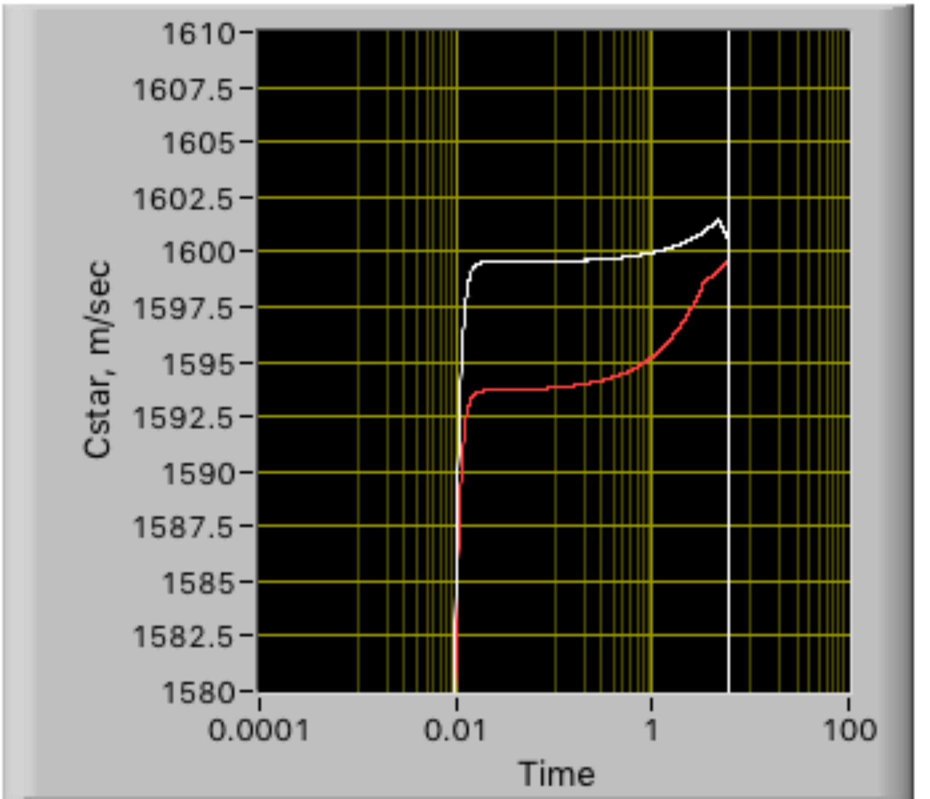

Thrust, kN




O/F Ratio

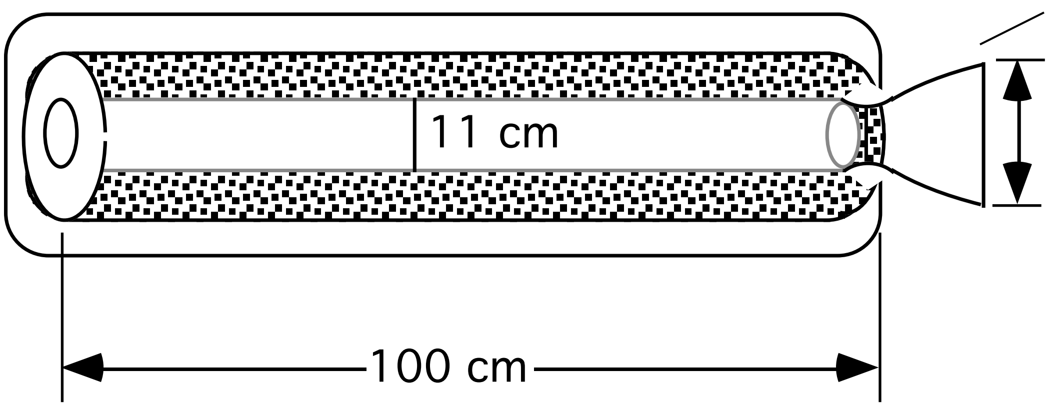



Characteristic Velocity



# Homework

- Nitrous Oxide HTPB Hybrid Rocket design
- Desired Thrust of 8 kNt
- Operate near optimal mixture ratio (based on $I_{sp}$)
- Nozzle $A/A^*$=16.4, exit diameter = 19.17 cm,
- Nozzle Exit Divergence angle = 10°
- Single Circular Grain Port, Initial Diameter 11 cm
- Grain length 100 cm
- Ambient pressure 60 kPa
- Assume Isentropic Flow in Nozzle



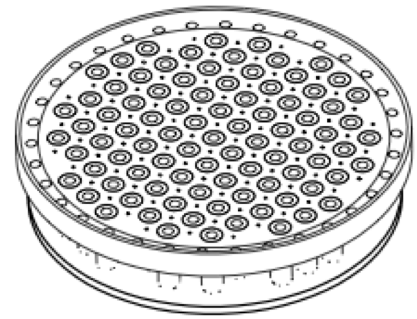
# Homework #4 (cont'd)

- CEA Mean Combustion Property Calculations, $P_0 \simeq 3000$ kPa

N20/HTPB Ideal combustion properties

| O/F Ratio | T0 K | γ | Mol.Wt kg/kg-mol |
|---|---|---|---|
| 2.000 | 2019.400 | 1.251 | 20.494 |
| 3.000 | 2329.500 | 1.256 | 20.823 |
| 3.500 | 2643.200 | 1.280 | 21.653 |
| 4.000 | 2895.800 | 1.256 | 22.779 |
| 5.000 | 3225.500 | 1.208 | 24.613 |
| 5.500 | 3315.000 | 1.185 | 25.332 |
| 6.000 | 3366.300 | 1.167 | 25.925 |
| 7.000 | 3399.400 | 1.148 | 26.807 |
| 8.000 | 3388.300 | 1.142 | 27.421 |
| 9.000 | 3359.400 | 1.141 | 27.871 |

# Homework #4 (cont'd)



- $N_2O$ Injector / Oxidizer properties
- 50 injector ports, 2.0 mm in diameter
- Assume each port has a discharge coefficient $C_d$=0.81
- Assume Saturation Liquid $N_2O$ density at 276K of 892 kg/$M^3$

# Gaseous $N_2O$ Viscosity properties

Use Southerland's Law (semi-empirical fit) for Viscosity terms

$$\mu(T) = \mu_0 \left( \frac{T}{T_0} \right)^{3/2} \left( \frac{T_0 + C_s}{T + C_s} \right)$$

| | | |
|---|---|---|
| **$C_s$** | **=** | **240 °K** |
| **$T_0$** | **=** | **300.00 °K** |
| **$\mu_0$** | **=** | **1.4889E-5 Nt-sec/$M_2$** |

- Assume Boundary Layer Prandtl Number of 0.5
- Assume combustor efficiency ($C^*_{actual}/C^*_{ideal}$) = 0.99

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# Homework #4 (cont'd)

- **HTPB Properties**

- Solid propellant density of 930 kg/M$^3$

- Latent heat of vaporization ($h_v$), 1.8 MJ/kg

- Solid Grain temperature (assume constant) 300°K

# Homework #6 (cont'd)

- **Select Injector pressure to give an approximate steady burn Thrust of 8 kNt**

- **Choose optimal propellant masses to give a 6 second burn time**

- **Plot predicted linear regression rate as a function of $N_2O$ mass velocity**

$$\rho_e U_e = \frac{m_{ox}}{A_{c_{chamber}}} \rightarrow$$

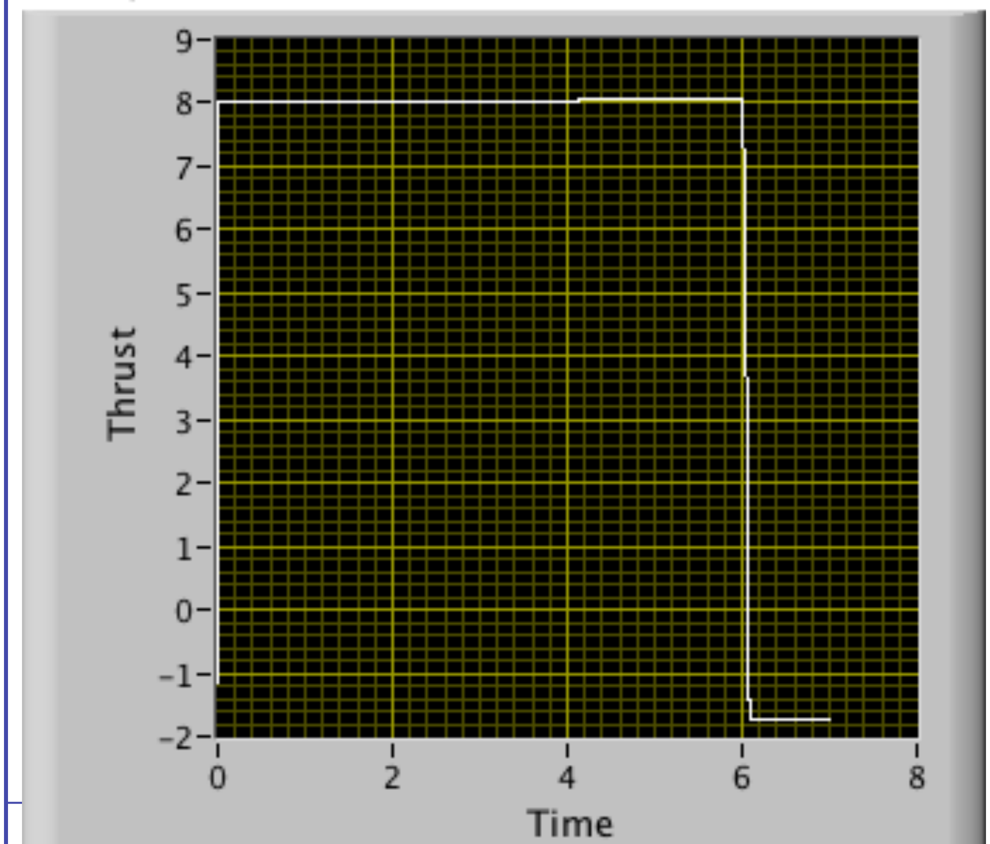
- ***Repeat Analysis for Motor with 157 cm grain length, compare average mixture ratio, average specific impulse, and total propellant consumed to 100 cm motor***

# L = 100 cm

- ***Select Injector pressure to give an approximate steady burn Thrust of 8 kNt***

$p_{inj} \approx 3354_{kPa}$ ***Marxman Only***

Thrust, kN




- Optimized for 6-second burn

$$HTPB\ fuel\ mass: \quad 2.95_{kg}$$

$$Oxidizer mass: \quad 17.45_{kg}$$

$$Total\ O+F\ mass: \quad 20.4_{kg}$$

- Mean O/F and Isp:

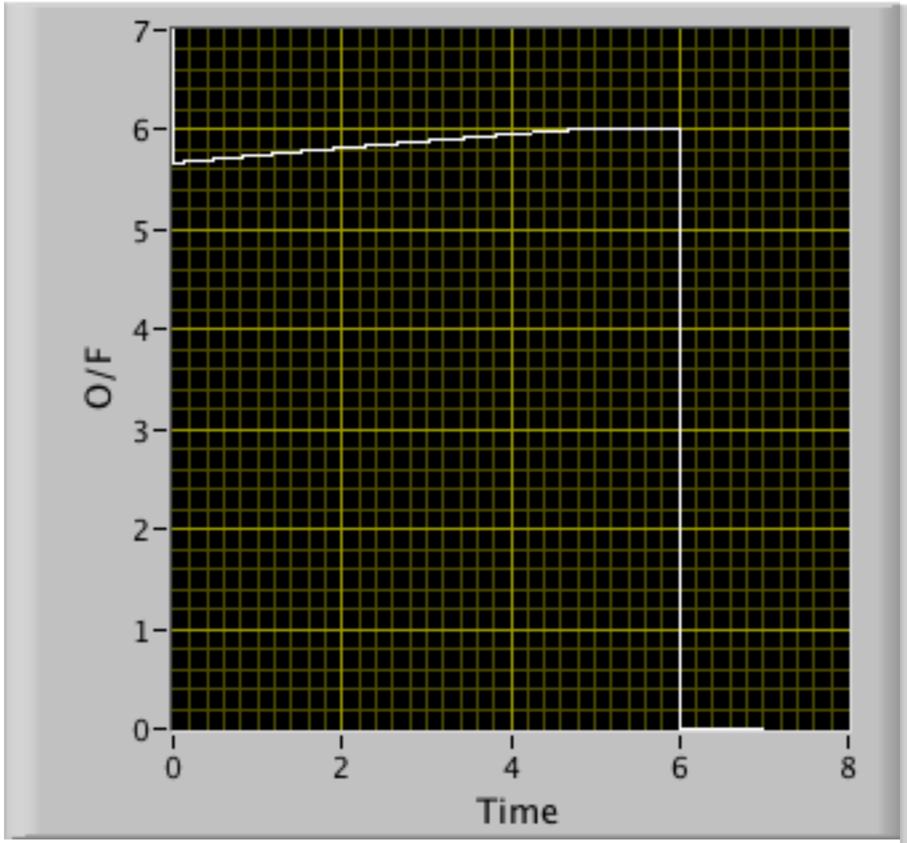
$$Mean\ O/F: 17.45/2.95 = 5.915$$

$$Mean\ I_{sp}: \frac{8000_{N} \cdot 6\,\text{sec}}{\left(9.8067_{\frac{m}{sec^2}} \cdot 20.4_{kg}\right)} = 239.932$$

# L = 100 cm (2)

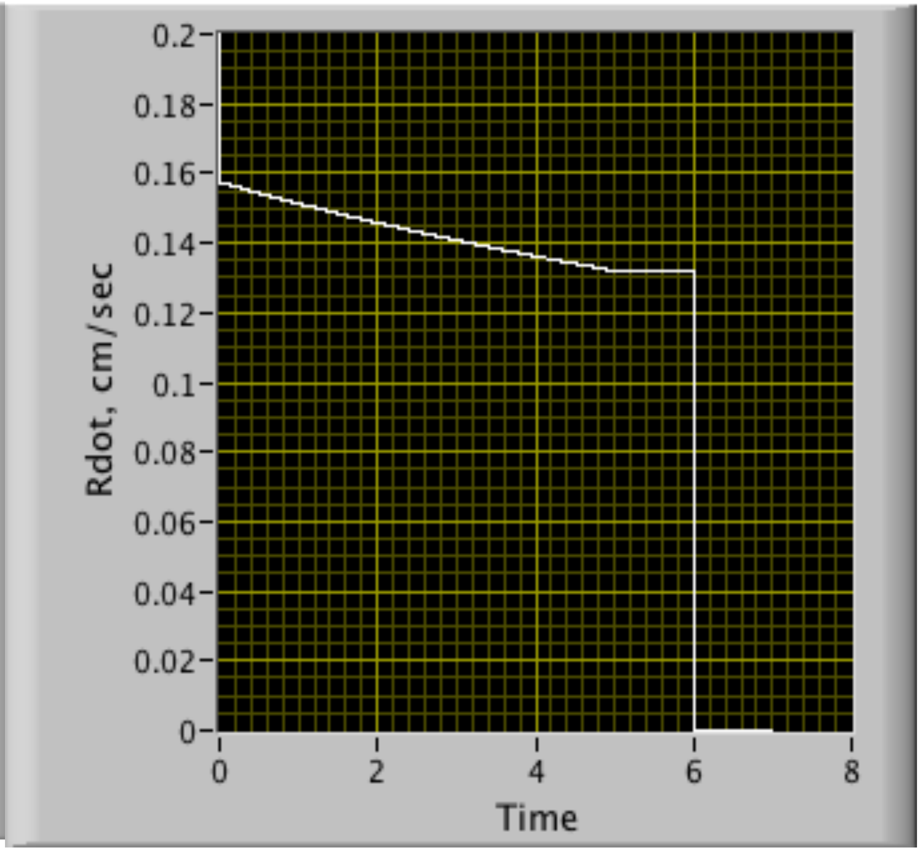
- ***O/F, Rdot Profile(s)***

O/F Ratio



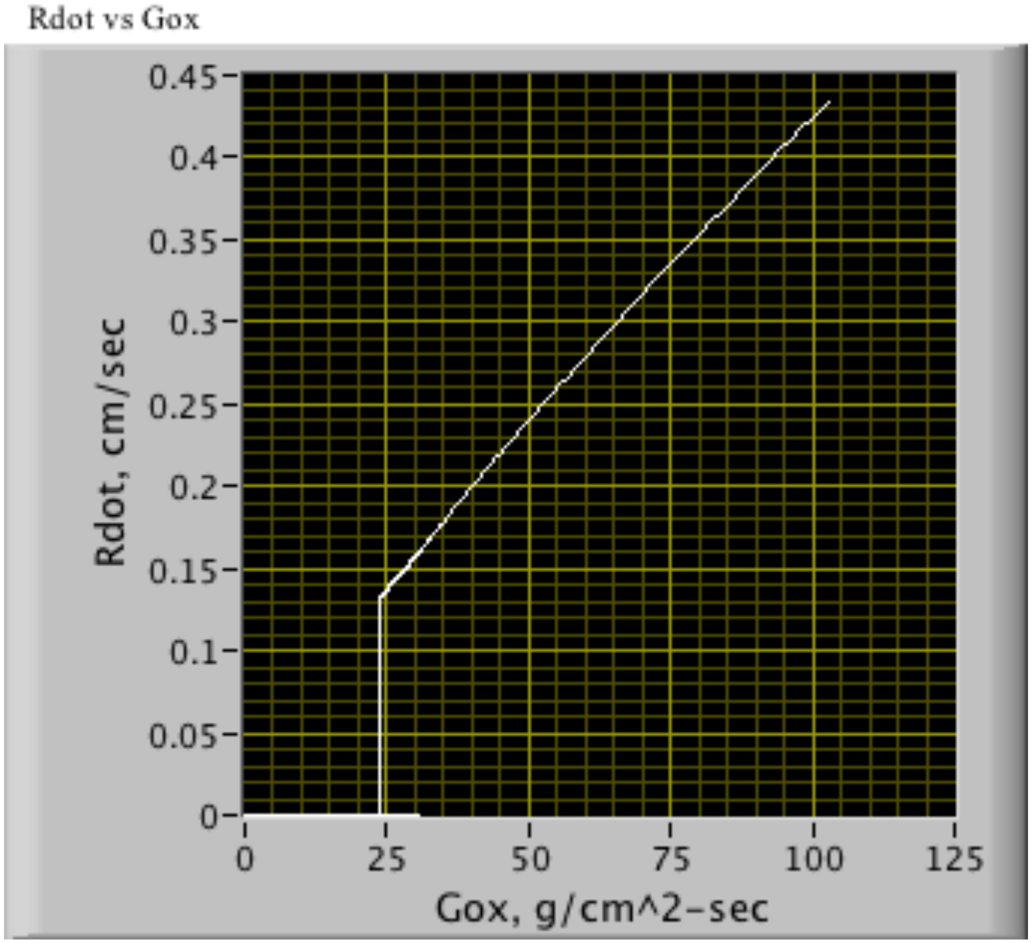

Rdot

***Marxman Only***



# L = 100 cm (3)

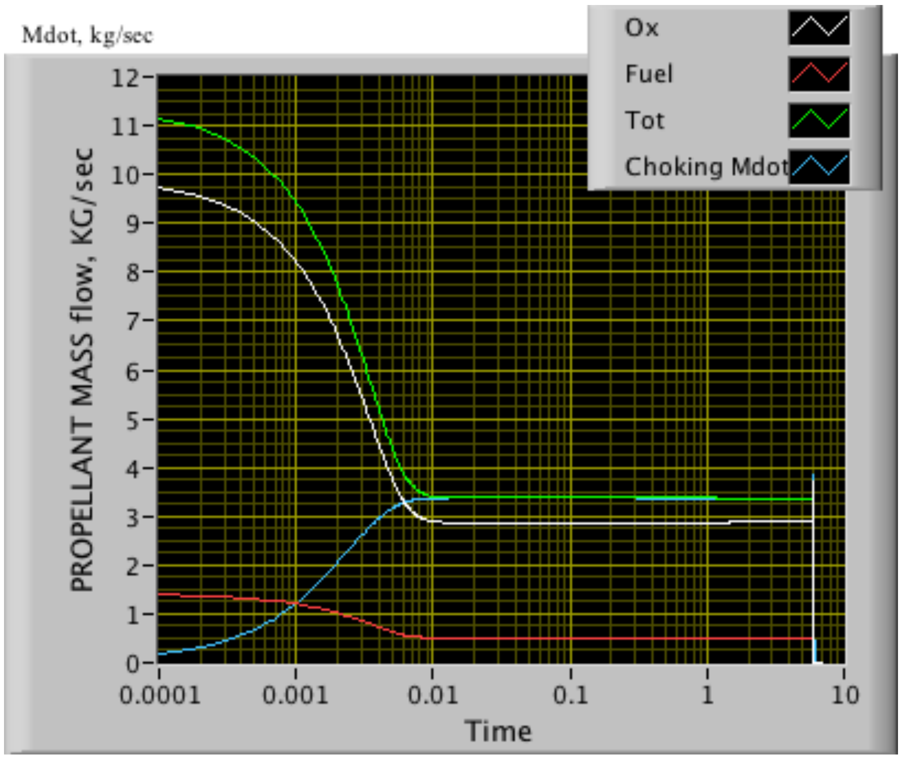
• ***Regression Rate Versus Oxidizer Mass Flux (Mass Velocity)***



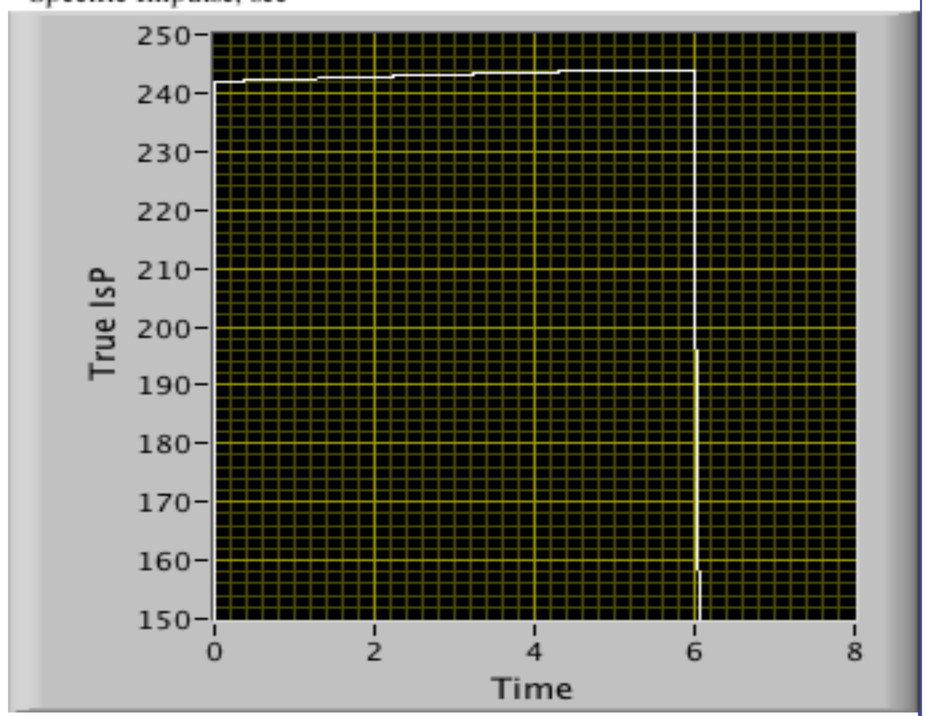
# L = 100 cm (4)

- ***Mass Flow Rate, Isp***

Mdot, kg/sec

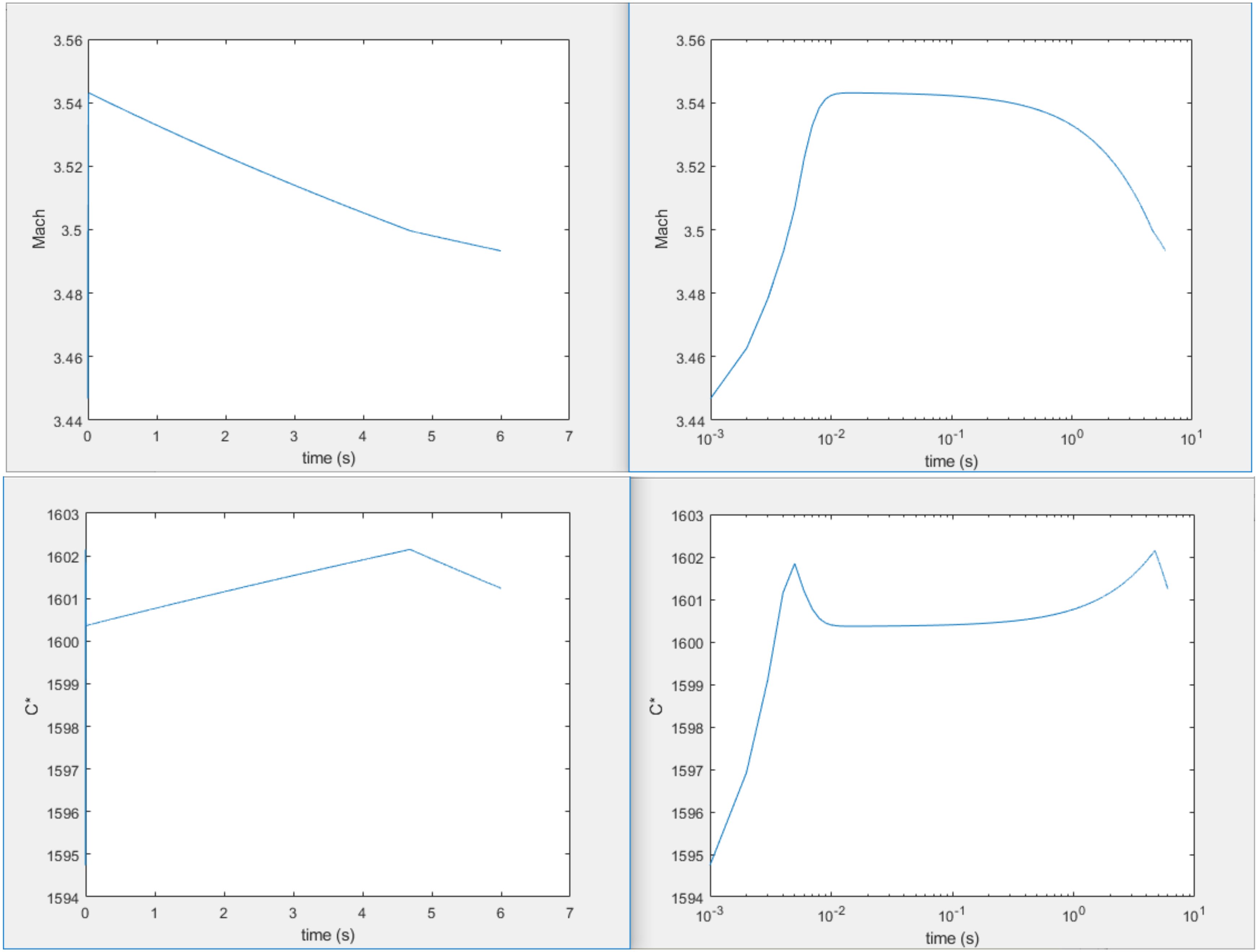



Specific Impulse, sec

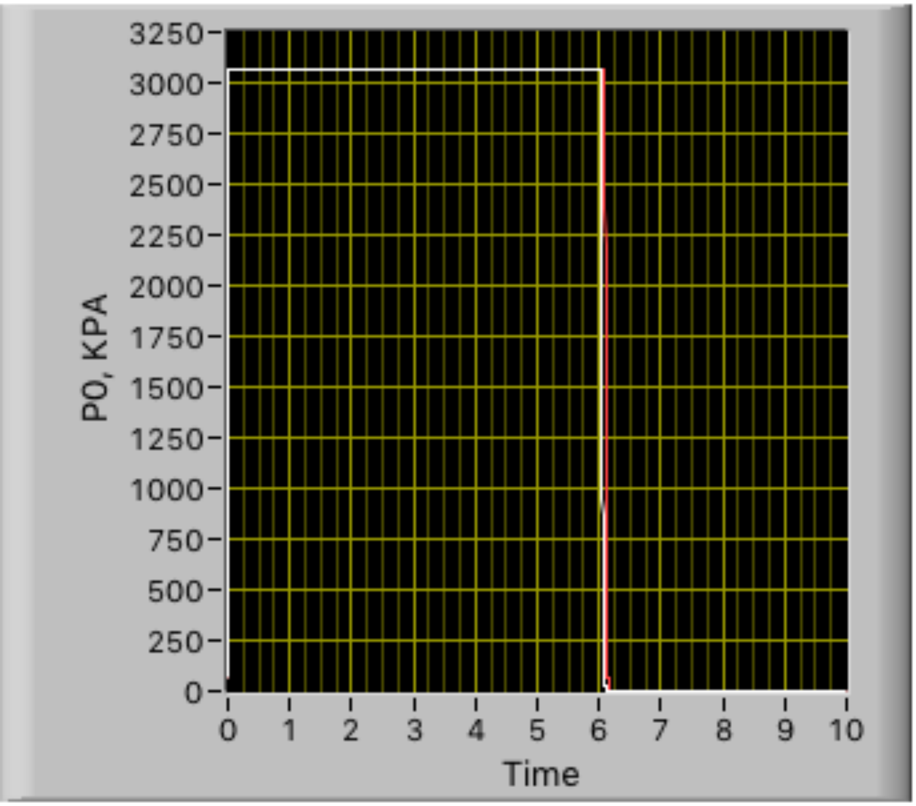


L=100 cm

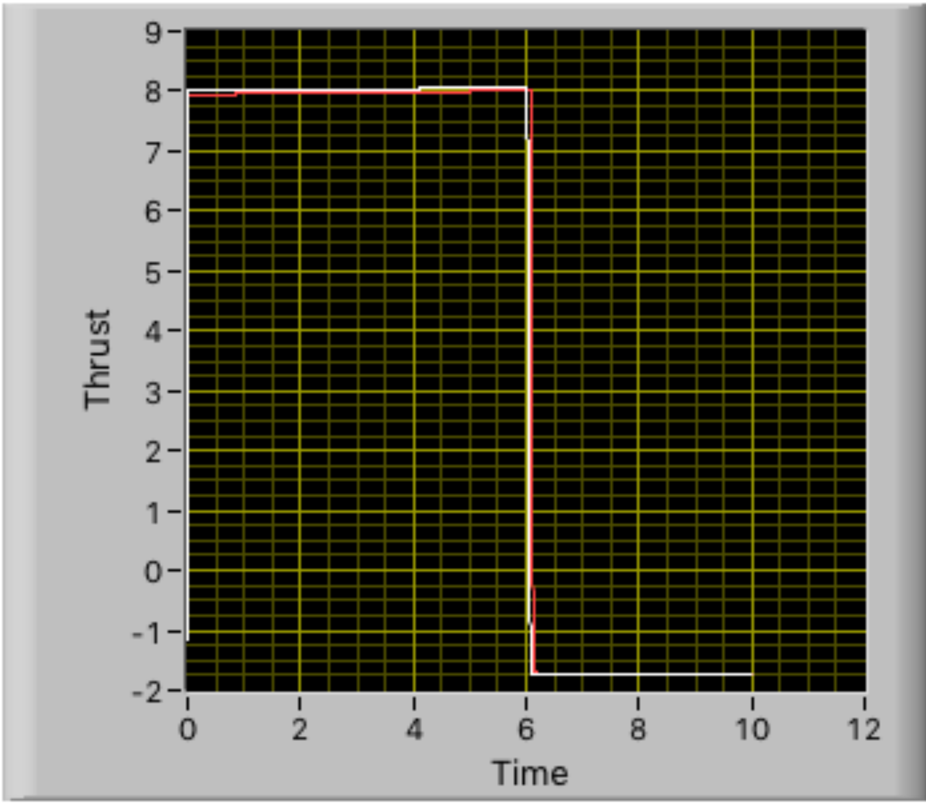
## Mach Number and C*:



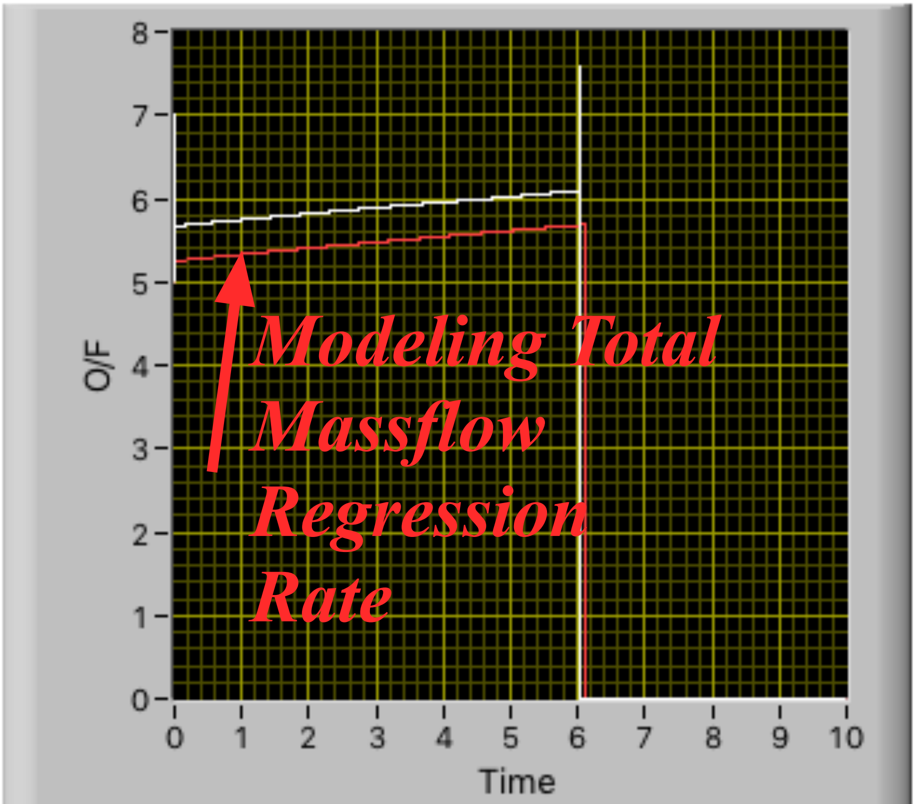
BURNER PRESSURE



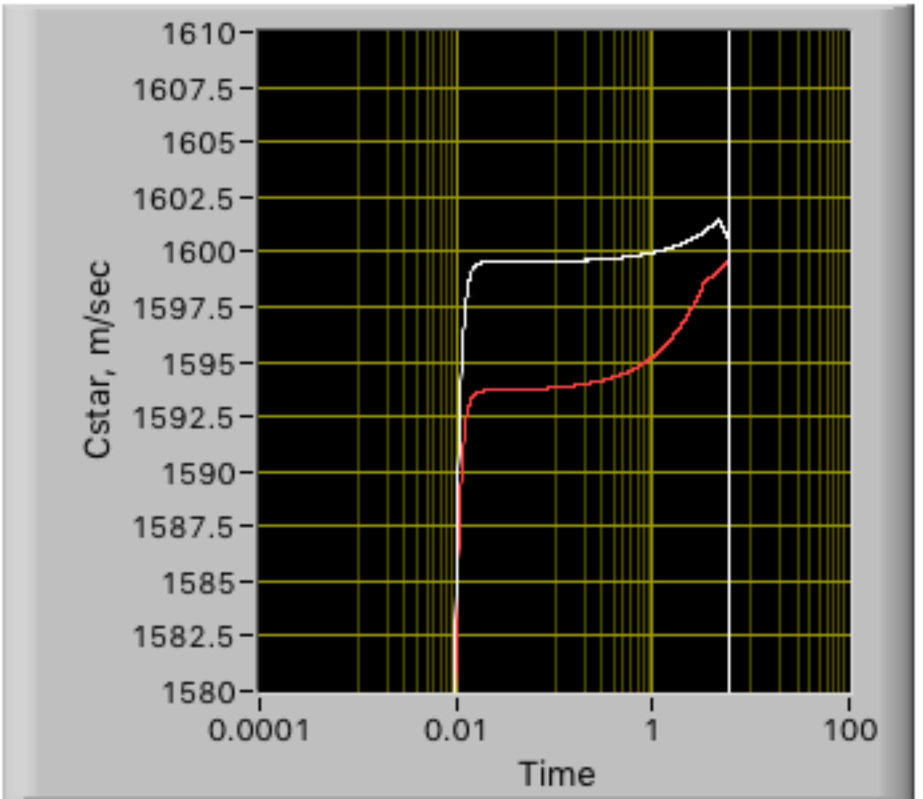

Thrust, kN



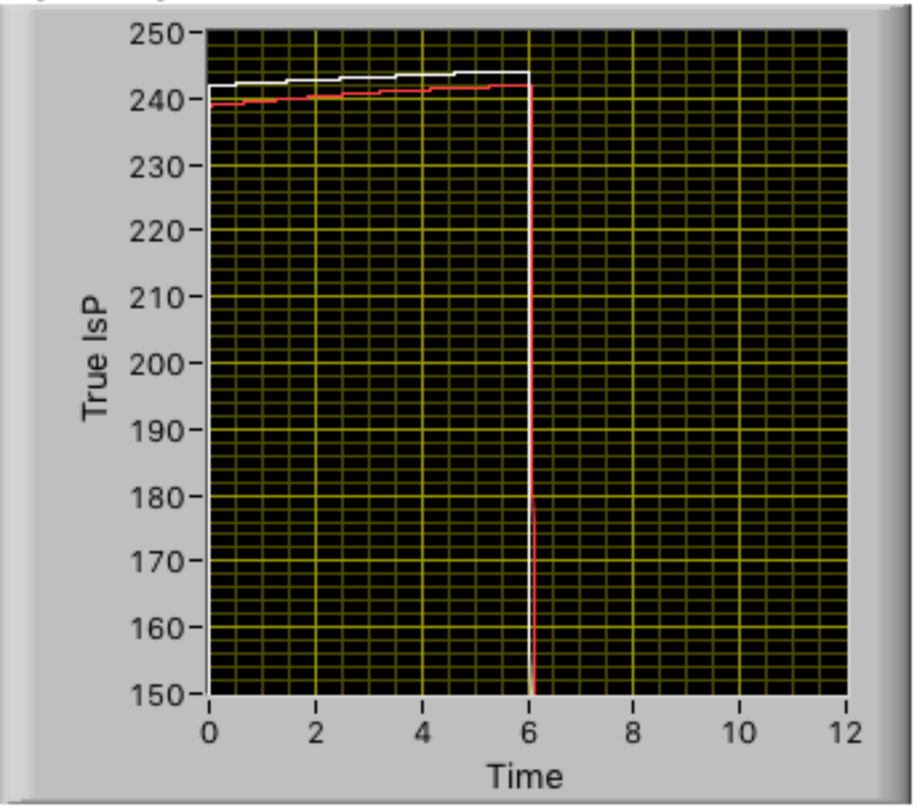

O/F Ratio



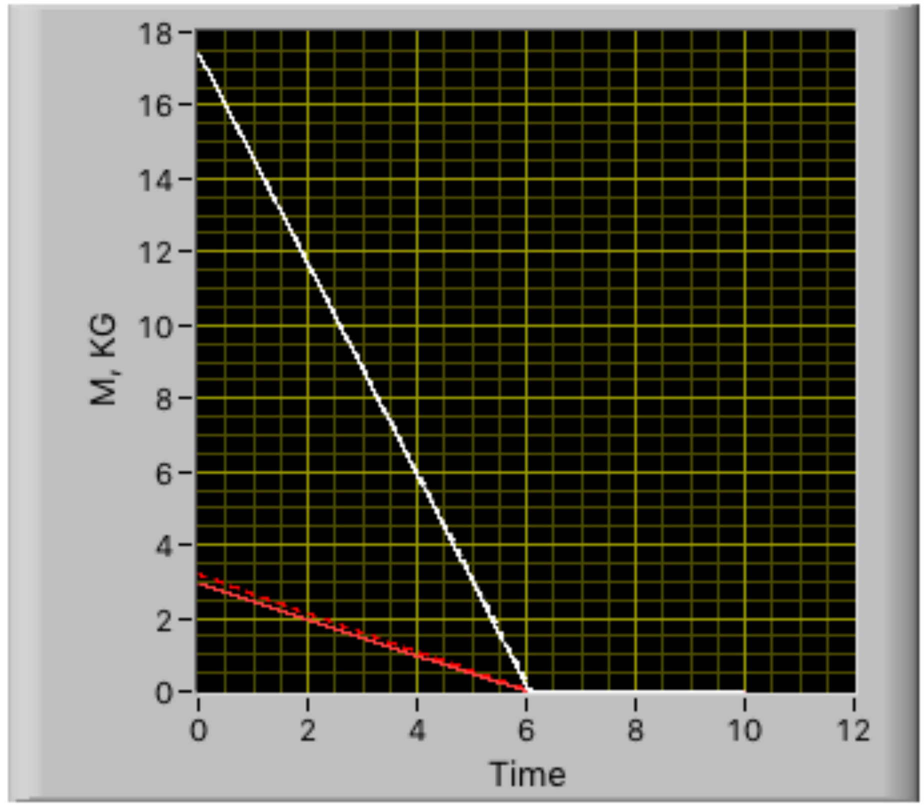

Characteristic Velocity



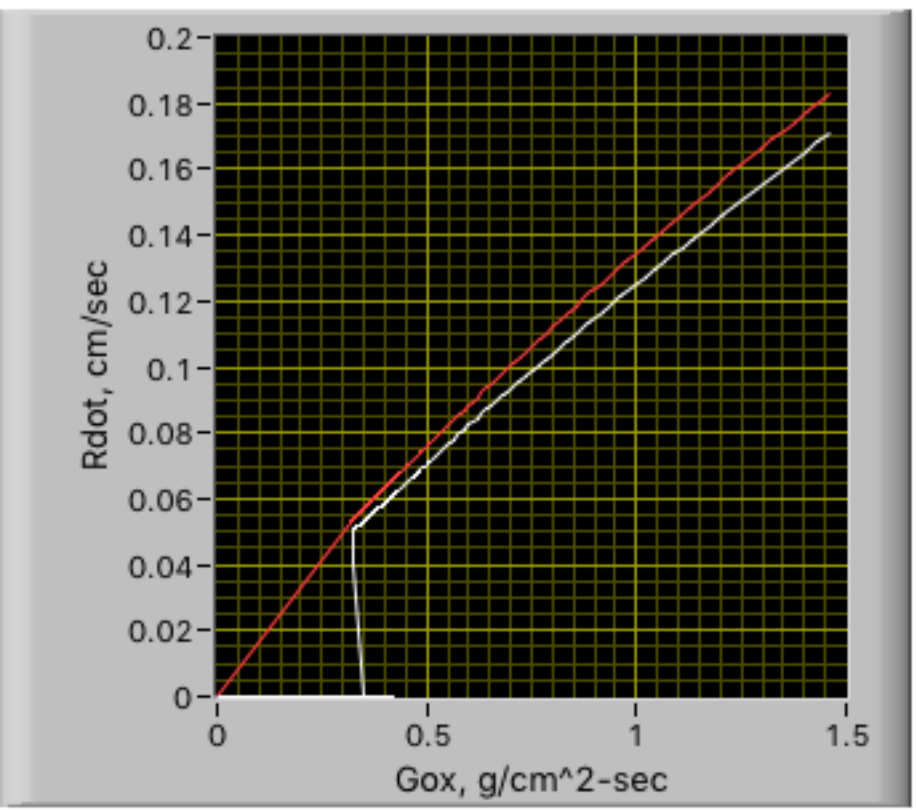
Specific Impulse, sec



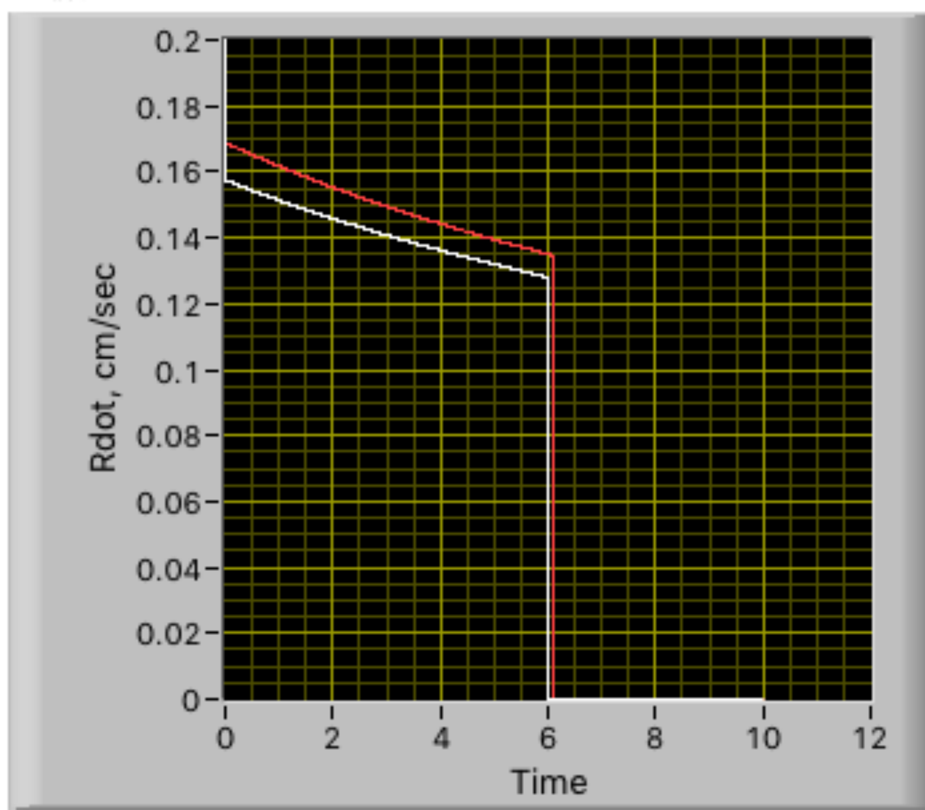

PROPELLANT MASSES




Rdot vs Gox

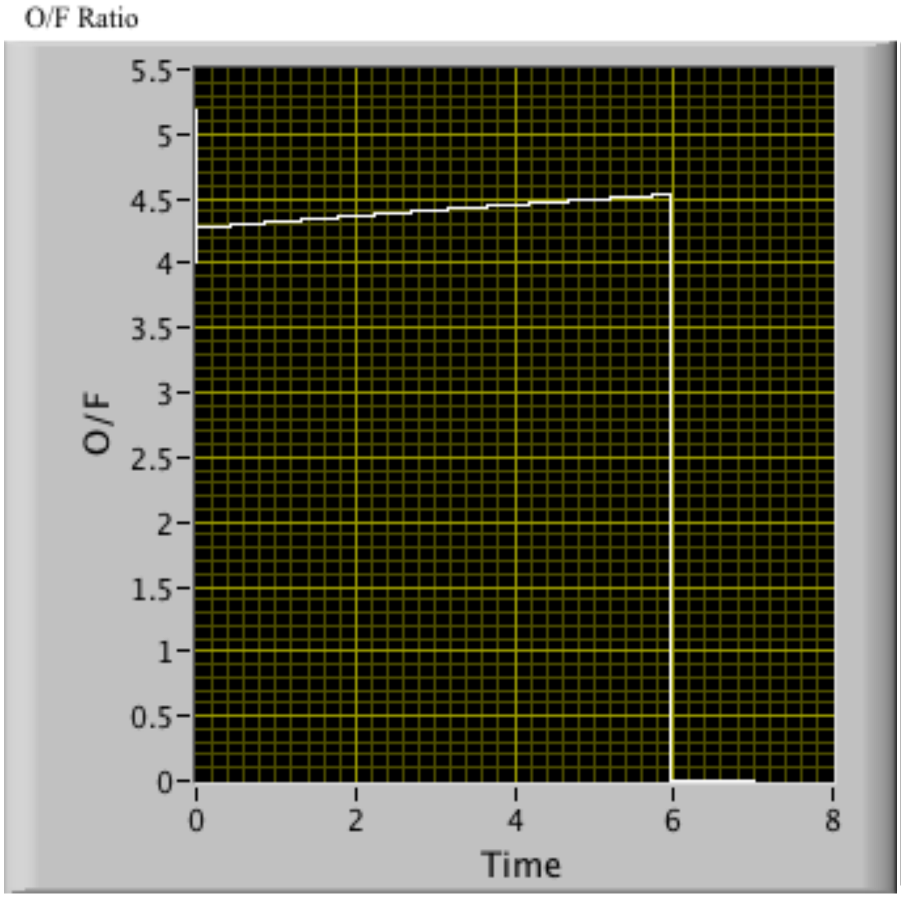


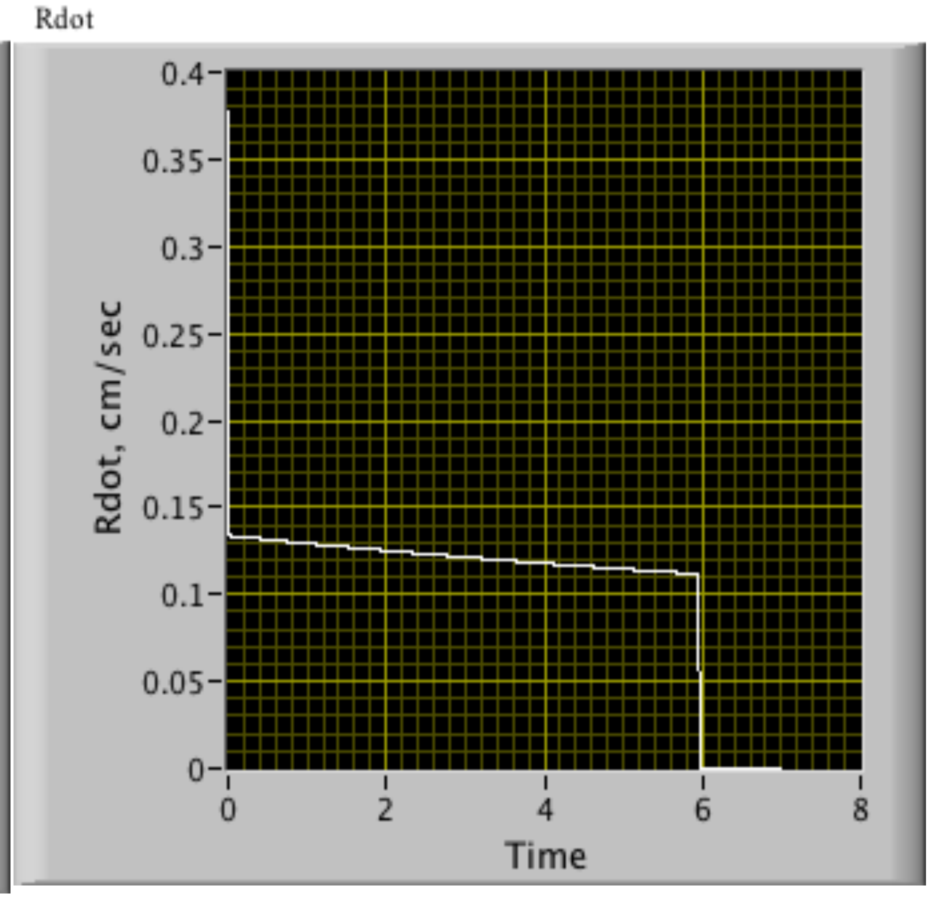

Rdot



# L = 157 cm (3)

- ***O/F, Rdot Profile(s)***



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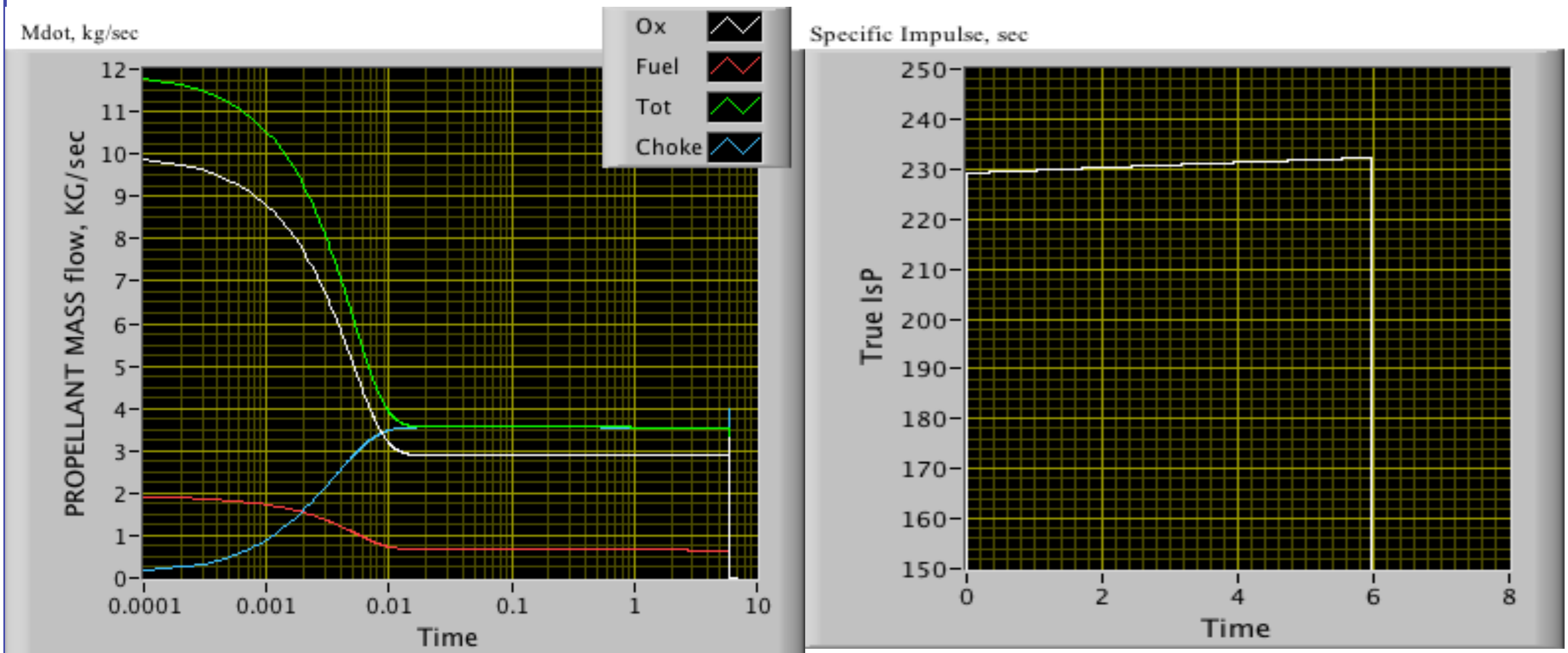
# L = 157 cm (4)

- ***Mass Flow Rate, Isp***

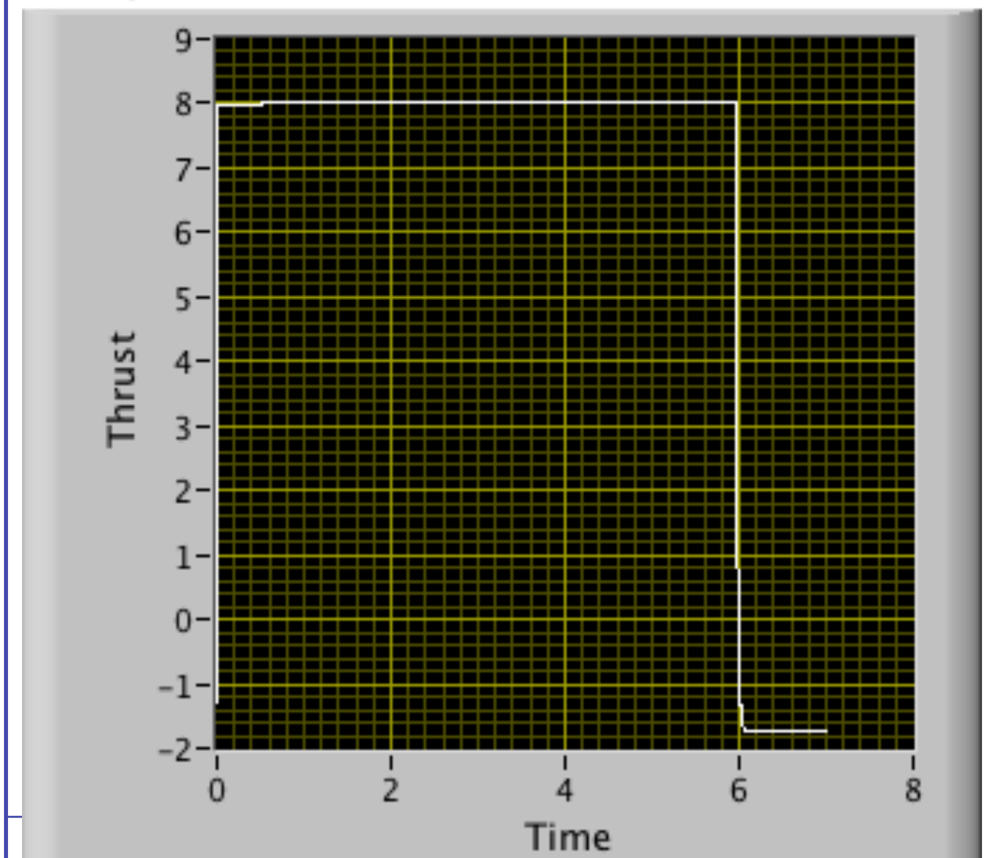


# L = 157 cm

- ***Select Injector pressure to give an approximate steady burn Thrust of 8 kNt***

$$p_{inj} \approx 3435 \quad kPa$$

Thrust, kN




- Optimized for 6-second burn

$$\begin{aligned} HTPB\ fuel\ mass: &\quad 3.911_{kg} \\ Oxidizer mass: &\quad 17.25_{kg} \\ Total\ O+F\ mass: &\quad 21.161_{kg} \end{aligned}$$

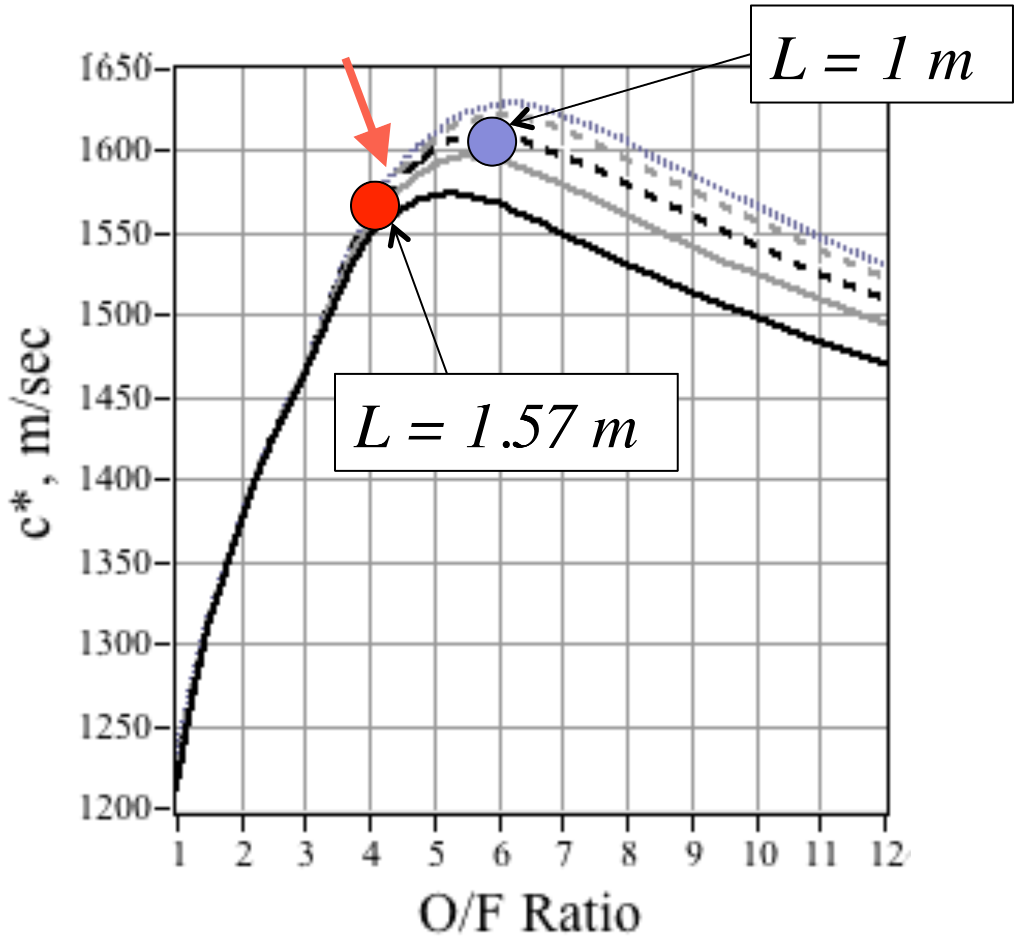
- Mean O/F and Isp:

$$Mean\ O/F: 17.25/3.911 = 4.4106$$

$$Mean\ I_{sp}: \frac{8000_{\mathrm{N}} \cdot 6\,\mathrm{sec}}{\left(9.8067_{\frac{\mathrm{m}}{\mathrm{sec}^2}} \cdot 21.161_{kg}\right)} = 231.303$$

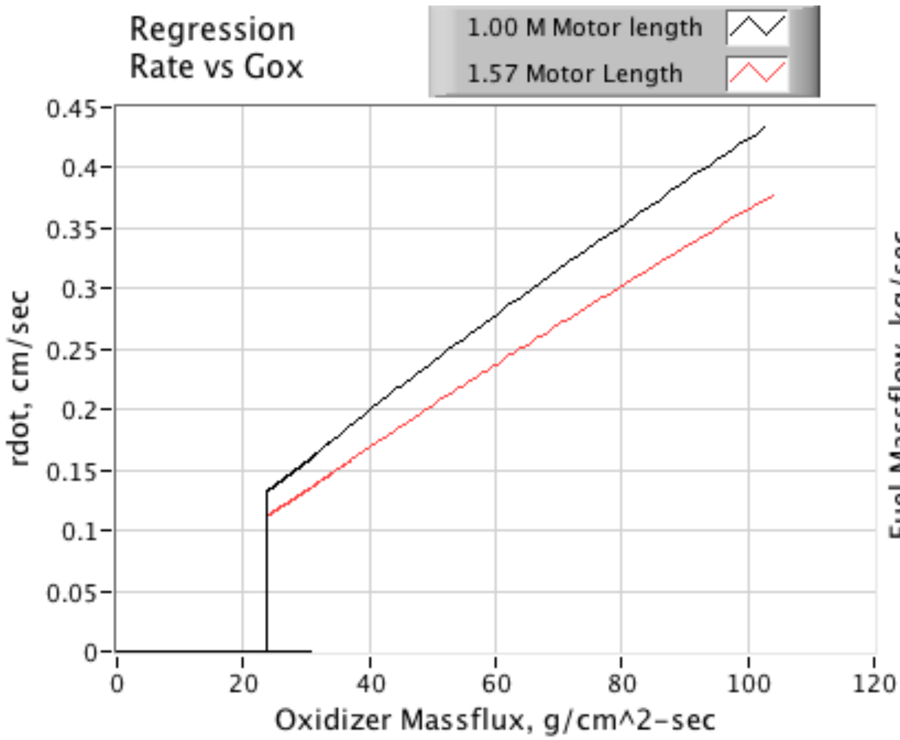
# L = 157 cm (2)

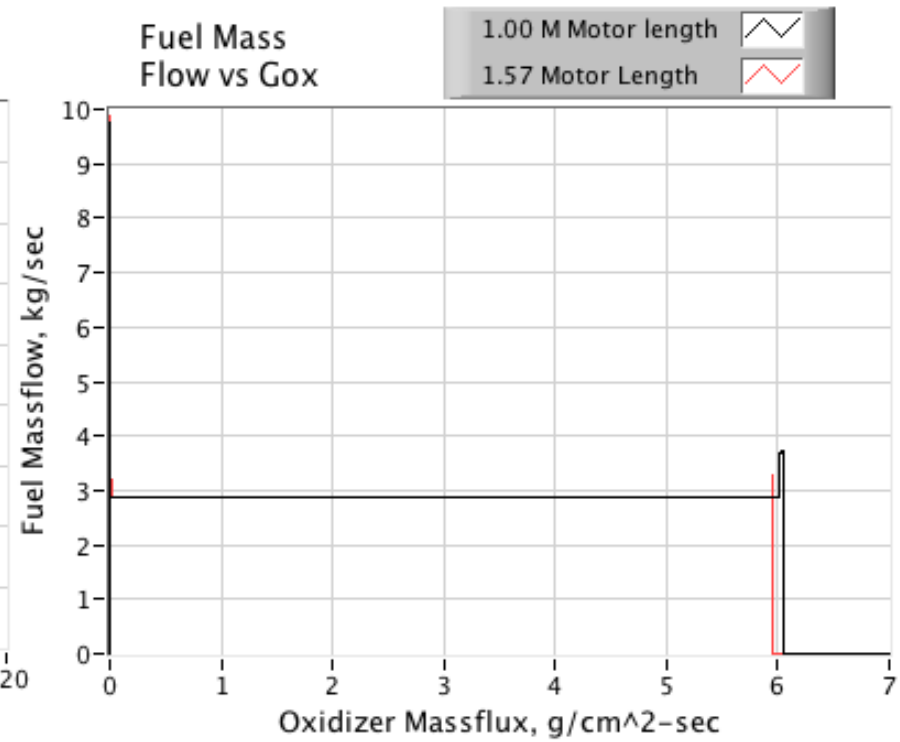
- ***Why the Lower $I_{sp}$ for Longer Motor?***



# L = 100 cm, 157 cm Comparisons

• ***Regression Rate vs Oxidizer Mass Flux***




• Long Motor Produces Nearly Identical Fuel MassFlow