CODE REVIEW

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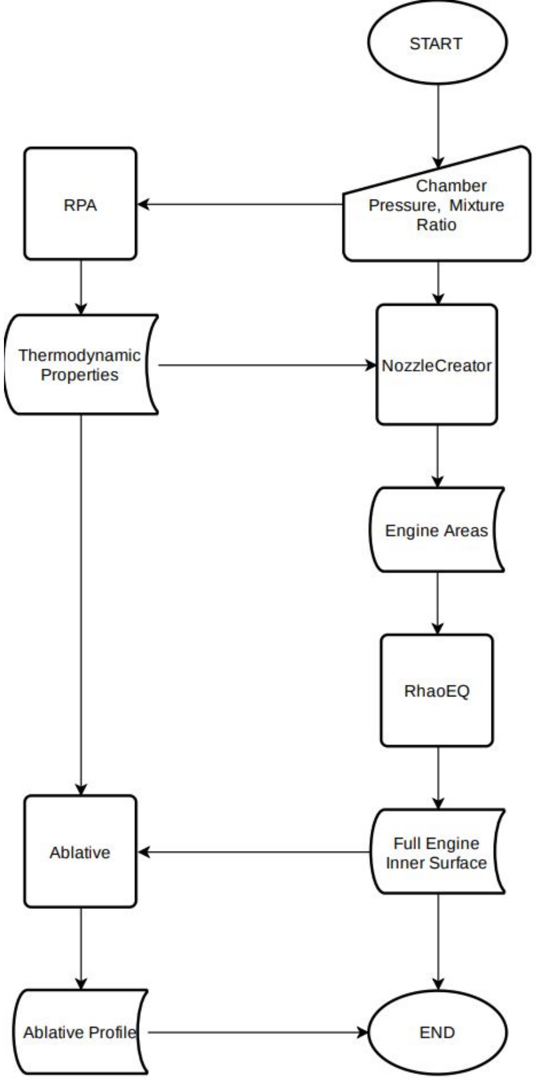
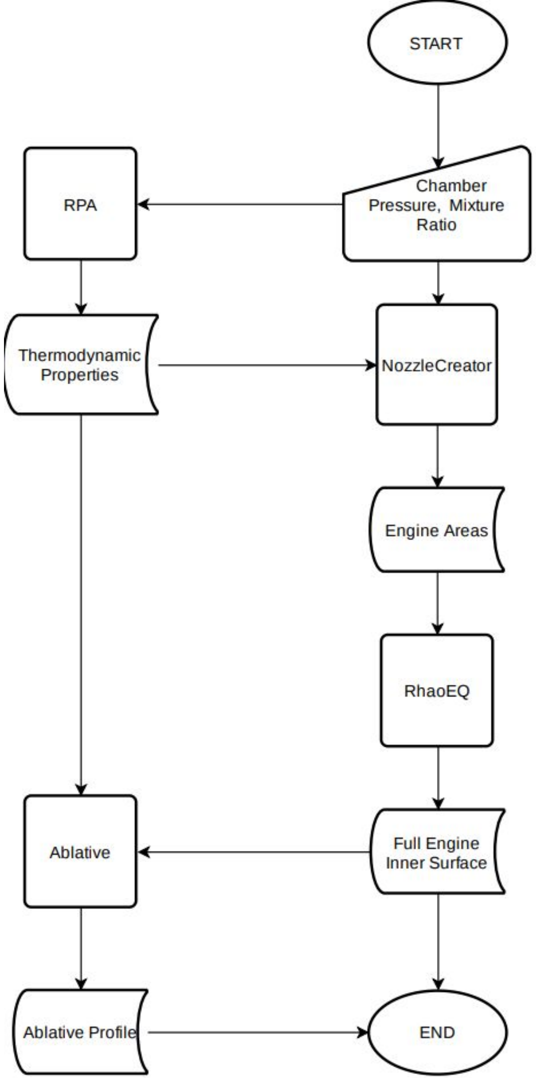
Section one - Engine Design



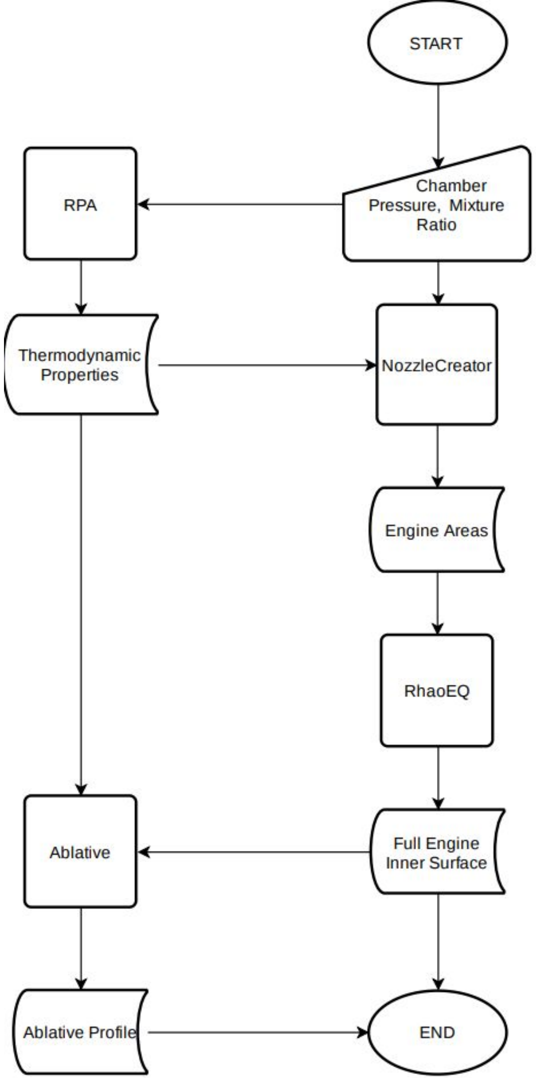
What this Codebase does

- Take in
  - Values for Chamber Pressure and Mixture Ratio
- Spit out
  - An engine profile and an ablative profile



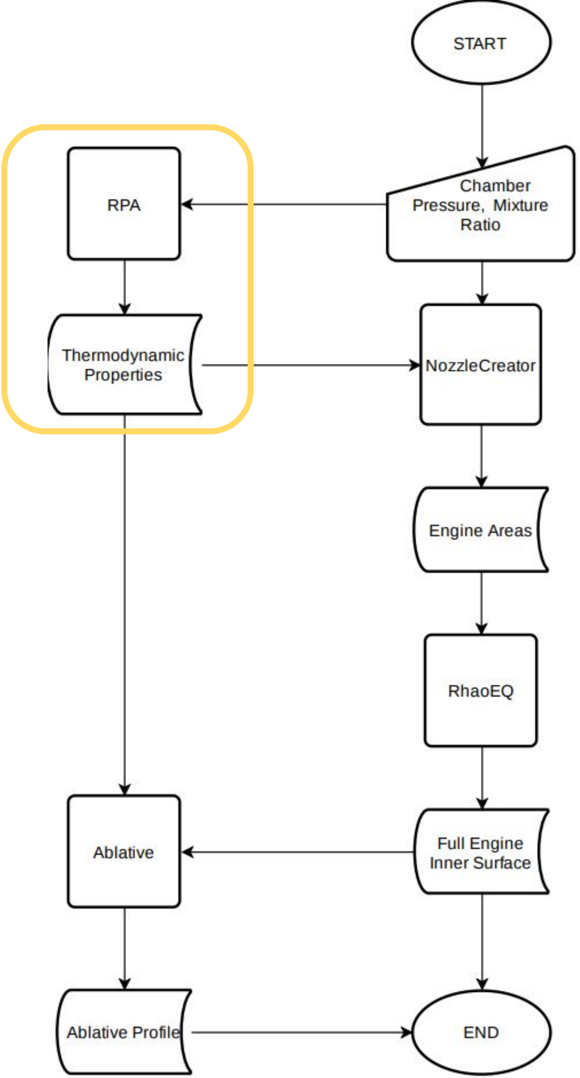
Why is it Like This

- For any given Thrust, PC, MR there exists ONE optimal nozzle and a family of optimal profiles
- Fix Thrust -> PC, MR determine system



What is RPA

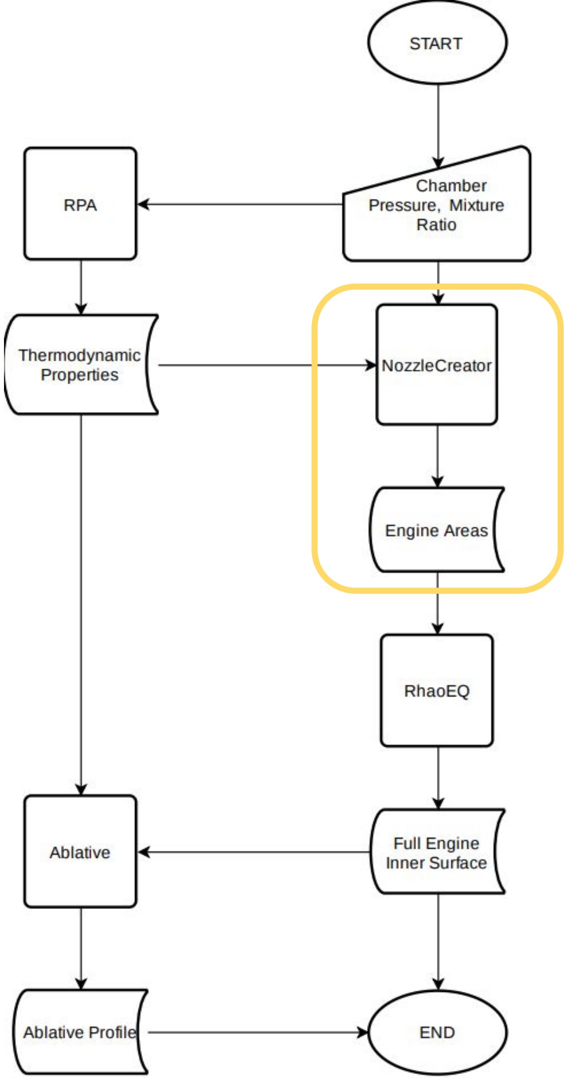
- It is our thermodynamics package
- Designed for rocketry
- Verified data validity over small range using CEA
- Their profiles agree with ours



What is NozzleCreator

- Defines Throat and Exit Areas

- We are designing around choked flow at A_t
- We assume the gas is radially and axially uniform
- We assume that the gas follows the adiabatic ideal gas law
- All equations are from (1) and (2)

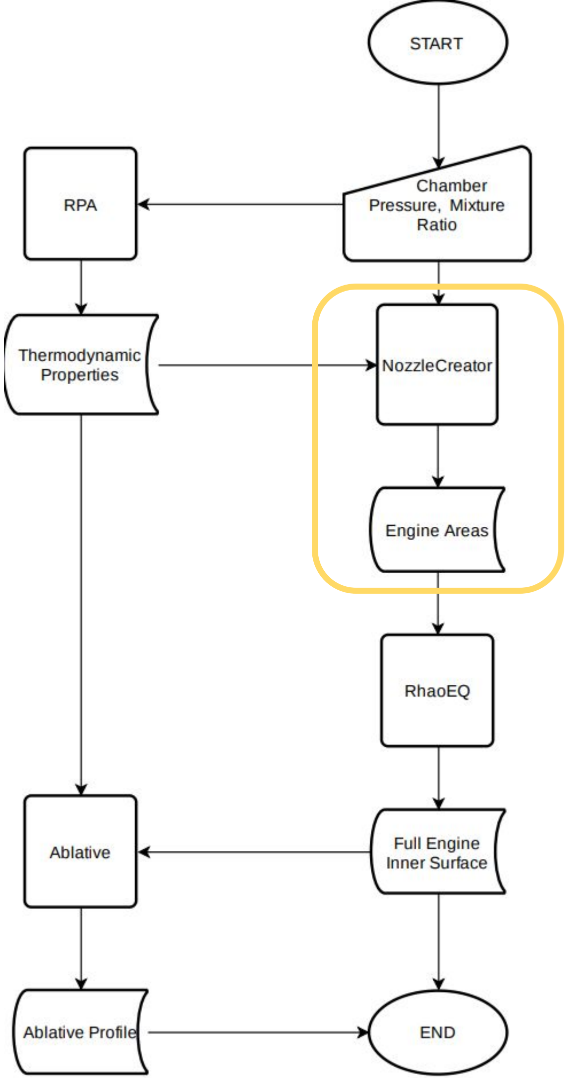


What is NozzleCreator

$$C_f = \sqrt{\frac{2\gamma^2}{\gamma - 1}\left[\frac{2}{\gamma + 1}\right]^{\frac{\gamma+1}{\gamma-1}}\left[1 - \left(\frac{p_e}{(p_c)_{ns}}\right)^{\frac{\gamma-1}{\gamma}}\right]} + \epsilon\left[\frac{p_e - p_a}{(p_c)_{ns}}\right]$$

$$C_f = \frac{F}{A_t(p_c)_{ns}}$$

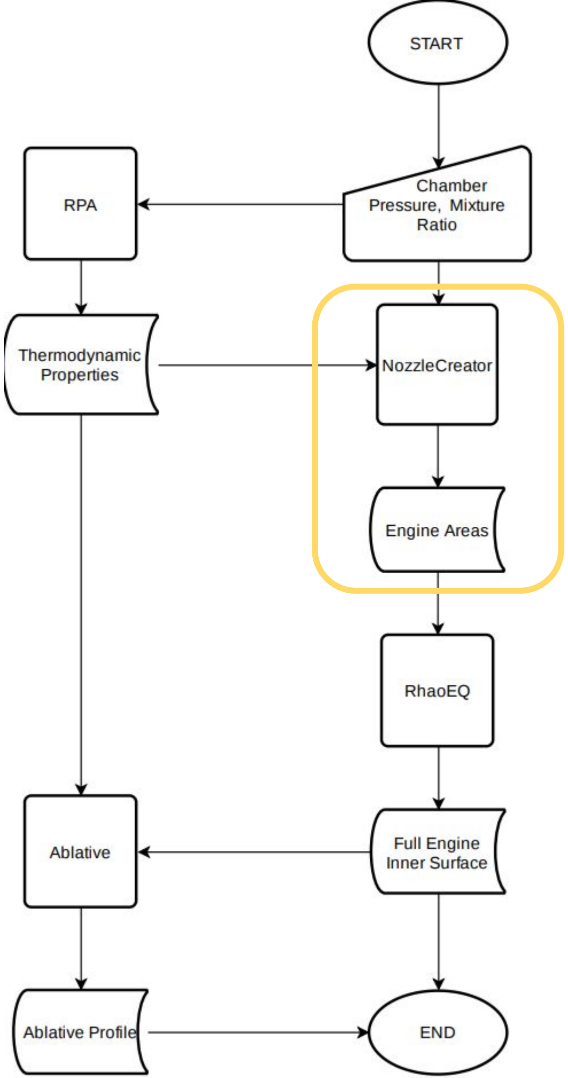
- We get gamma from RPA as a function of (MR,PC)
- **This gives us A_t**



What is NozzleCreator

$$\frac{A_t}{A_x} = \frac{V_t v_x}{V_x v_t} = \left(\frac{k+1}{2}\right)^{1/(k-1)} \left(\frac{p_x}{p_1}\right)^{1/k} \sqrt{\frac{k+1}{k-1}\left[1 - \left(\frac{p_x}{p_1}\right)^{(k-1)/k}\right]}$$

- K is the gamma from before
- P_x is set to exit pressure (1atm)
- P_1 is chamber pressure
- **This gives us A_e**



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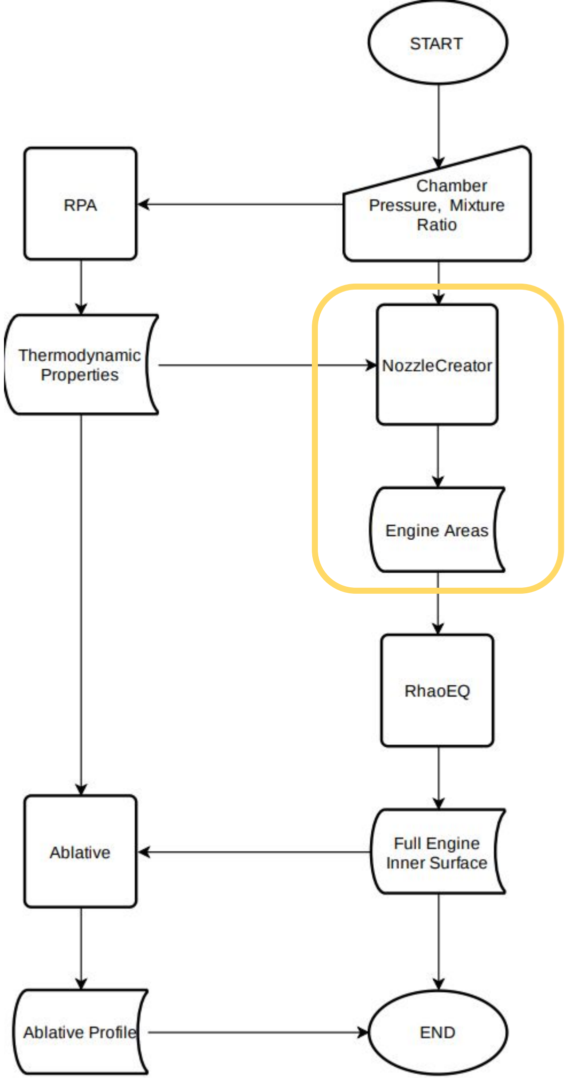
$$C_f = \frac{F}{A_t(p_c)_{ns}}$$

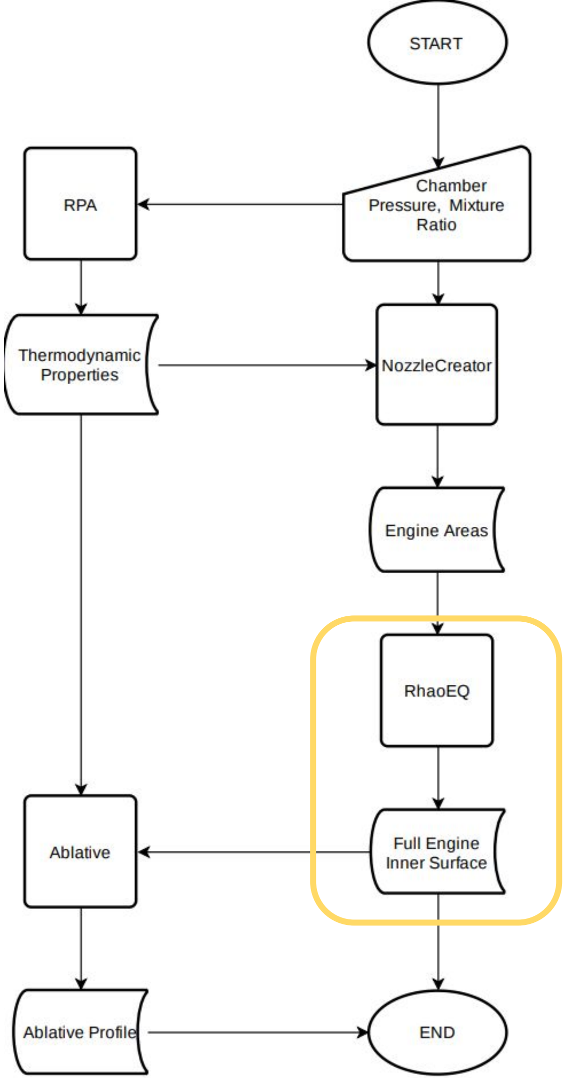
- Setting P_e in the EQ gives us **thrust as a function of altitude**
- Epsilon is A_e/A_t



What is RaoEQ

- Defines inner engine surface

- Approximation of a MOC optimal nozzle
- 80% length, 99% efficiency
- All data from (3)



What is RaoEQ: Nozzle

- **Arc, Arc, Bezier Curve**

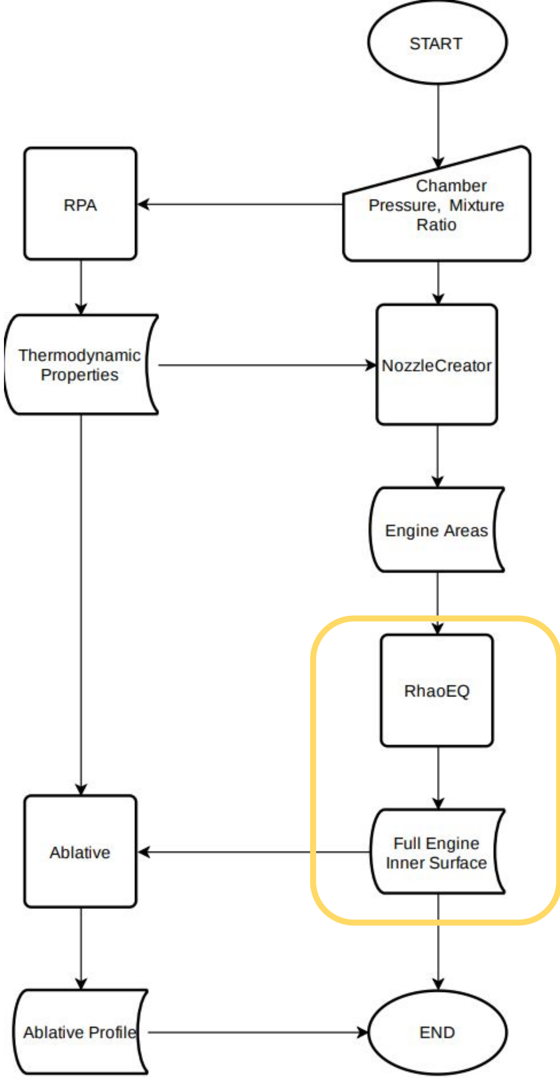
$$x = 1.5\,R_t \cos\theta$$
$$y = 1.5\,R_t\,\sin\theta + 1.5\,R_t\, + R_t$$

where: $-135 \leq \theta \leq -90$

$$x = 0.382\,R_t \cos\theta$$
$$y = 0.382\,R_t\,\sin\theta + 0.382\,R_t\, + R_t$$

where: $-90 \leq \theta \leq (\theta_n - 90)$

- **Converging arc, Diverging arc**

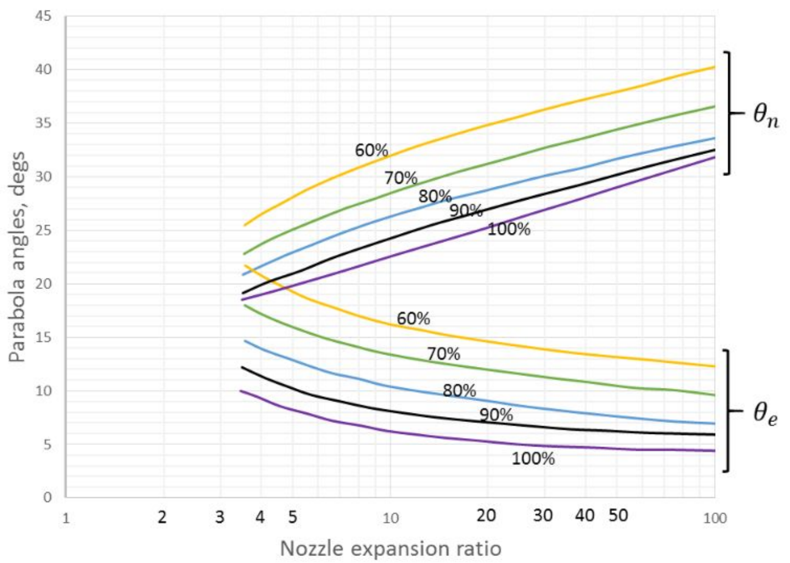


What is RaoEQ: Nozzle

- **Bezier Curve Definition**

$$x(t) = (1-t)^2 N_x + 2(1-t)t\, Q_x + t^2 E_x \qquad 0 \le t \le 1$$
$$y(t) = (1-t)^2 N_y + 2(1-t)t\, Q_y + t^2 E_y \qquad 0 \le t \le 1$$

- N is the end of the last arc
- E is the exit of the nozzle
- Q is the intersection of the tangent lines at N and E

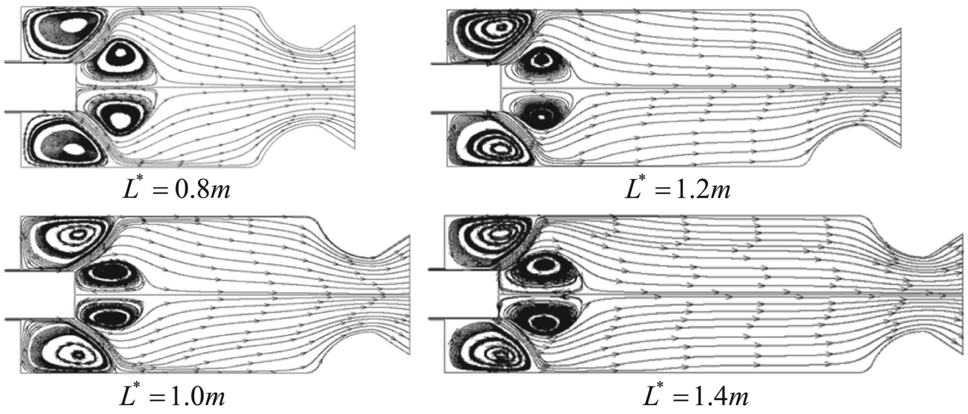


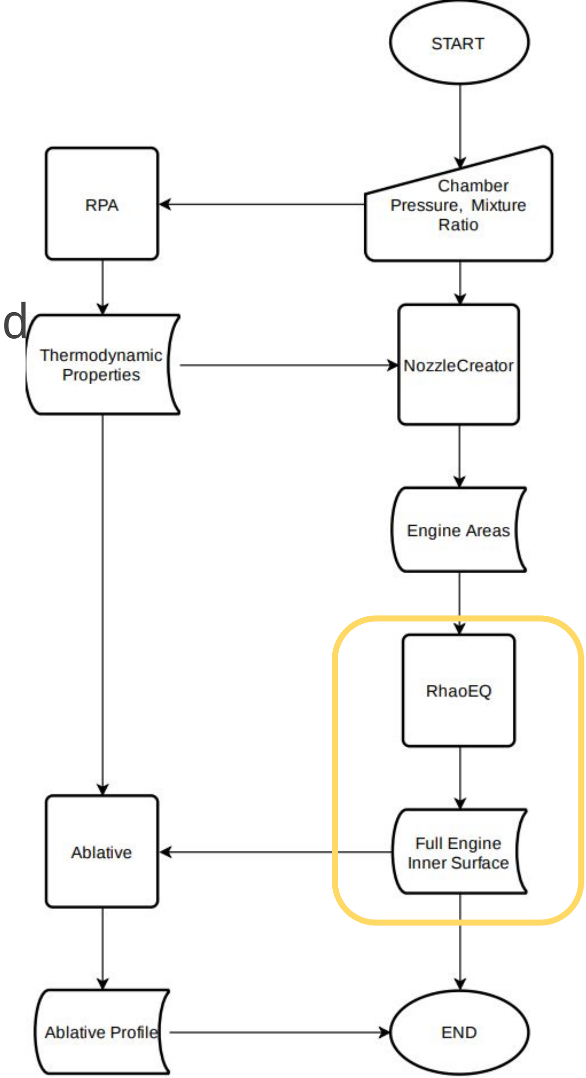
The radius of the nozzle exit: $R_e = \sqrt{\epsilon}\, R_t$ **equ. 2**

and nozzle length $L_N = 0.8\left(\frac{(\sqrt{\epsilon}-1)\, R_t}{\tan(15)}\right)$ **equ. 3**

What is RaoEQ: Chamber

- Chamber is a cylinder whose volume is defined by characteristic length L* (4)
- $L^*A_t = V_c$
- Set A_c to A_e



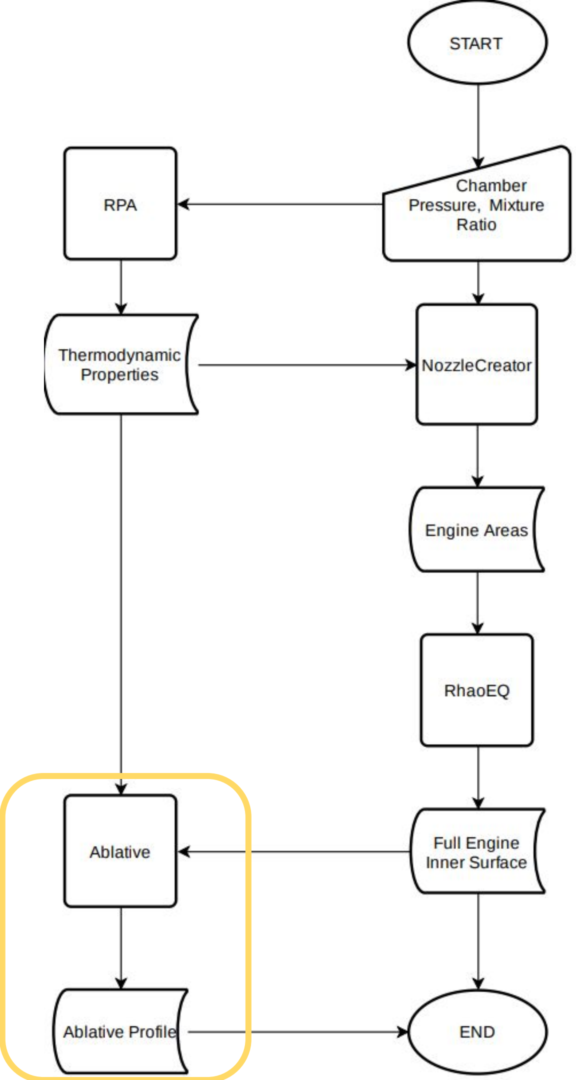


What is Ablative

- Defines the thickness of ablative material
- Material parameters from (5)

Thermal Overview

- Material is two-phase: resin and fibre
- Very low thermal conductivity (.9 W/MK)
- Resin vaporises, taking heat away
- Fibre retains structure



What is Ablative

The Math

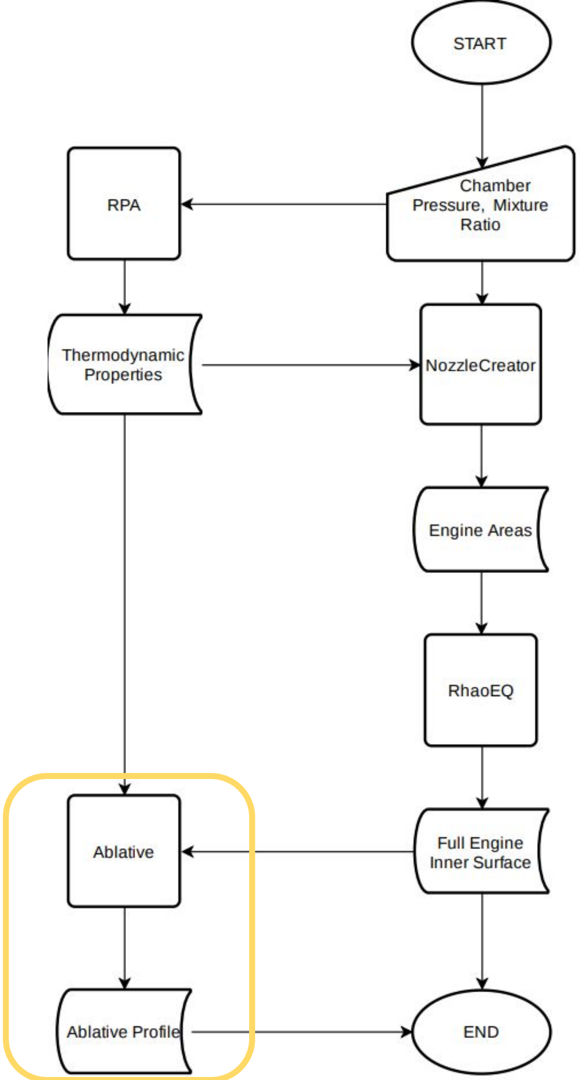
$$\frac{dT}{dt} = \alpha \frac{d^2T}{dx^2} - \frac{H_{vap}\rho \frac{dV}{dt}}{V \rho c_p}$$

$$\rho_0^{\mathrm{p}} \frac{\partial V^{\mathrm{p}}}{\partial t} = -J^{\mathrm{p}}$$

$$\rho_0^{\mathrm{c}} \frac{\partial V^{\mathrm{c}}}{\partial t} = J^{\mathrm{p}}(1 - \Gamma^{\mathrm{p}})$$

$$J^p = A_0 \frac{V^{\mathrm{p}}}{V_0} \exp\left(-\frac{E_a}{RT}\right)$$

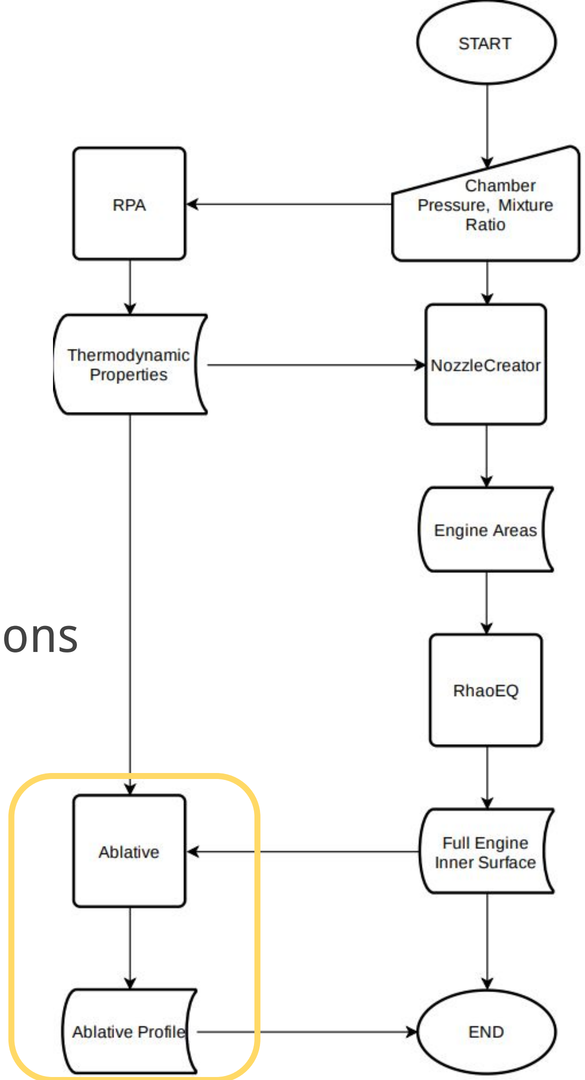
$$Q = h_g(T_{aw} - T^0)$$



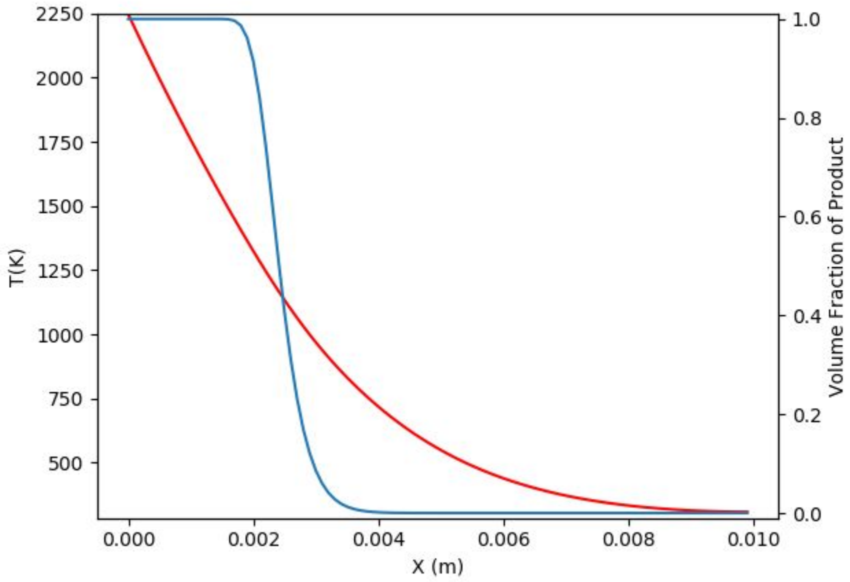
What is Ablative

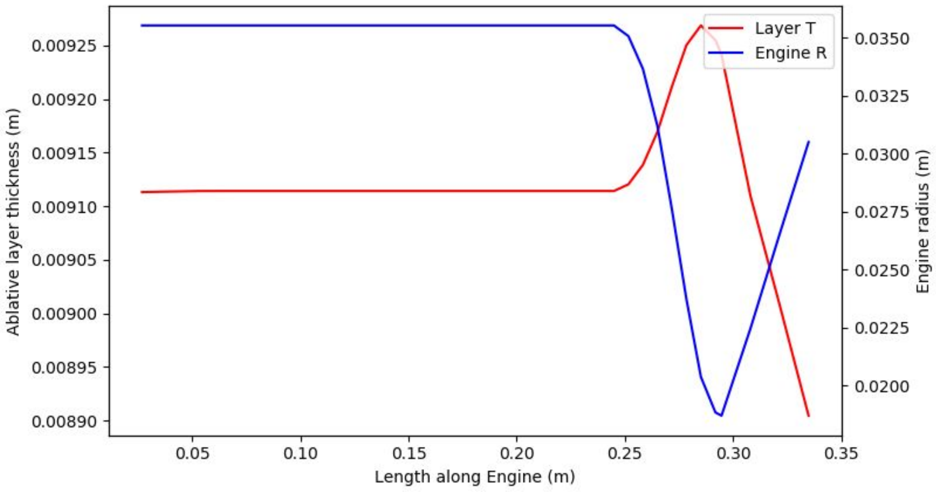
- Methodology

- Split nozzle into toroidal stations
- Split toroidal station into circular hoop stations



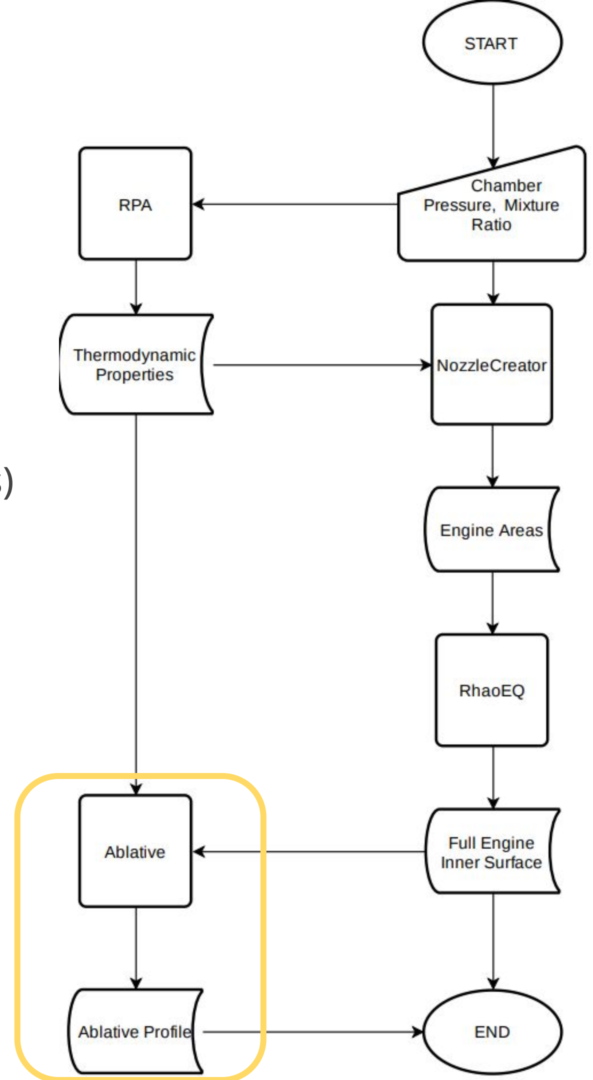
What is Ablative



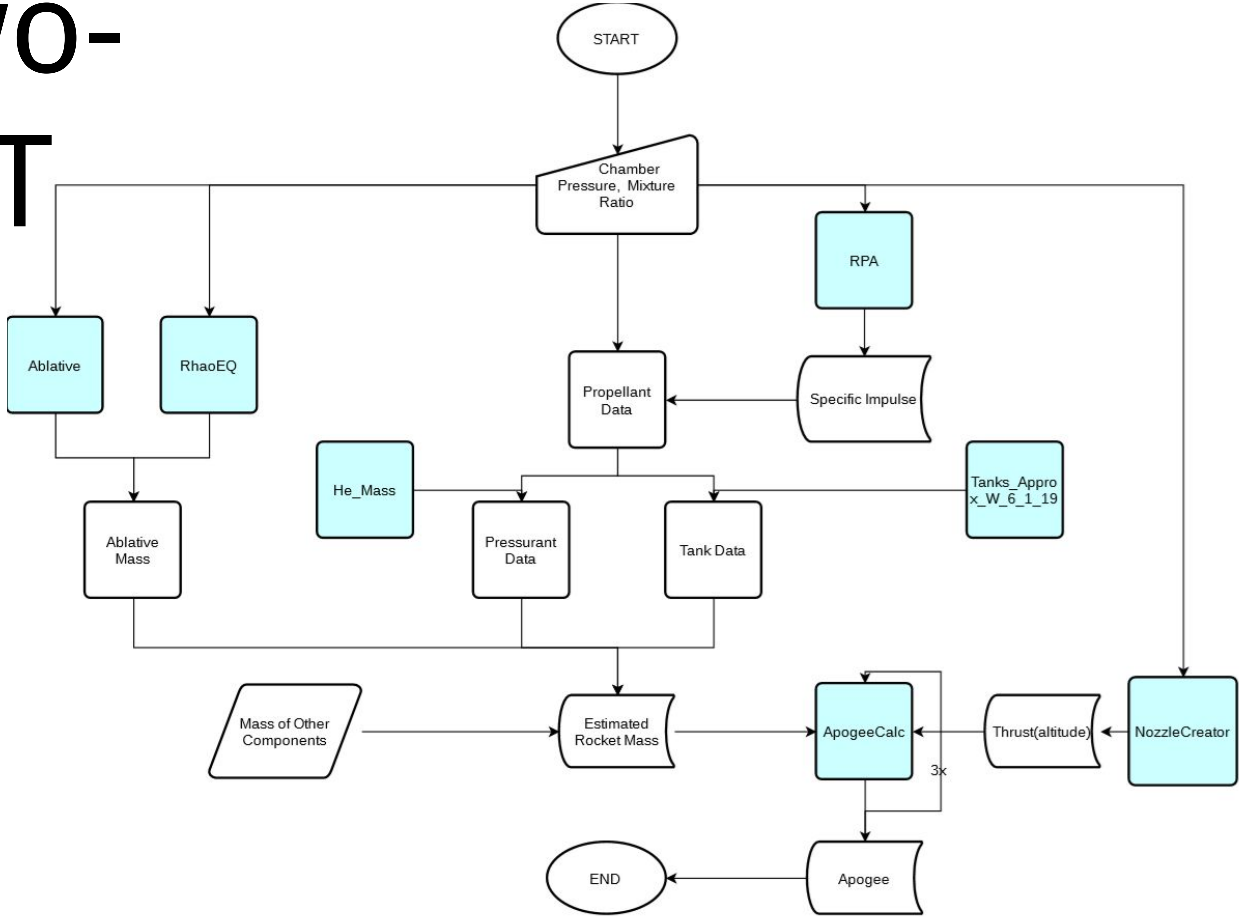


What is Ablative

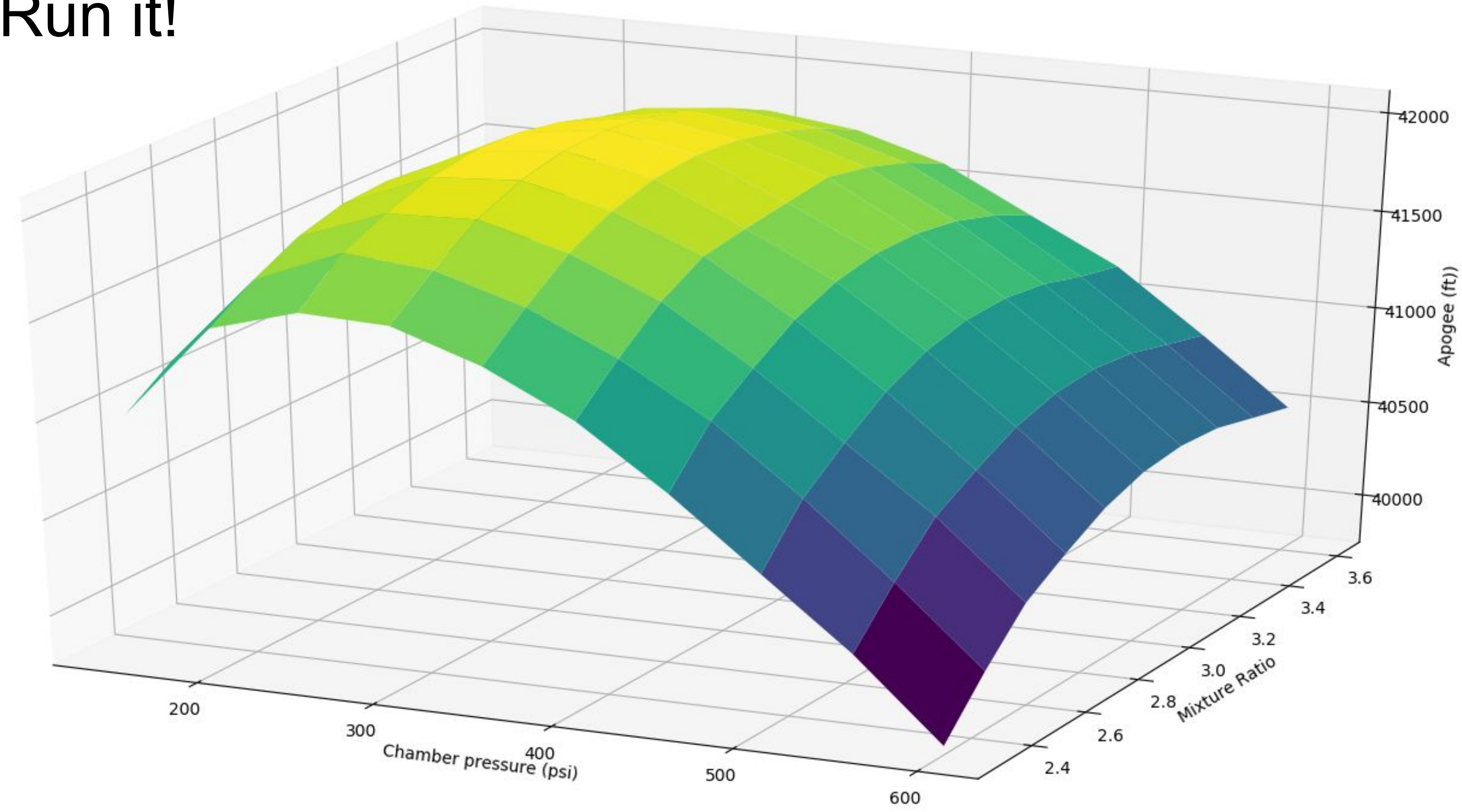
- Underlying assumptions
  - Geometrically imperfect
  - Longitudinal and Tangential q = 0
  - Data from paper was **modified to make paper consistent with our simulation** (real sin hours)
- This code is a heavy WIP
  - Disagrees with Compositex's input



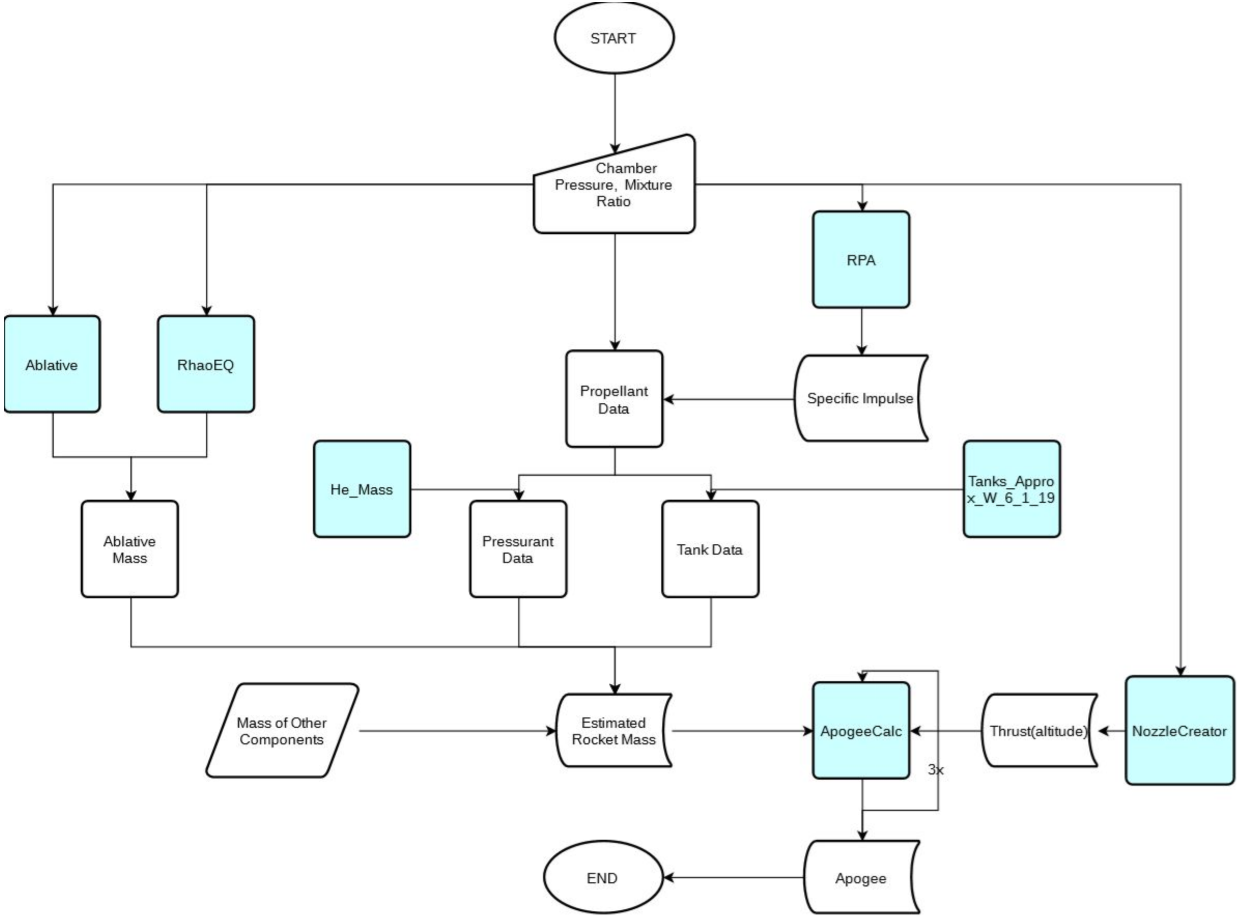
Section Two- Engine OPT



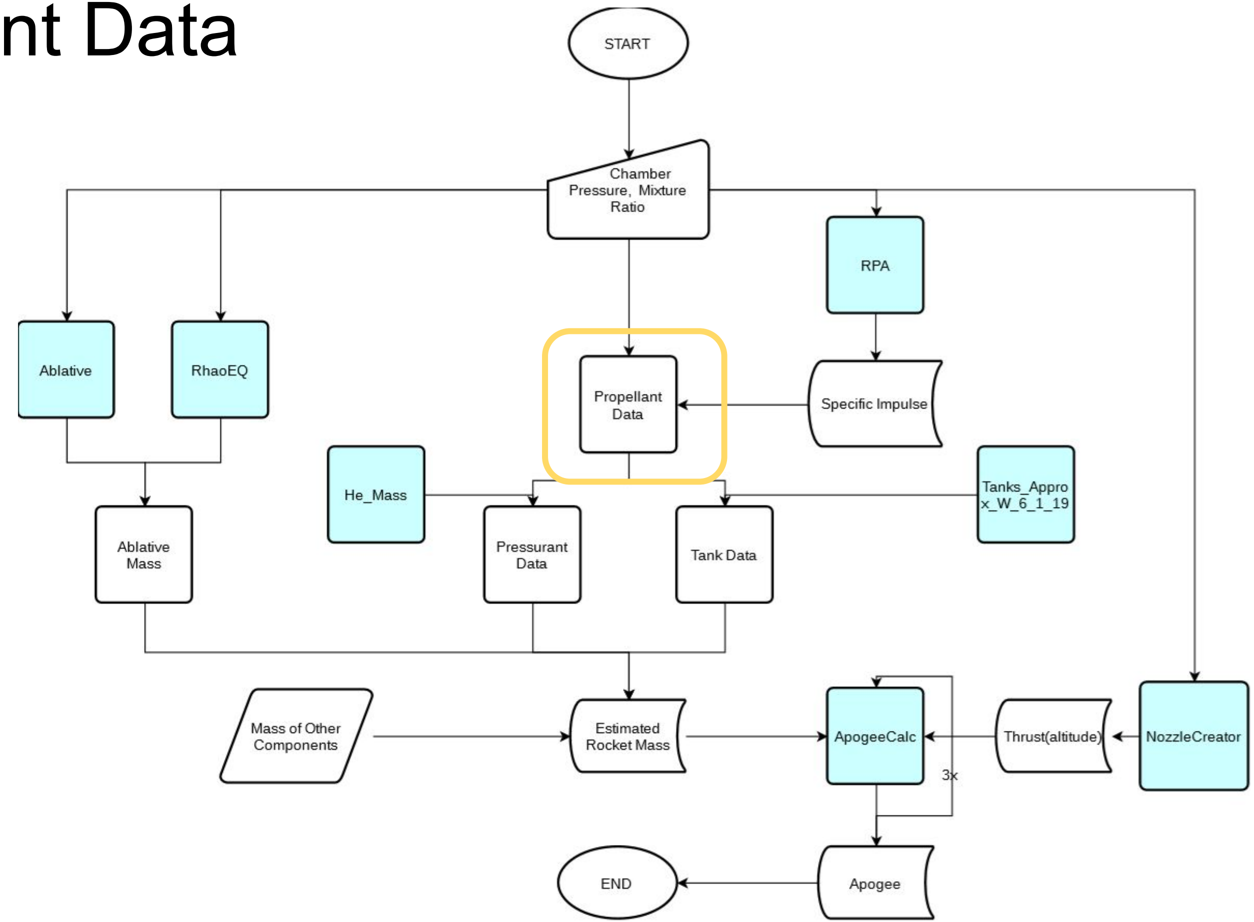
Run it!


42000
41500
41000
40500
40000
Apogee (ft))
200
300
400
500
600
Chamber pressure (psi)
2.4
2.6
2.8
3.0
3.2
3.4
3.6
Mixture Ratio

Why is it like this



What is Propellant Data



What is Propellant Data

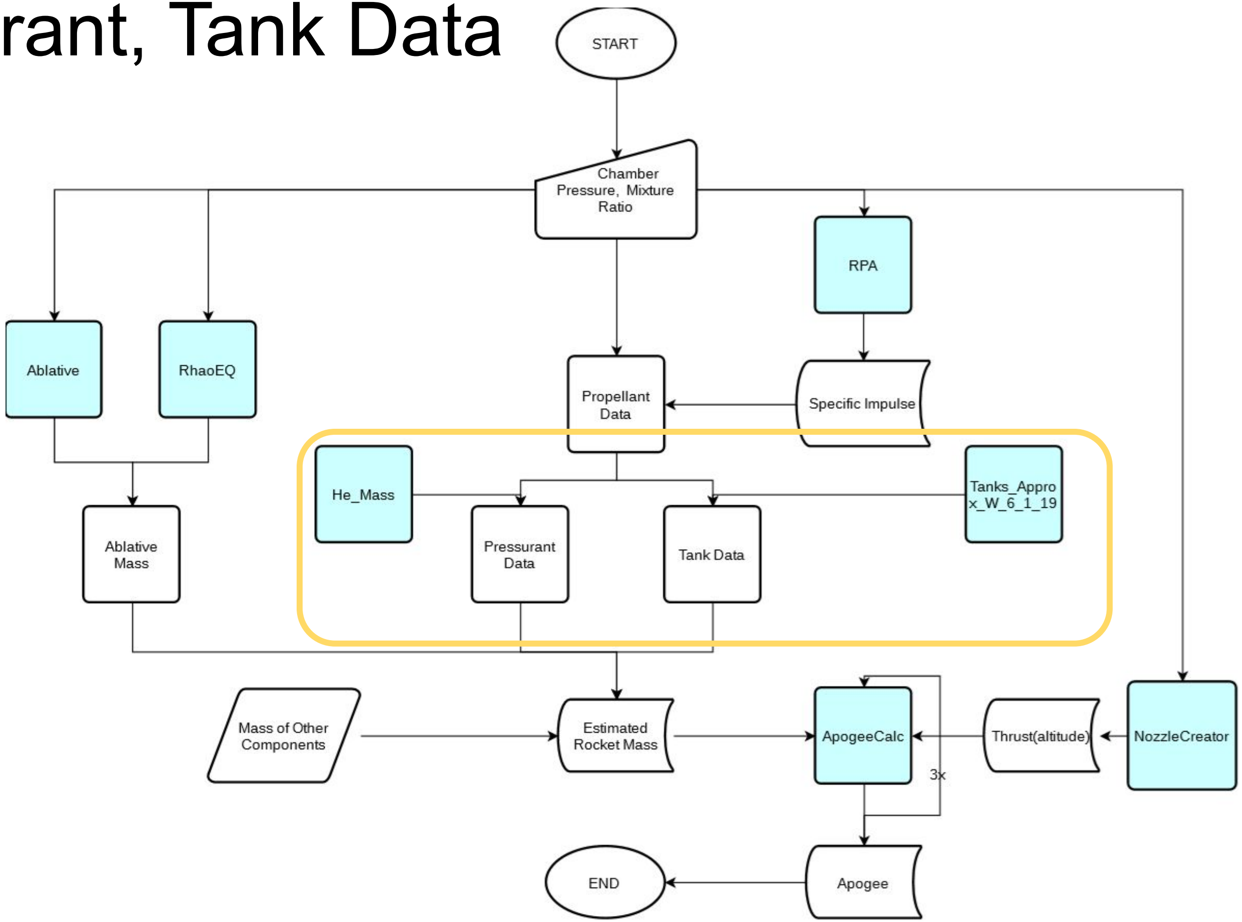
$$\dot{m} g \mathrm{Isp} = T$$
$$m g \mathrm{Isp} = I$$

$$\mathrm{MR} = \frac{m_o}{m_f}$$
$$m_o + m_f = m$$

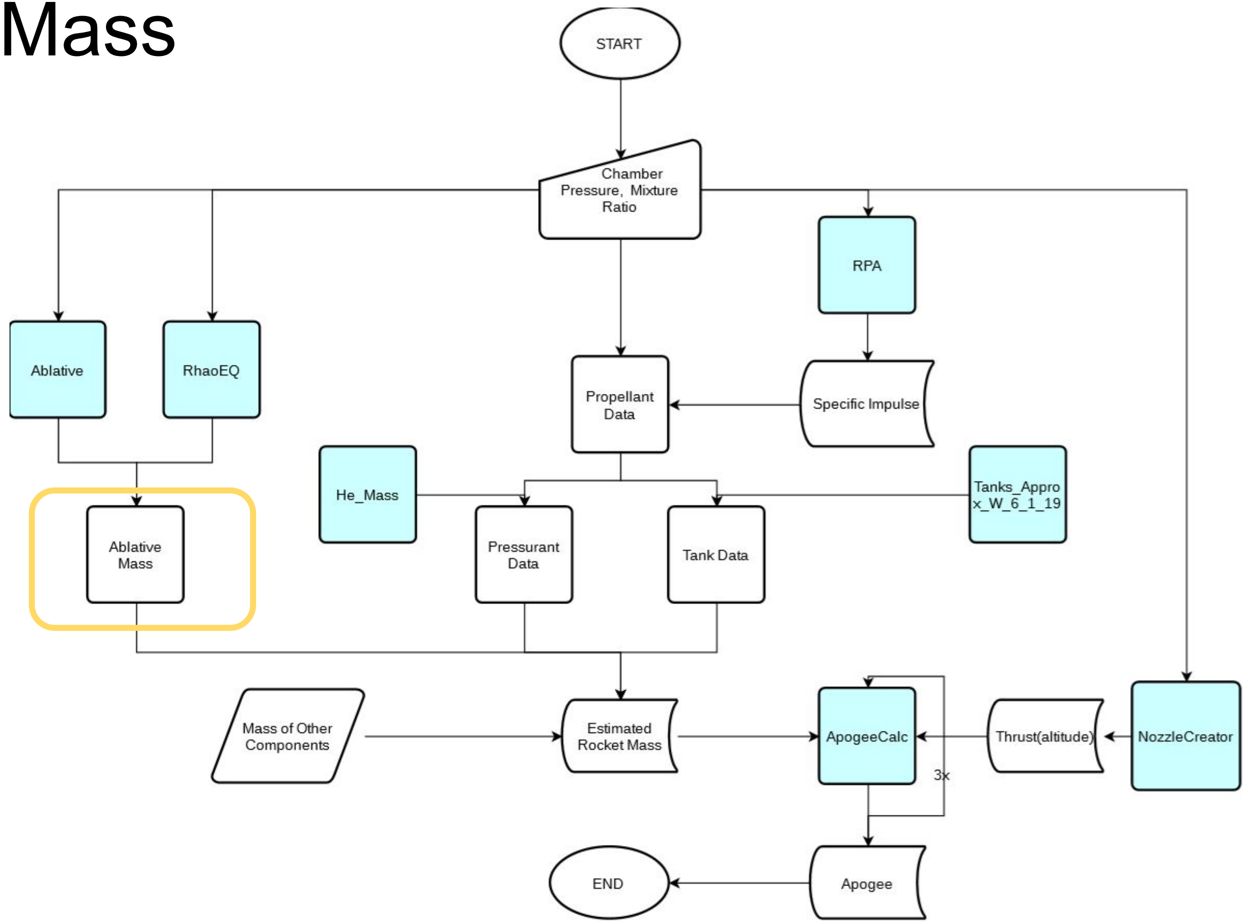
$$m_o = \frac{m}{1 + \frac{1}{MR}} \quad m_f = \frac{m}{1 + MR}$$

- **Takes IN:**
  - Isp from RPA
- **Gives us:**
  - Prop mass, Prop volumes

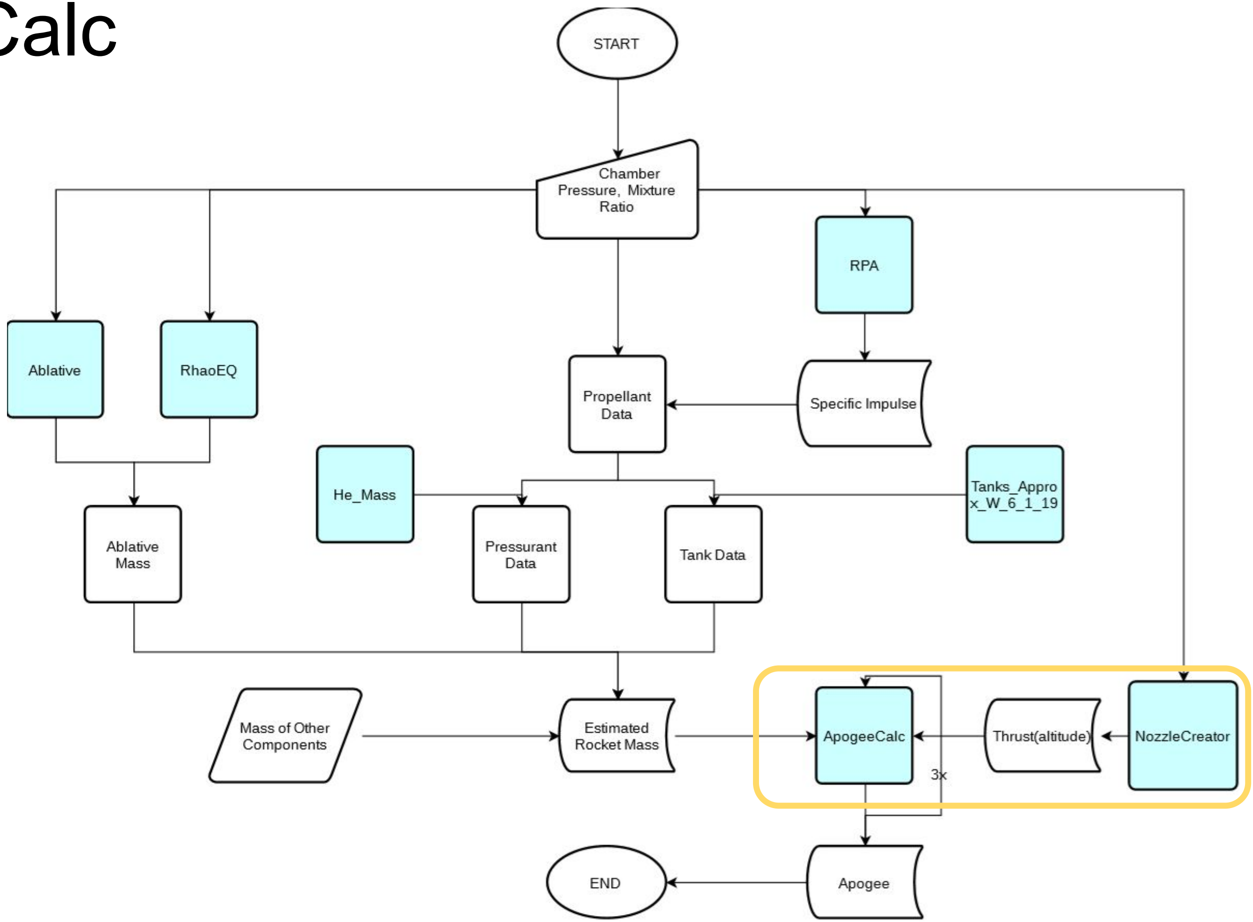
What are Pressurant, Tank Data



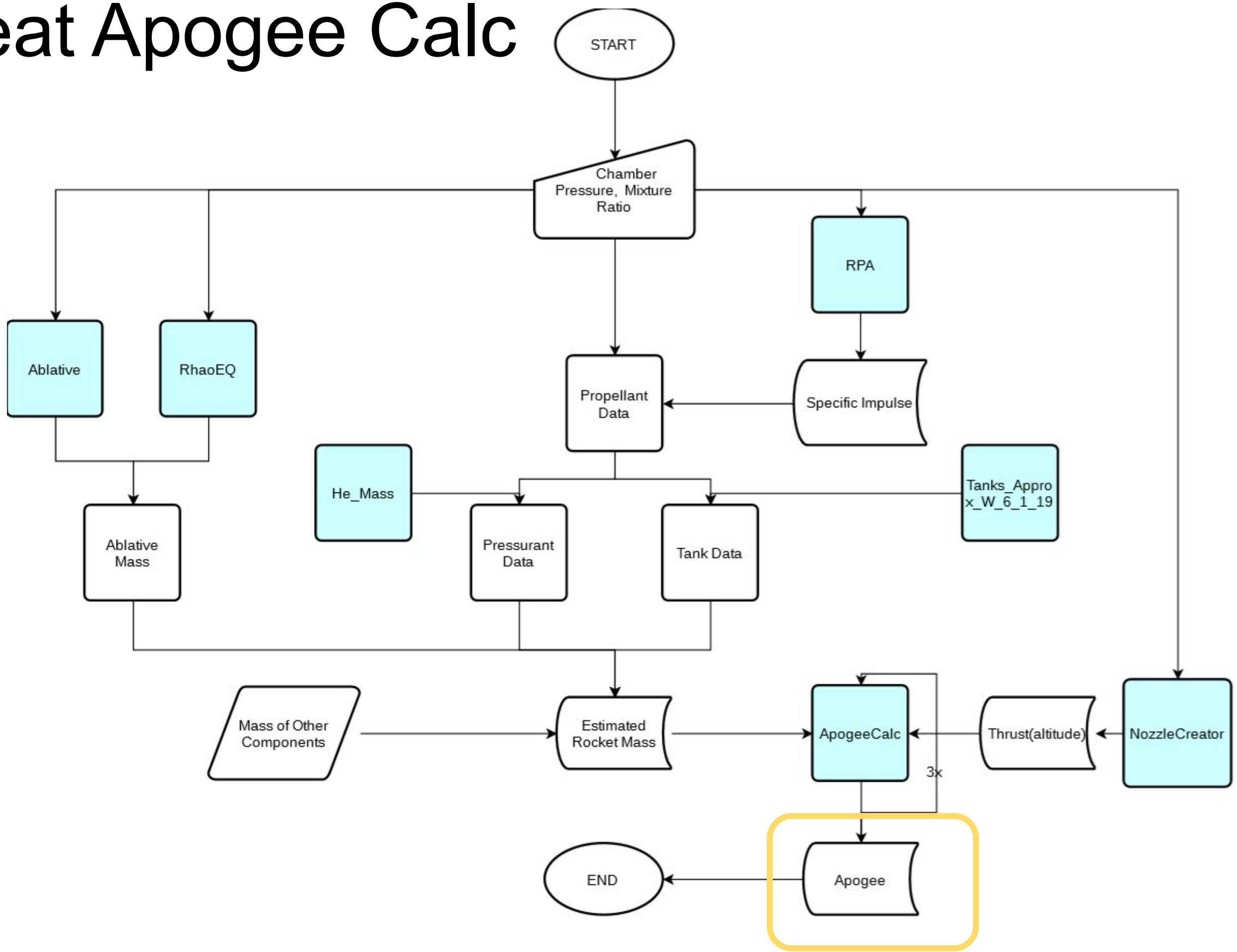
What is Ablative Mass



What is ApogeeCalc



Why do we Repeat Apogee Calc



Source List

1. Rocket Propulsion Elements by Sutton and Biblarz
2. Modern Rocket Engine Design by Huzel and Huang
3. The Thrust Optimised Parabolic nozzle by Newlands
4. Study on atomization and combustion characteristics of LOX/methane pintle injectors by Fang and Shen
5. Modeling of one-dimensional thermal response of silica-phenolic composites with volume ablation by Shi, Yi, Fang