

# BLAST OFF

End Term Project Report



OUR MENTORS -

Vasu Paliwal

Adit Jain

Shashank Sinha



# TIMELINE

HISTORY OF  
ROCKETS

SESSION 1

ROCKET  
EQUATIONS



PROPELLS

BASIC  
ANATOMY

SSTO, RE-ENTRY,  
HEAT SHIELDS

ORBITAL  
DYNAMICS

TRAJECTORY  
PLANNING

ENGINES

SESSION 10

SESSION 9

SESSION 8

SESSION 7

SESSION 6

APPLICATION  
OF MOGA TO  
SSTO

GENETIC  
ALGORITHM

# HISTORY OF ROCKETS



GODDARD'S ROCKET



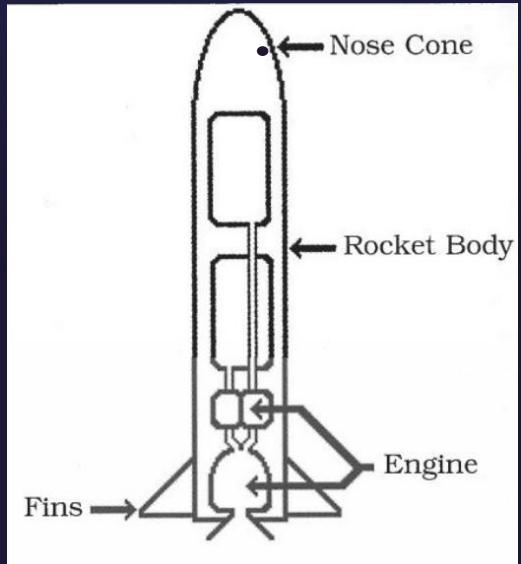
V2 ROCKET



APOLLO 11



STARSHIP



## PARTS OF A ROCKET



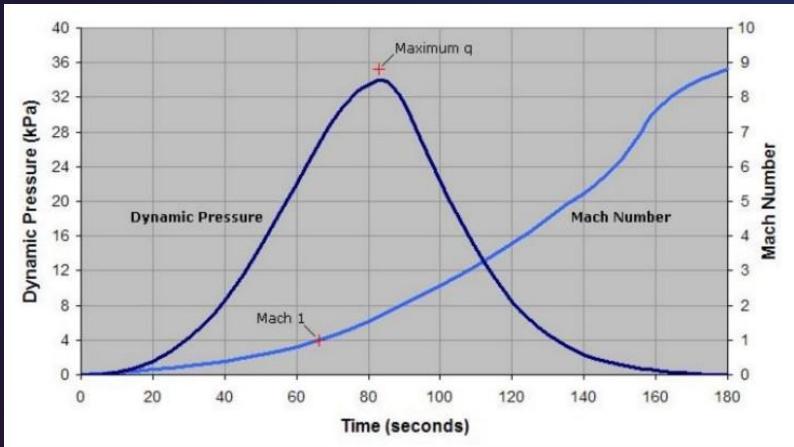
## MS TREE CATCHING A FALCON 9 FAIRING



## FAIRING



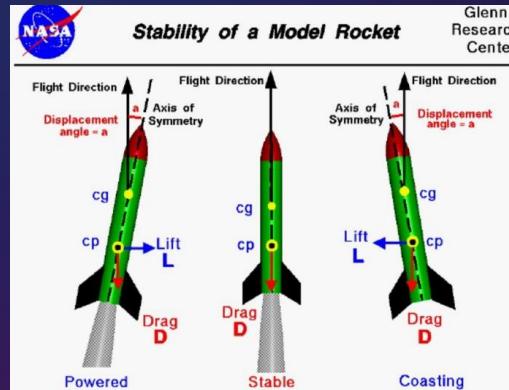
# STRUCTURAL SYSTEM AND STABILITY



$$q = \frac{1}{2} \rho v^2$$

Dynamic pressure formula

Structural system of rocket

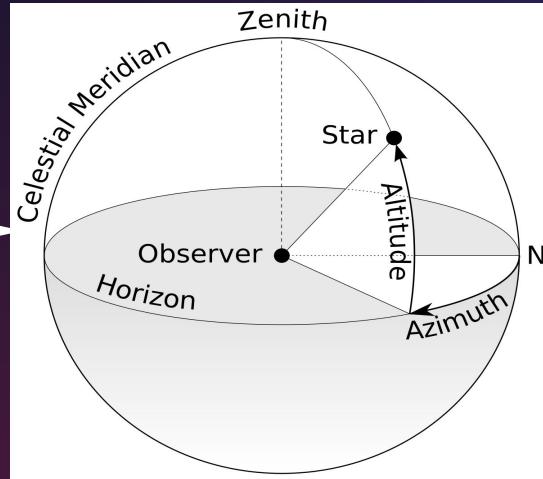


C<sub>g</sub> should always be higher than C<sub>p</sub>!!

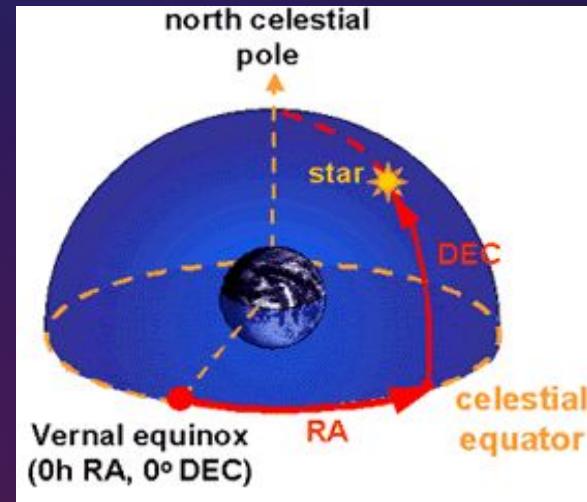


# COORDINATE SYSTEMS

ALT-AZ SYSTEM



RA-DEC SYSTEM



# THE ROCKET EQUATIONS

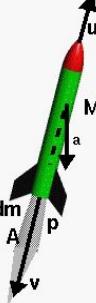
## MATHEMATICAL MODEL

$$\Delta M/M = 1 - \exp(\Delta v/v_{ex})$$

## SPECIFIC IMPULSE

$$\Delta v = I_{sp} g_0 \ln(M_o/M_f)$$

**Ideal Rocket Equation**



M = instantaneous mass of rocket    A = exhaust area  
u = velocity of rocket    p = exhaust pressure  
v = exhaust velocity     $p_0$  = atmospheric pressure  
In time increment  $dt$ , exhausted mass =  $dm$      $dm = \dot{m} dt$   
Change in momentum of system =  $M du - dm v$   
Force on system =  $(p - p_0)A - Mg \cos a$  (neglect drag)  
Change in momentum = Impulse = Force  $dt$   
 $M du - dm v = [(p - p_0)A - Mg \cos a] dt$   
 $M du = [(p - p_0)A + \dot{m}v] dt$  (neglect weight)  
 $V_{eq} = \text{equivalent exhaust velocity} = \frac{(p - p_0)A + v}{\dot{m}}$   
 $M du = V_{eq} \dot{m} dt = -V_{eq} \frac{dm}{M}$   
 $du = -V_{eq} \frac{dM}{M}$   
 $\Delta u = -V_{eq} \ln \left( \frac{M_e}{M_f} \right)$   
MR = propellant mass ratio =  $\frac{m_f}{m_e}$   
$$\Delta u = V_{eq} \ln \left( \frac{m_f}{m_e} \right) = V_{eq} \ln MR = I_{sp} g_0 \ln MR$$

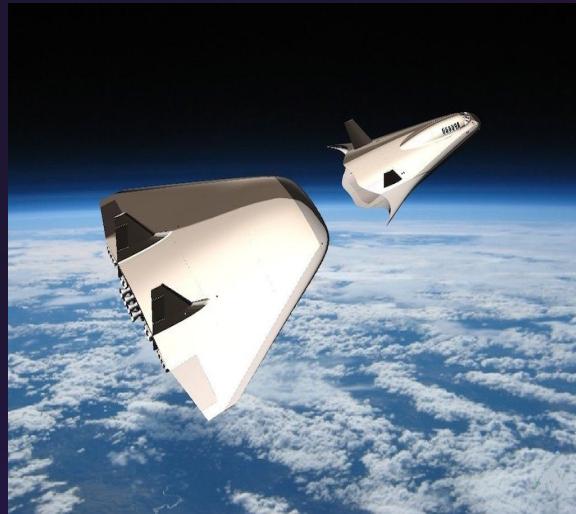
# SSTO

SINGLE STAGE TO ORBIT



# DSTO

DOUBLE STAGE TO ORBIT



# ★ STAGING ★

PARALLEL STAGING



SERIAL STAGING



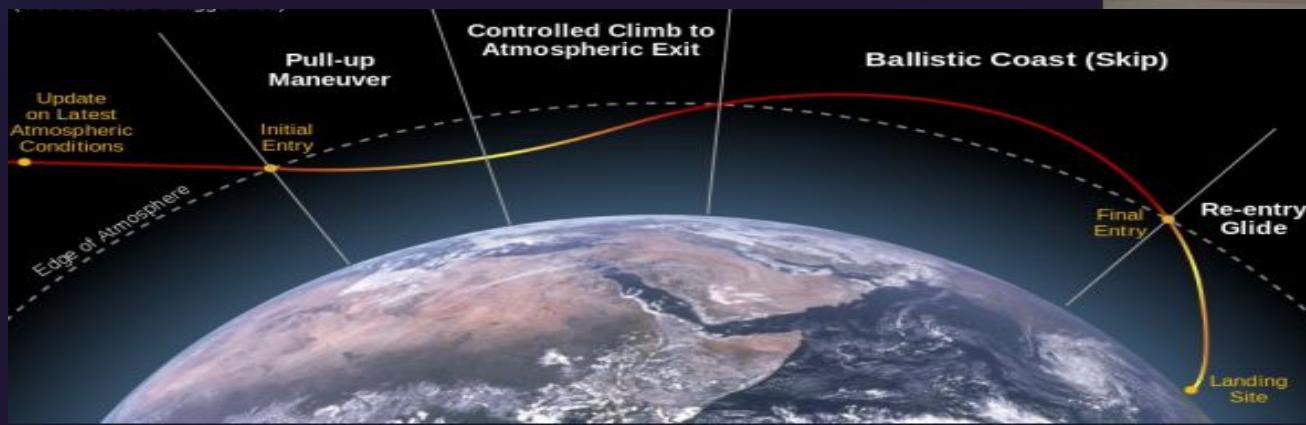
# RE-ENTRY

## RE-ENTRY MANEUVER

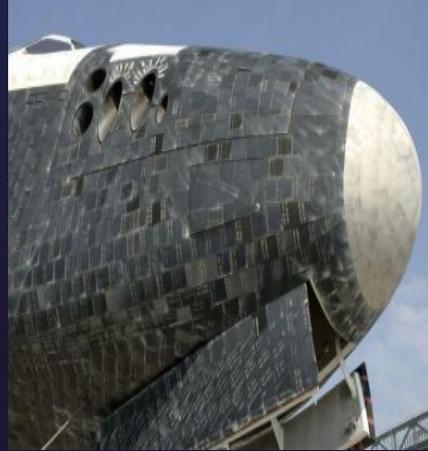
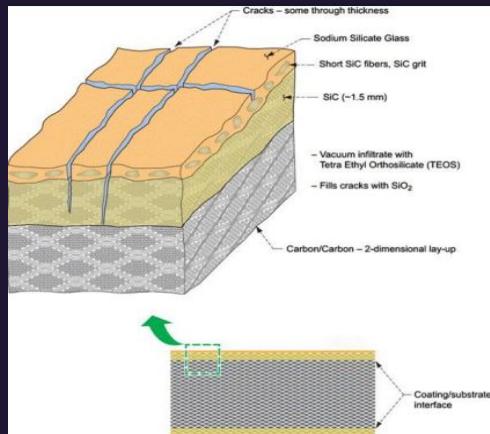


GUIDED

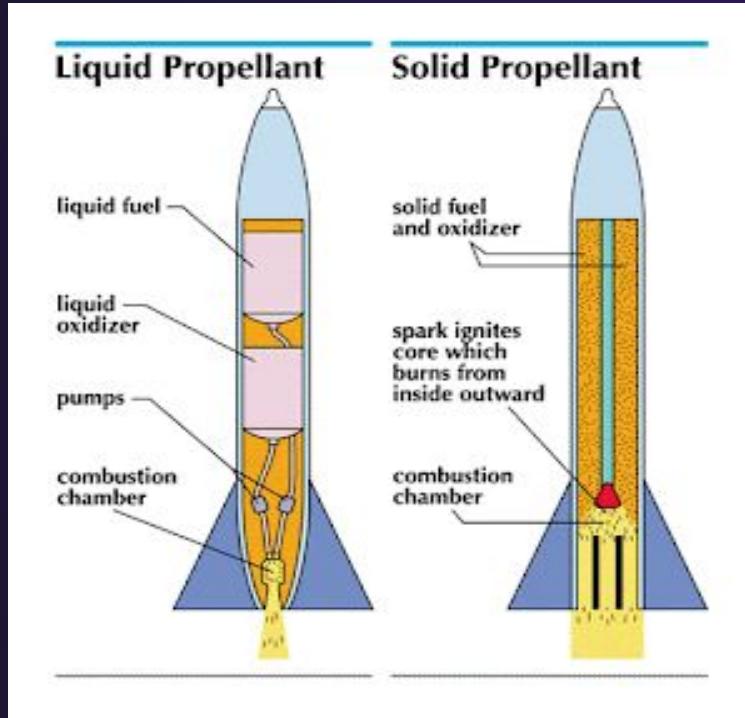
UNGUIDED



# HEAT SHIELDS



# PROPELLANTS



RP1

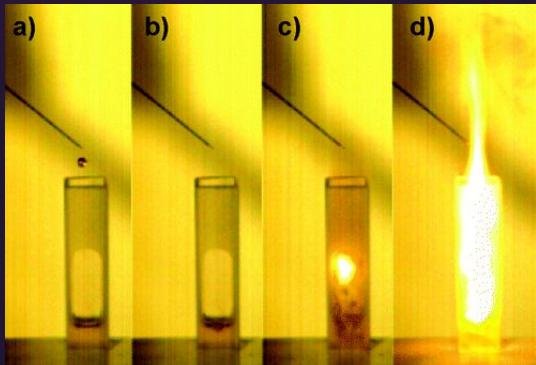


LH2

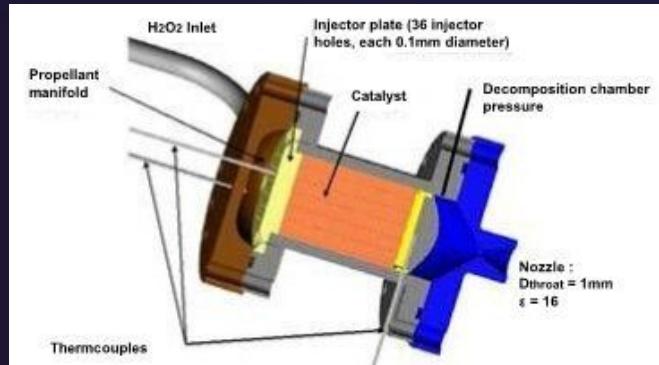


# PROPELLANTS

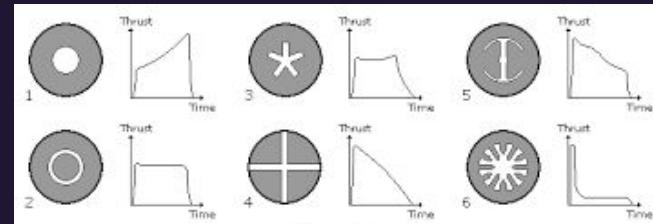
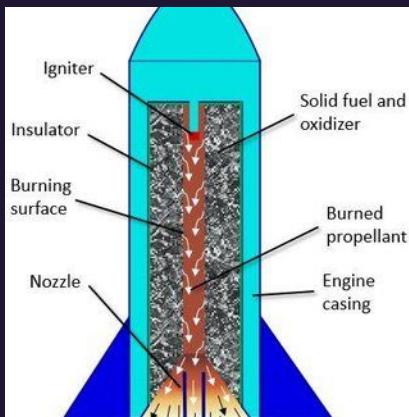
## HYPERGOLS



## MONOPROPELLANTS

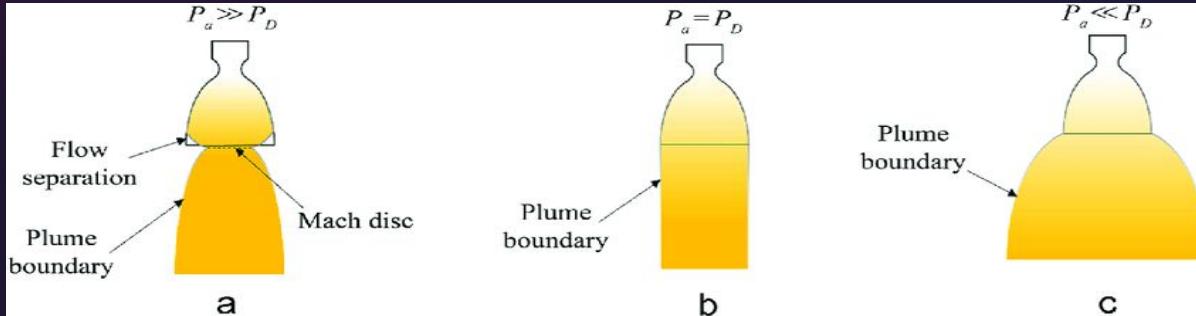


## SOLID ROCKET BOOSTERS



# PARTS OF ROCKET ENGINE

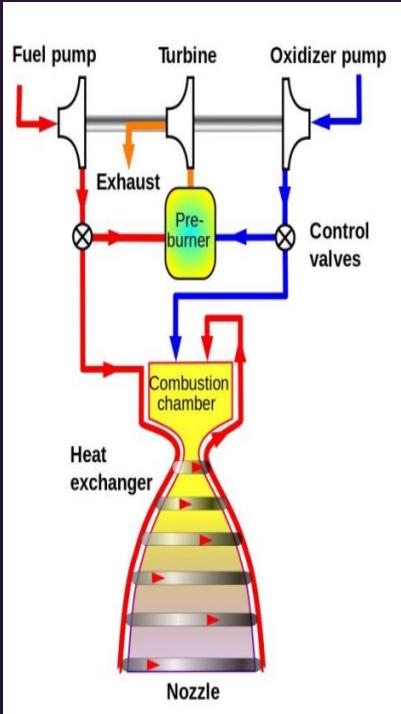
## NOZZLE



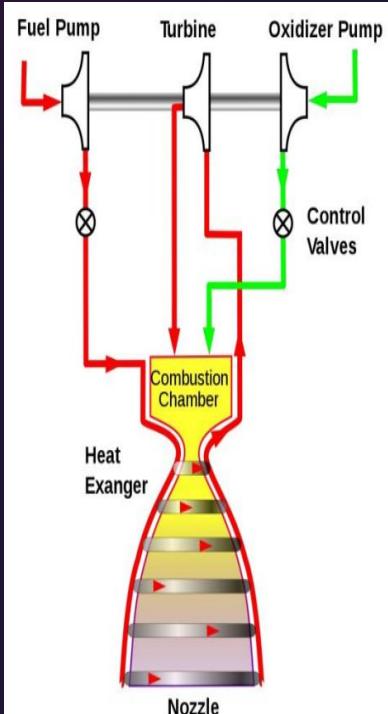
## CHAMBER AND INJECTOR



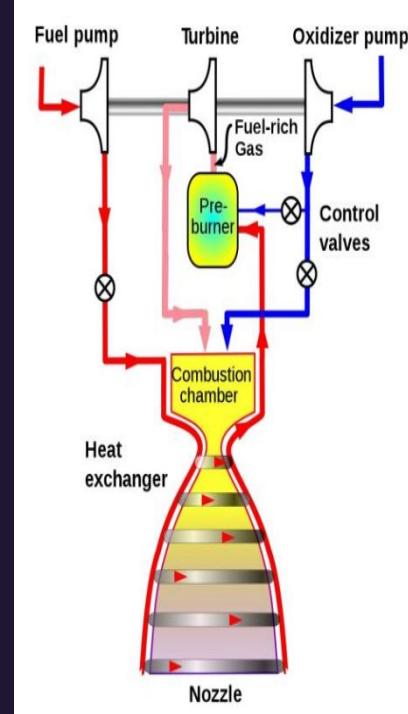
# POWER CYCLES



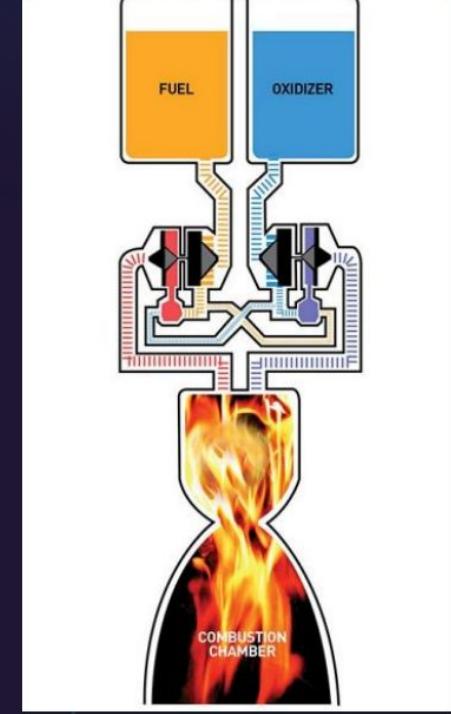
GAS GENERATOR CYCLES



EXPANDER CYCLE



STAGED COMBUSTION



FULL FLOW STAGED COMBUSTION

# TRAJECTORY PLANNING

So now how do you launch your rocket ?



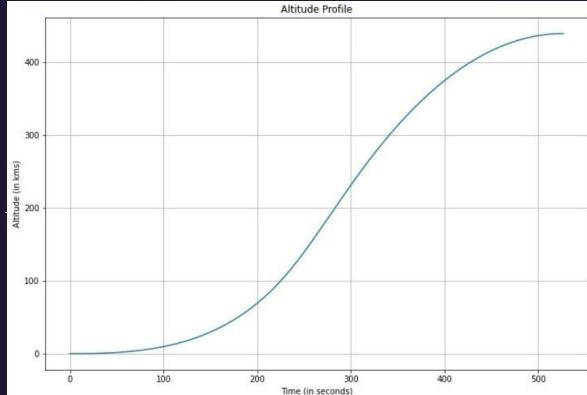
- Thrust at 5 different altitude
- Gravity turn altitude of start and end
- Cone Half Angle
- Rocket Radius
- Initial Wet Mass

5 PARAMETERS

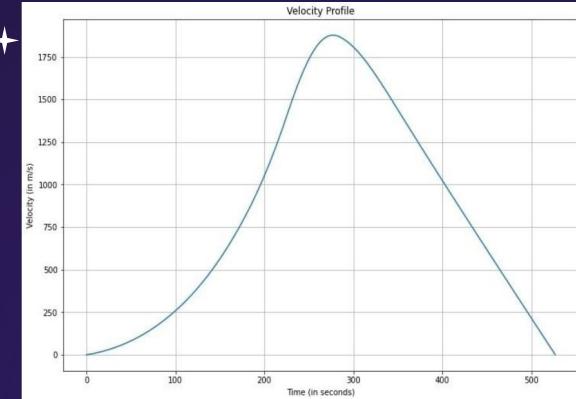
$$\begin{aligned}\frac{d}{dt} \mathbf{r} &= \mathbf{r}' \\ \frac{d}{dt} \mathbf{r}' &= -\frac{\mu}{r^2} + \mathbf{r}\theta^2 + \frac{T(r) - D(r, r')}{m} \cos(\alpha(r)) \\ \frac{d}{dt} \theta &= \theta' \\ \frac{d}{dt} \theta' &= \frac{T(r) - D(r, r')}{r * m} \sin(\alpha(r)) \\ \frac{d}{dt} m &= \frac{-T(r)}{I_{sp} * g_o}\end{aligned}$$

THE ROCKET EQUATIONS

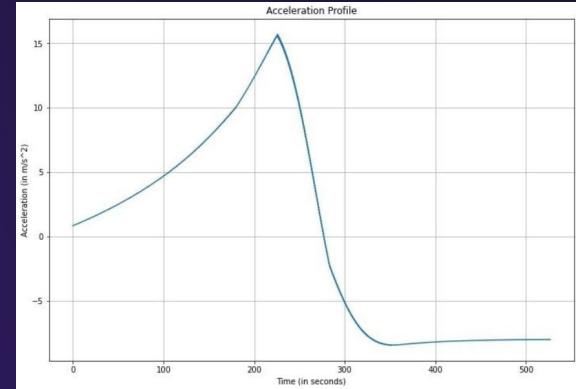
# SOME OF THE GRAPHS OF AN IDEAL ROCKET...



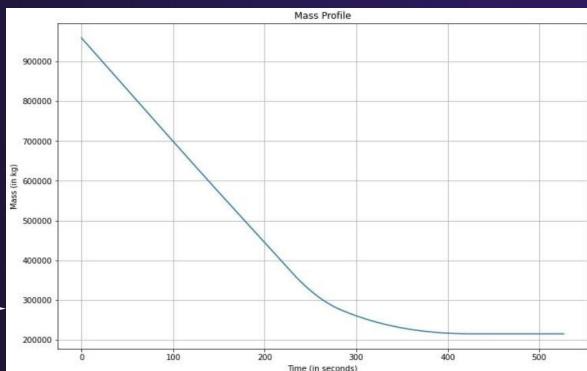
ALTITUDE VS TIME



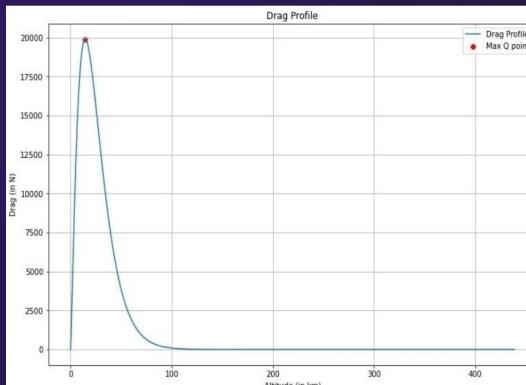
VELOCITY VS TIME



ACCELERATION VS TIME



MASS VS TIME

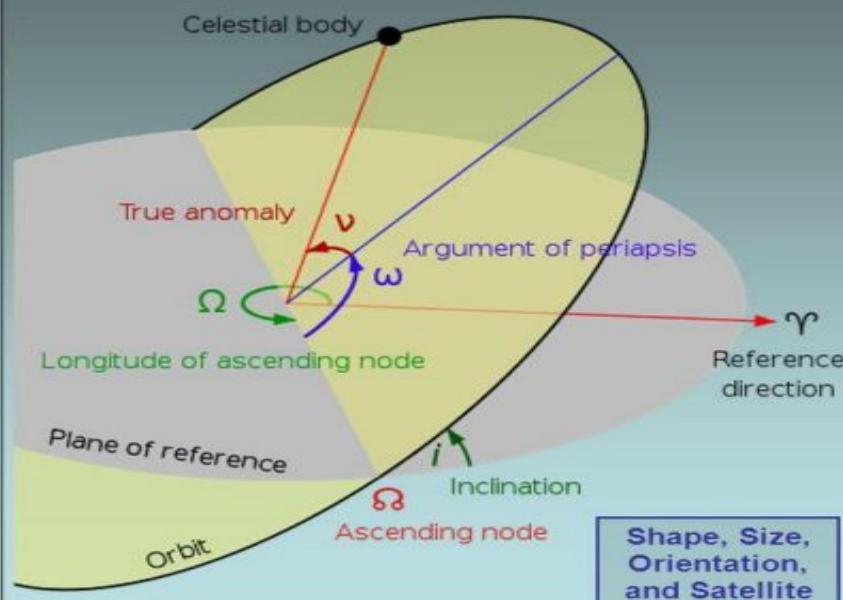


DRAG VS ALTITUDE

# ORBITAL DYNAMICS

## The Six Keplerian Elements

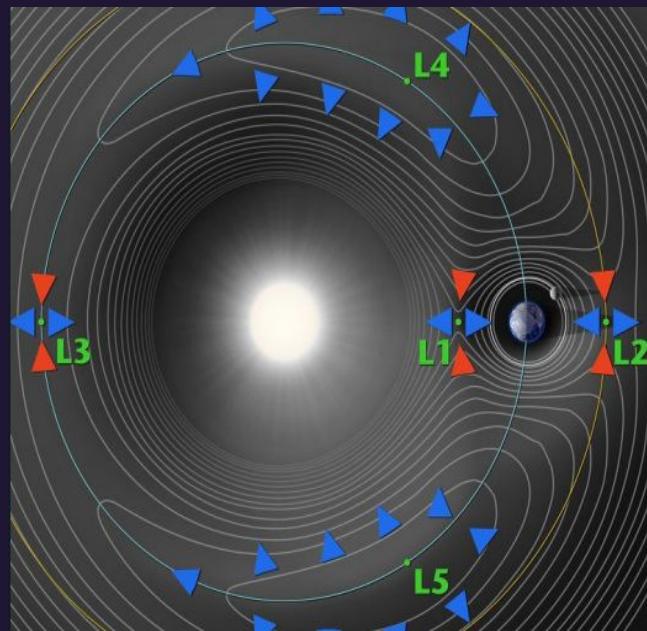
- a** = **Semi-major axis** (usually in kilometers or nautical miles)
- e** = **Eccentricity** (of the elliptical orbit)
- v** = **True anomaly** The angle between perigee and satellite in the orbital plane at a specific time
- i** = **Inclination** The angle between the orbital and equatorial planes
- $\Omega$**  = **Right Ascension (longitude) of the ascending node** The angle from the Vernal Equinox vector to the ascending node on the equatorial plane
- $\omega$**  = **Argument of perigee** The angle measured between the ascending node and perigee



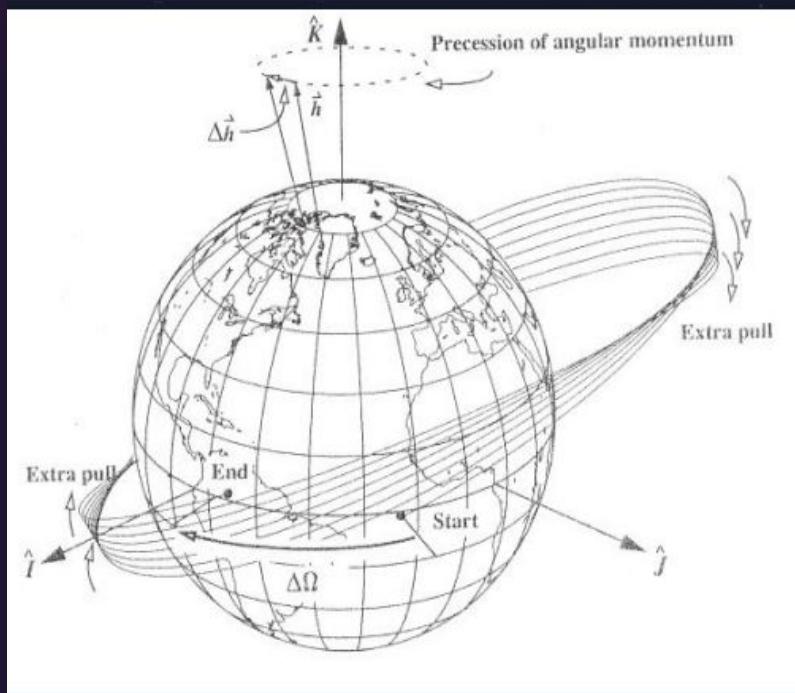
Shape, Size,  
Orientation,  
and Satellite  
Location.

# ORBITAL DYNAMICS

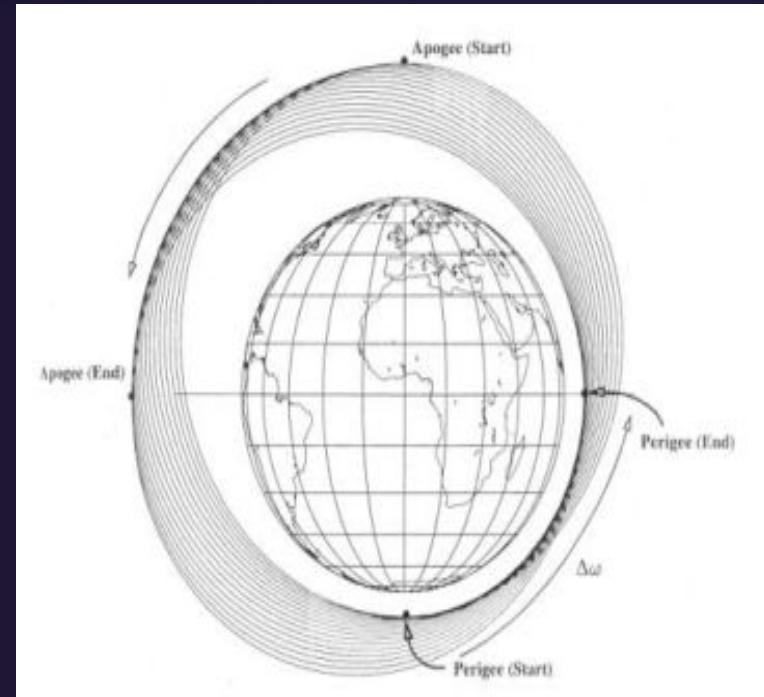
## LAGRANGE POINTS



# ORBITAL DYNAMICS

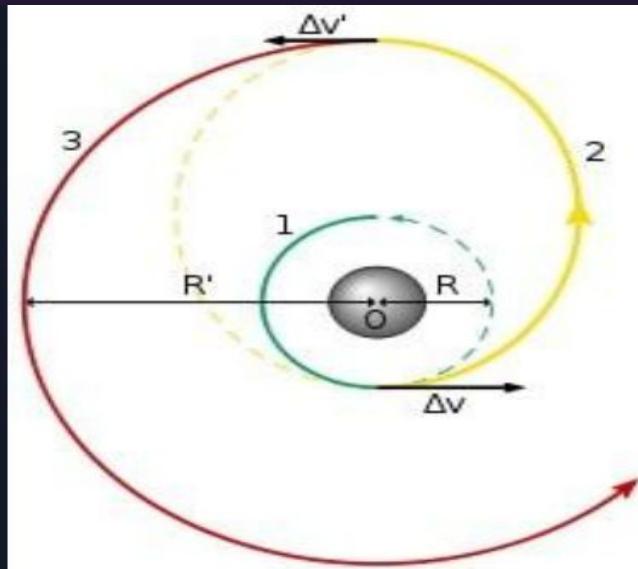


J2 NODAL REGRESSION

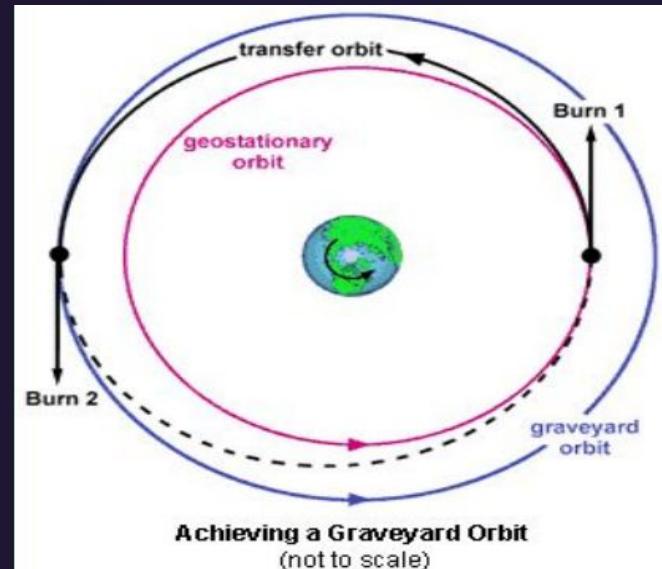


J2 APSIDAL ROTATION

# ORBITAL DYNAMICS

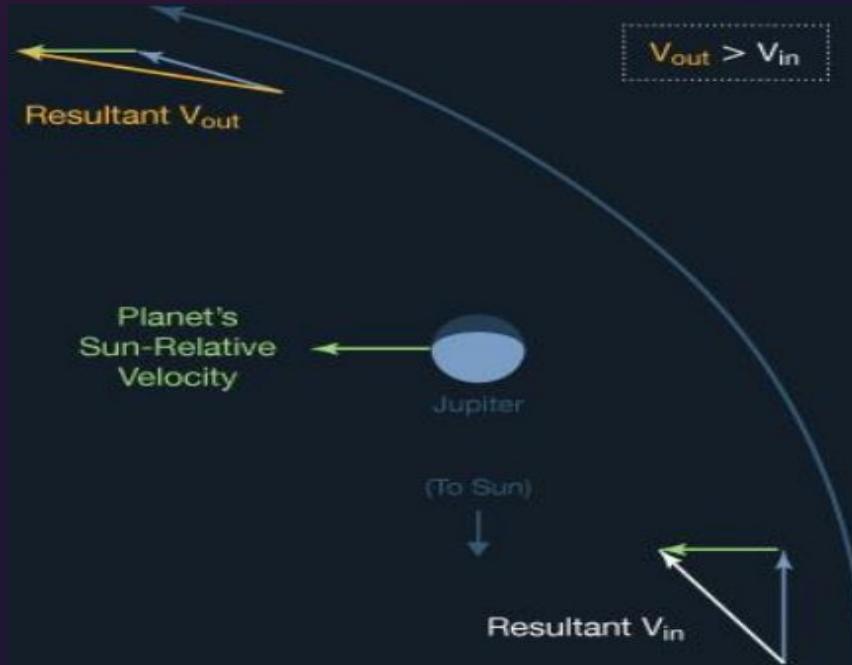


HOHMANN TRANSFER

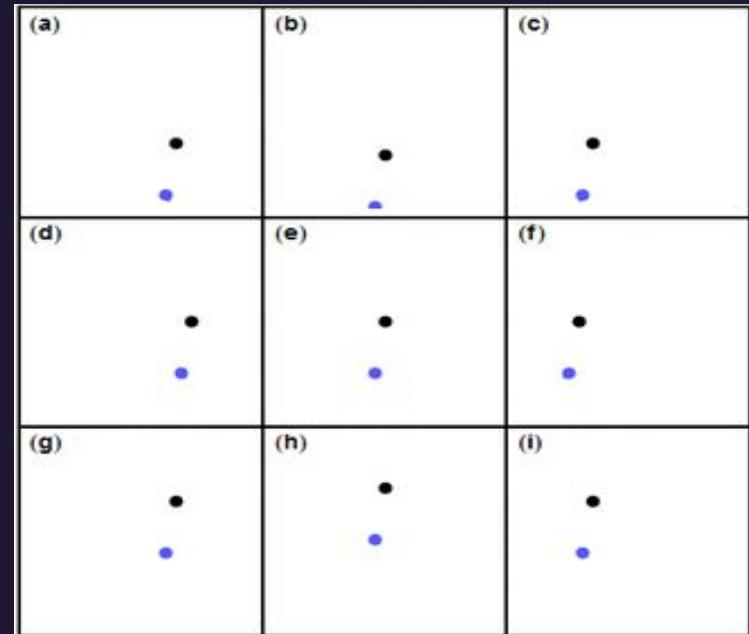


GRAVEYARD ORBIT

# ORBITAL DYNAMICS

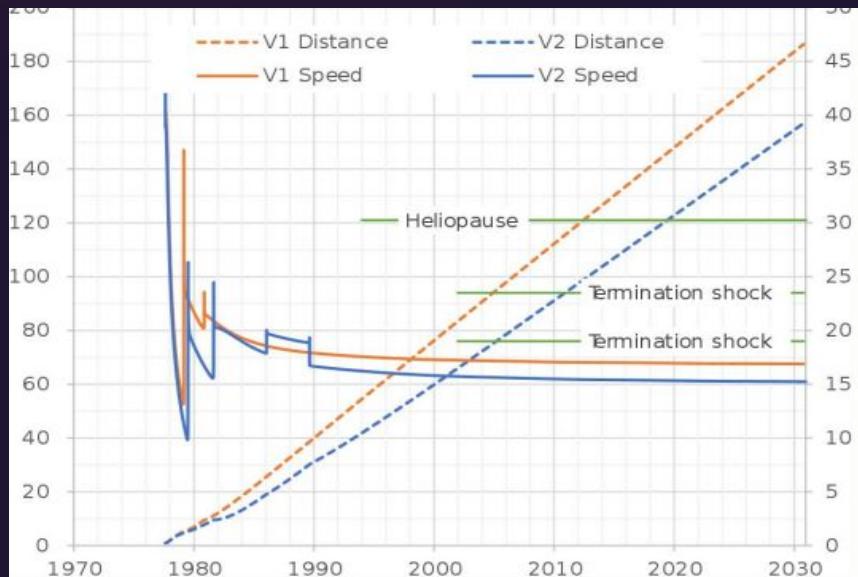


GRAVITATIONAL ASSIST

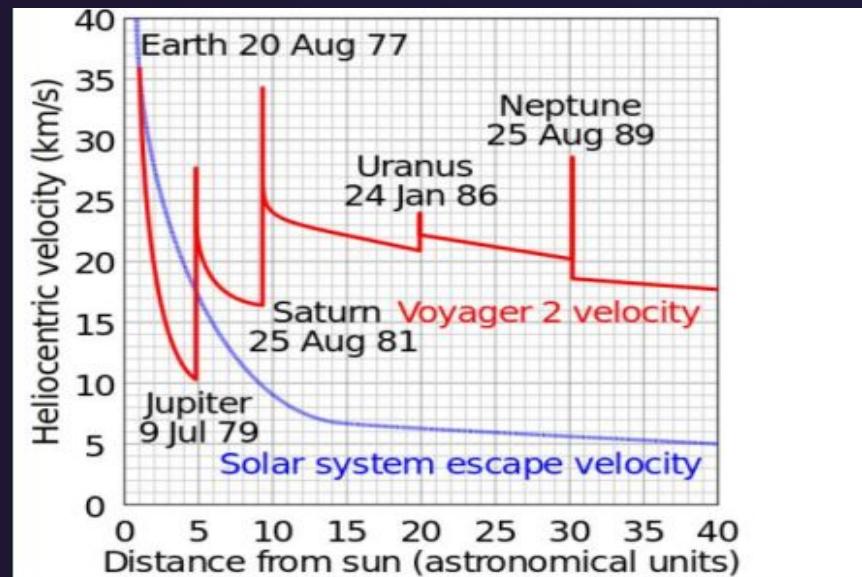


POSSIBLE OUTCOMES OF  
GRAVITATIONAL ASSIST

# ORBITAL DYNAMICS



VOYAGER SPEED VS.  
DISTANCE FROM THE SUN

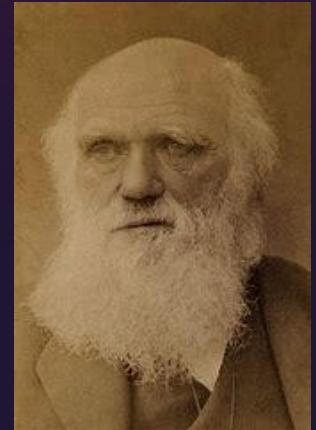


HELIOCENTRIC VELOCITY OF VOYAGER 2 VS.  
DISTANCE FROM THE SUN

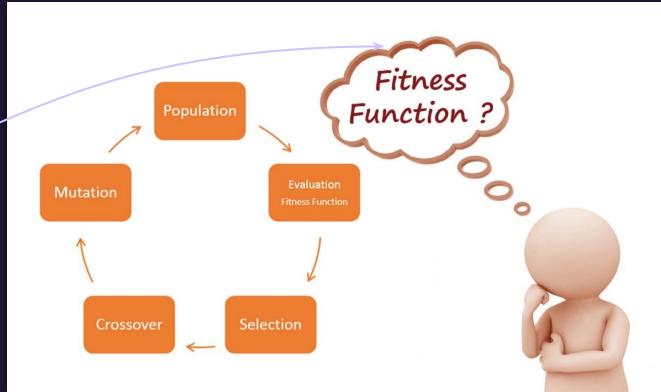
# GENETIC ALGORITHM

Inspired by Charles Darwin's Theory of Natural Selection

Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection.



BUT ON WHAT BASIS??

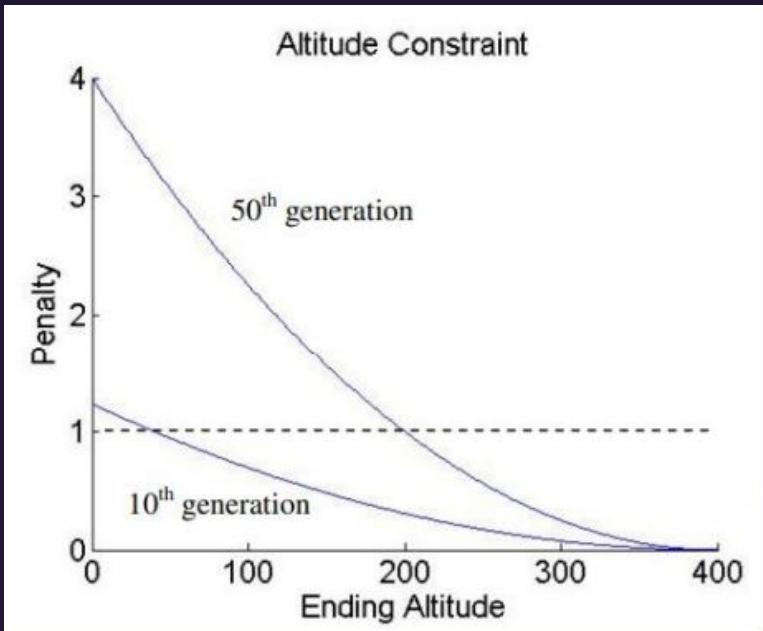


# APPLICATION OF MOGA TO SSTO ROCKETS

PENALTY :  $p(A_{\text{final}}) = [\text{abs}(400 - A_{\text{final}})/\max\{1, 400 - 4 * \text{gen}\}]^2$

FITNESS :  $F = \max\{1.0 - 0.01 * n_{\text{dom}} - p(A_{\text{final}}), 0\}^2$  PARAMETERS RANGE

```
THRUST_VECTOR_RANGE = [  
    [10.1e6, 10.3e6],  
    [9.7e6, 9.9e6],  
    [10.0e6, 10.2e6],  
    [3.7e6, 3.9e6],  
    [2e3, 4e3]  
]  
  
ANGLE_VECTOR_RANGE = [  
    [350, 450],  
    [320e3, 320e3]  
]  
  
CONE_HALF_ANGLE = [0.10, 0.15]  
ROCKET_RADIUS = [3.8, 4.2]  
TOTAL_MASS = [950e3 980e3]
```



# APPLICATION OF MOGA TO SSTO ROCKETS

## COST CALCULATION

### ENGINE COST

$$C_E = M_E * (C_{ESS}/M_{ESS})$$

$$C_{ESS} = 30 \text{ million \$}$$

$$M_{ESS} = 3,500 \text{ kg}$$



### STRUCTURAL COST

$$C_S = M_S * (C_{Sss}/M_{Sss})$$

$$C_{Sss} = 75 \text{ million \$}$$

$$M_{Sss} = 760,000 \text{ kg}$$

### PROPELLANT COST

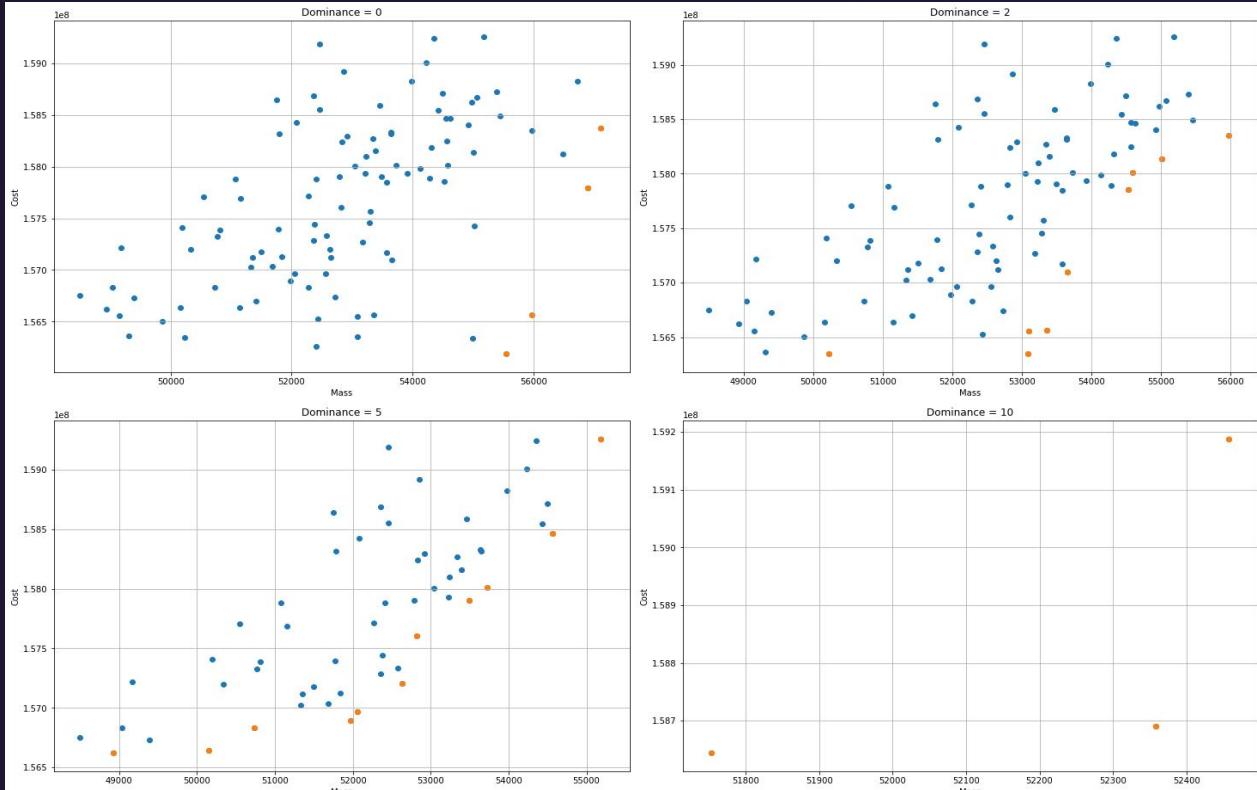
$$C_P = (M_P * C_{O2} * (6/7)) + (M_P * C_{H2} * (1/7))$$

$$C_{O2} = 0.155 \text{ \$/kg}$$

$$C_{H2} = 9.5 \text{ \$/kg}$$

# ROCKET OPTIMIZATION USING PARETO FRONT AND DOMINANCE

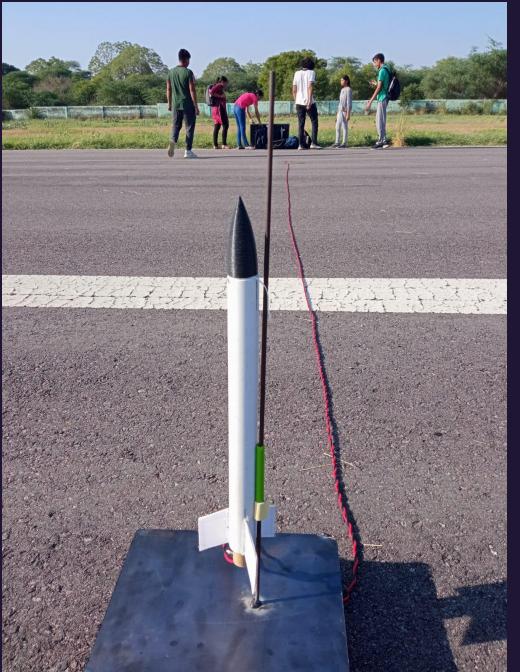
We need to increase payload mass going into orbit while simultaneously minimizing the cost it takes to do so.

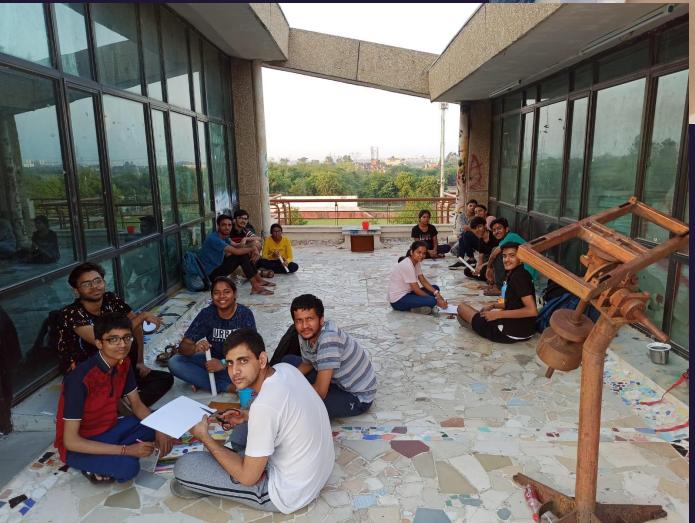


# CONCLUSION

We calculated the Payload Mass, Total Cost and Mass to Cost Ratio of our fittest rocket and compared them with the actual properties of some mission and finally calculated the percentage error!

PROPERTY	CALCULATED VALUE	ACTUAL VALUE	PERCENTAGE ERROR
Payload Mass	52818.27 Kg	52100 Kg	1.38%
Total Cost	159.04 million \$	157.3 million \$	1.11%
$M_p/C$	332.11 Kg/M\$	331.21 Kg/M\$	0.27%







# LAUNCHING OUR ROCKET





# THANK YOU !!

COSMOS IS WITHIN US