Society for Space Education Research & Development

EDUCATE - INSPIRE - INNOVATE

CHAAND

Collective Hive of Advanced Autonomous Navigation & Design

The Team

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(Communication Subsystem- Swarm)

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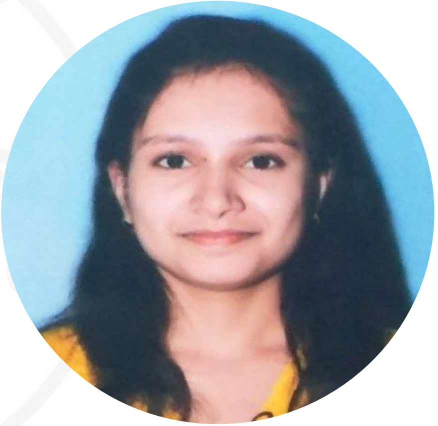
Vice Team Leader
(Communication Subsystem- WPT)

The Team - Soft Landing Subsystem

Ishita Bhatnagar



Prachi Singh

The Team - Mechanical Subsystem

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(WPT)

Mission, Vision, and Objectives

Design and build next generation rovers for **Lunar Exploration**.

Help establish a **city** on **CHAAND**.

- Ensure soft landing of the rover.
- Create a robust chassis which ensures safe traversal of the lunar terrain.
- Build compute models to help in navigation and terrain-mapping.
- Find perfect site for excavation of lunar regolith and minerals.

- Establish a lunar communication network with the help of swarm robotics. As the rovers disperse away from the queen, they drop repeaters at intervals to amplify communication signals and keep communicating with the queen and other mini rovers.
- Wireless powering of the rover to carry out its functionalities.

Subsystem - Soft Landing

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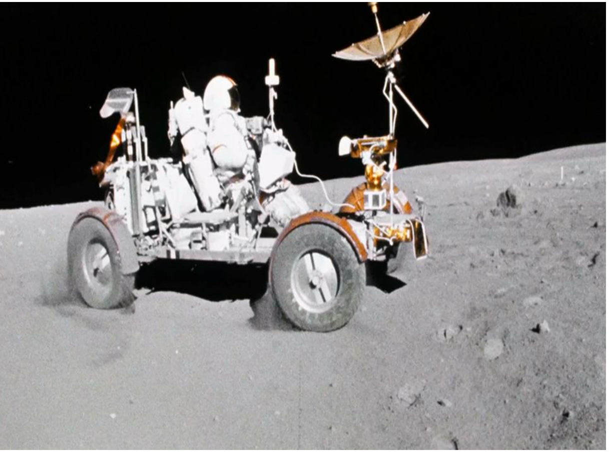
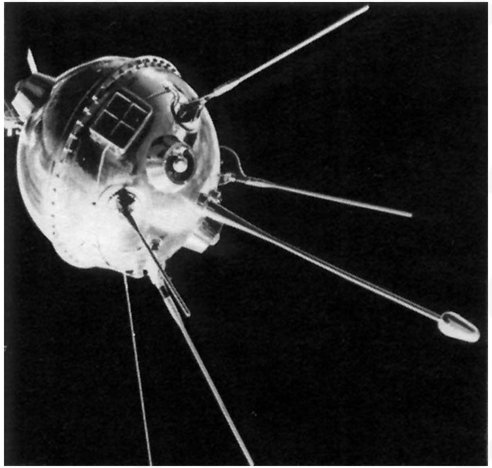
Moon Landing - Introduction & History





Subsystem - Soft Landing

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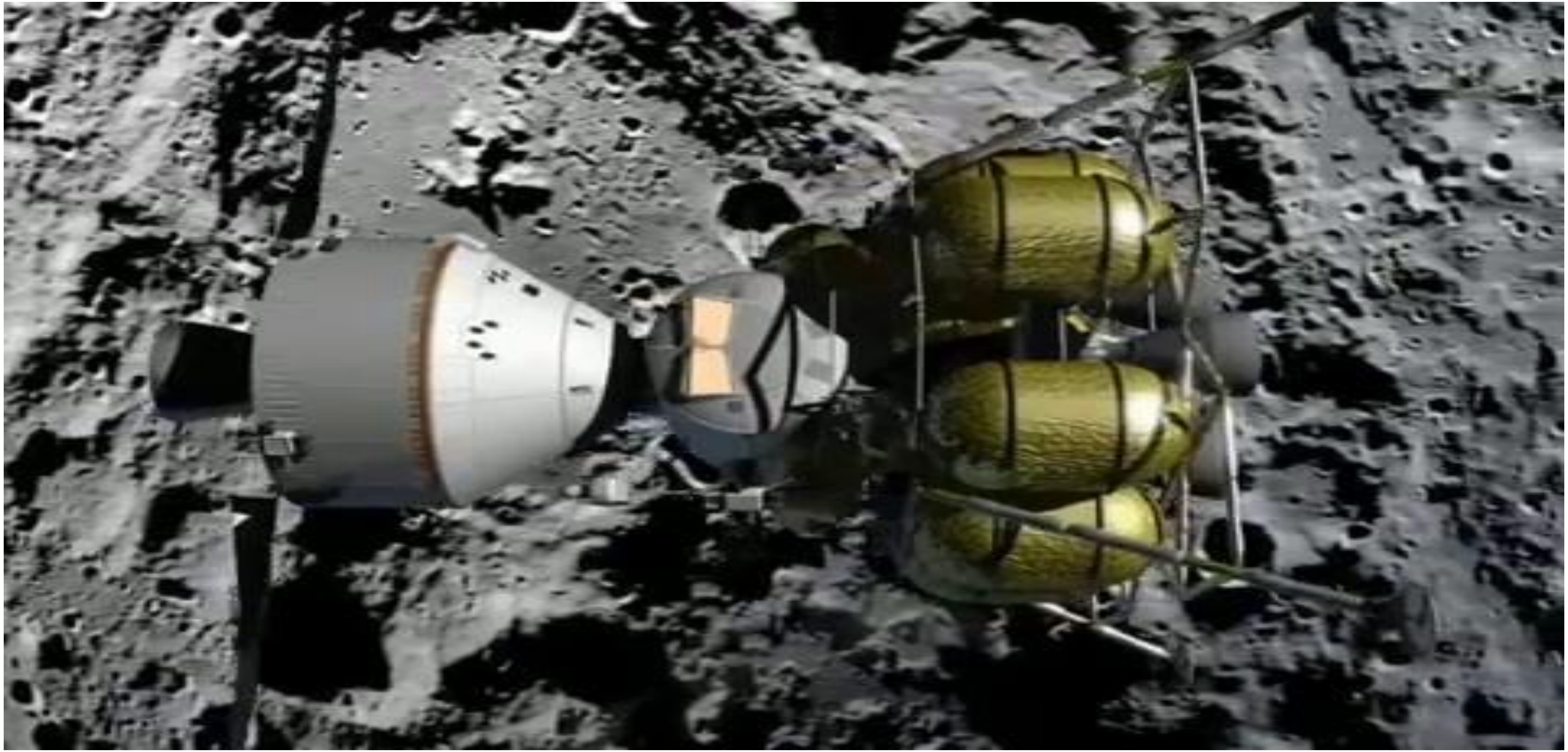
Soft Landing & Fuel Optimization



Problem Solving

Problem Statement

Fuel optimal trajectory optimization for soft landing of the rover on the lunar surface.

Assumptions

- Aerodynamic forces and gravitational forces of bodies other than the Moon are negligible and lateral motion is ignored.
- descent trajectory is vertical and the thrust vector is perpendicular to the ground.

Objective Function

$$J = -m(t_f)$$

Symbol	Value	Symbol	Value
H_0	R_M +15.7 km	V_{z0}	0 m/s
A_0	−1.43°	T_{max}	43,148.0 N
B_0	−8.43°	I_{sp}	302.39 s
γ	285.30°	m_0	15,234.0 kg
H_f	R_M	$\omega_{\alpha\ max}, \omega_{\beta\ max}$	5.0 °/s
A_f	−23.45°	μ	4.9028e12 m^3/s^2
B_f	−2.94°	R_M	1738 km
V_{x0}	1694 m/s	g_0	9.80 m/s^2
V_{y0}	−7.0 m/s	ε	1.0e−3

Mission Information Table

Solution Process

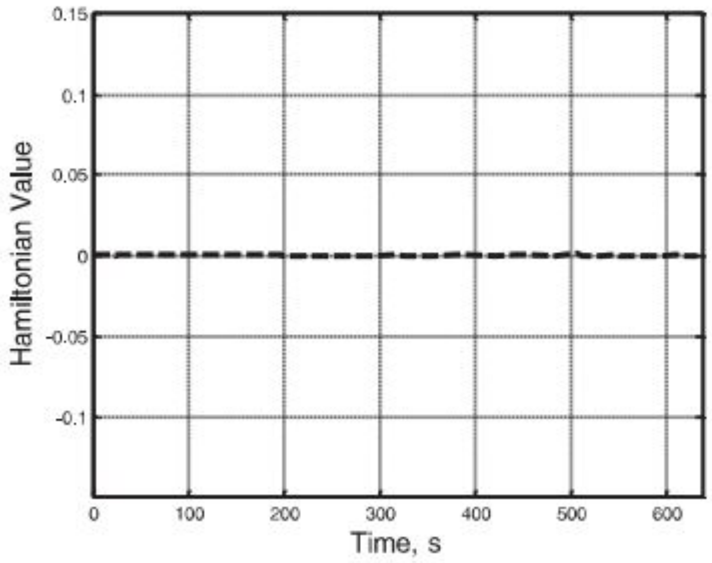
Simultaneous Dynamic Optimization Approach	Adaptive mesh refinement strategy

$$
\begin{aligned}
&\min \ \Phi(z(t_f)) \\
s.t.\quad &\frac{dz}{dt} = f(z(t), y(t), u(t)),\ z(t_0) = z_0 \\
&g(z(t), y(t), u(t)) = 0 \\
&u_L \le u(t) \le u_U \\
&\psi(z(t_f)) \le 0
\end{aligned}
$$

$$
\begin{aligned}
H(t) = {} & \lambda(t)^T f(z(t), y(t), u(t)) + \eta(t)^T g(z(t), y(t), u(t)) \\
& + \alpha^L(t)^T (u(t) - u_L) + \alpha^U(t)^T (u_U - u(t))
\end{aligned}
$$

Subsystem - Soft Landing

Conclusion



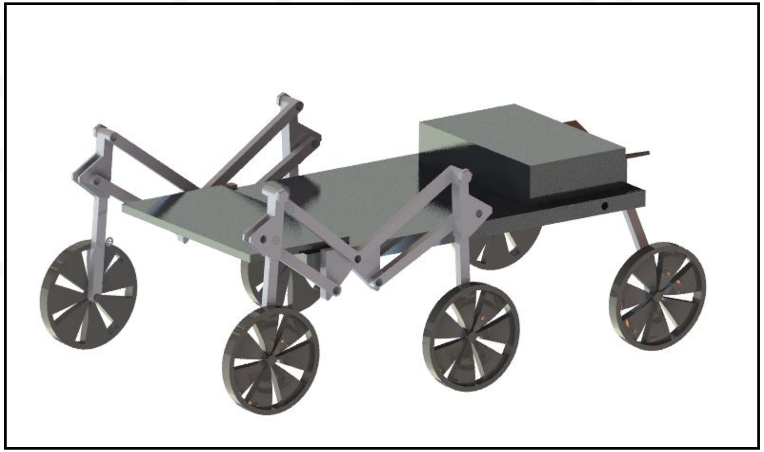
We observed that the Hamiltonian profile is almost constant over time, which illustrates that the results are optimal.

Objective :

- To design and model a chassis for the lunar rover which is stable and has good obstacle surmounting capabilities
- To also design the swarm rover and a mechanism to deploy them from the mother rover

The chassis of the rover should be designed keeping in mind the following points

- Stability of the main body of the rover
- Obstacle climbing capacity
- Provide even weight distribution



Pic credits : Aditya G

Subsystem - Mechanical (chassis)

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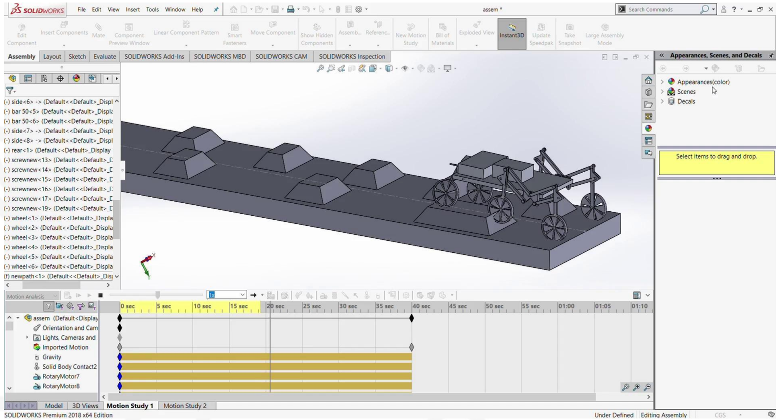
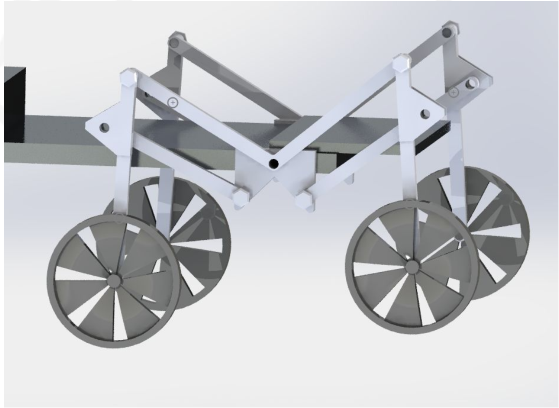
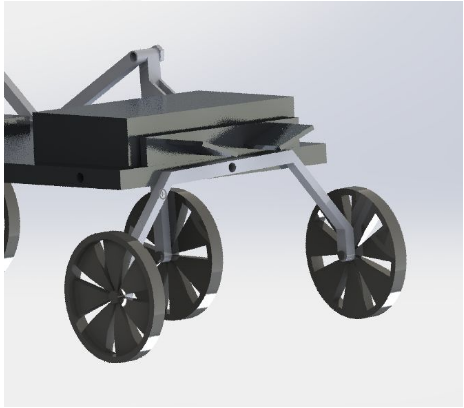
The Mantis Design



Key Features

- Six wheel individual motor design
- Balanced even weight distribution
- distributes weight away from the lowest wheel
- More robust and does not require telescopic or hydraulic suspensions
- system promotes a gliding behavior





Pic credits : Aditya G

Materials

Mother rover and swarm rovers

Rover **main body** - **Aluminium alloy 2219- O**
Tensile Strength -170000000 N/m^2

- high fracture toughness
- Is weldable and resistant to stress corrosion cracking

Rover **wheels** - Aluminium alloy 2219

Stress intensive parts in the rover - Al alloys or Ti alloys

- good strength to weight (Al)
- low cost (Al)
- High temperature and radiation (Ti)
- High strength (Ti)

Mother Rover Design

Pic credits : Ashraf R and Aditya

Pic credits : Ashraf R and Aditya

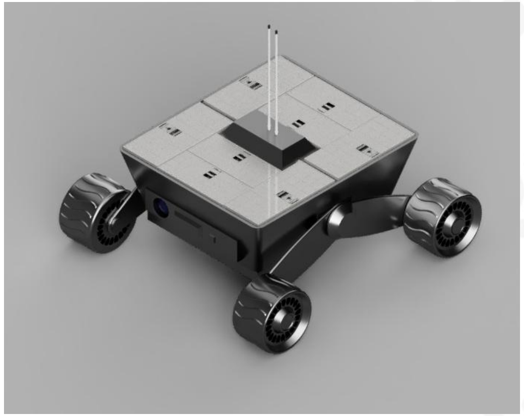
- The large 6 wheel design paired with a large centre of gravity provides excellent control and stability over any terrain.

Dimensions of the mother rover - **1.5 * 1 * 1.2 metres**

Weight of the rover - Approximately 750-850 kgs (including onboard equipments)

Subsystem - Mechanical (chassis)

Swarm rovers



Pic credits : Ashraf R

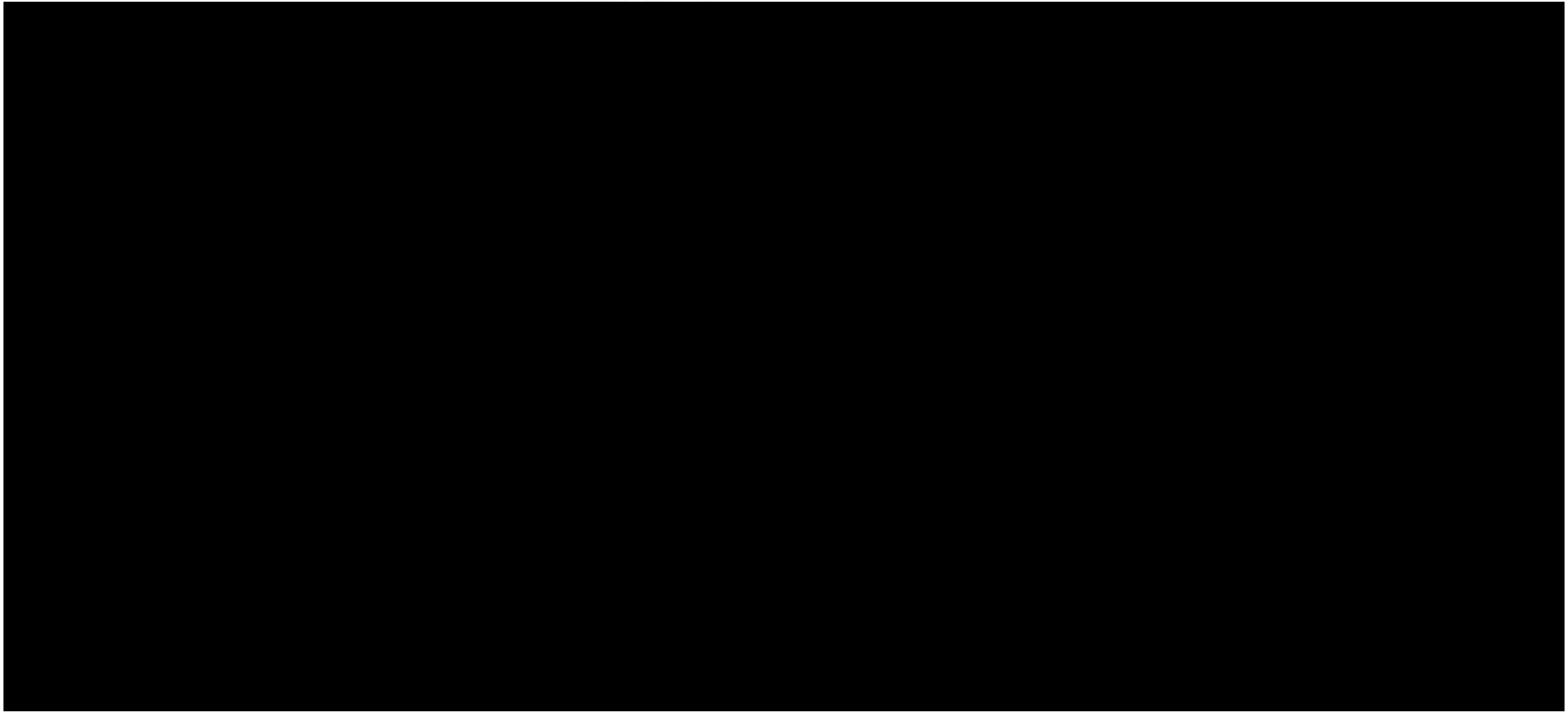
Pic credits : Ashraf R

Dimensions of the mini rover : 30 x 30 x 20 cm

Mass of the mini rover : Approximately 15-20 kg (based on onboard electronics)

Subsystem - Mechanical (chassis)

Swarm rover deployment



Video credits : Ashraf

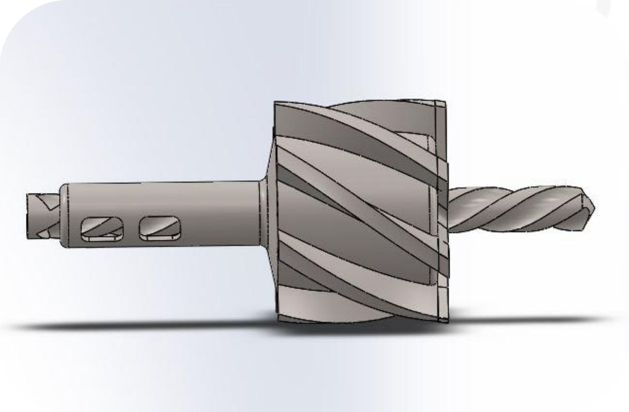
Subsystem - Mechanical (Excavation)

Main Objective :

To perform drilling operation and collect the sample required at different depths .

- ***Basic principle*****:** To excavate using drilling operation and collect the required sample in the collector
- ***Principle steps to consider*** :

1. Drilling
2. Flushing unwanted soil/regolith
3. Collection of required sample respective of the depth in a sample collector
4. Retraction of drill

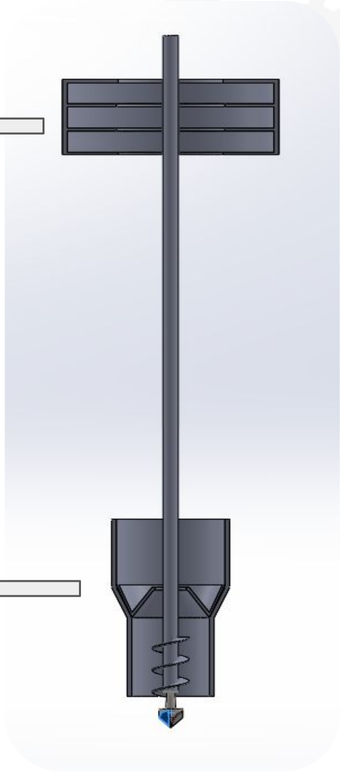


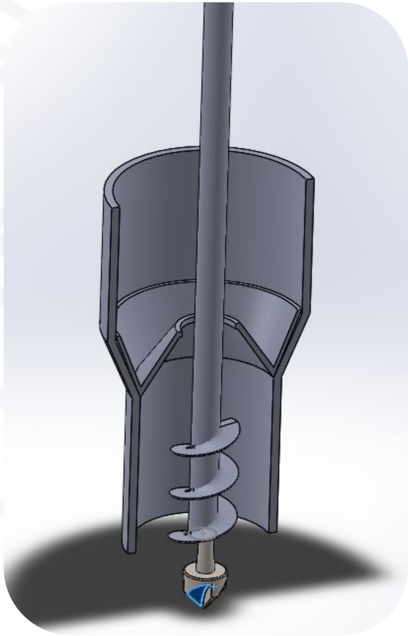
Subsystem - Mechanical (Excavation)

- ***Conceptual design :***

Sample storage

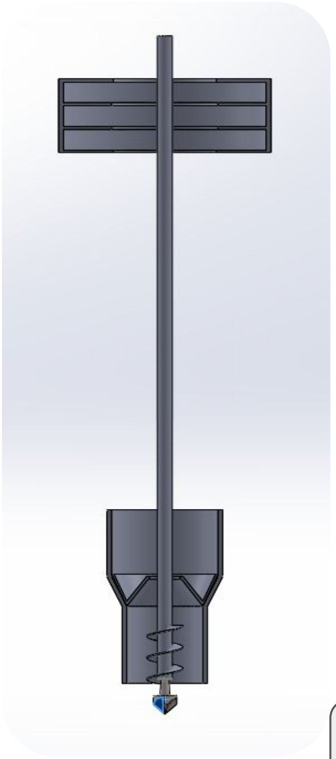
Outer cylinder
+
Sample bucket

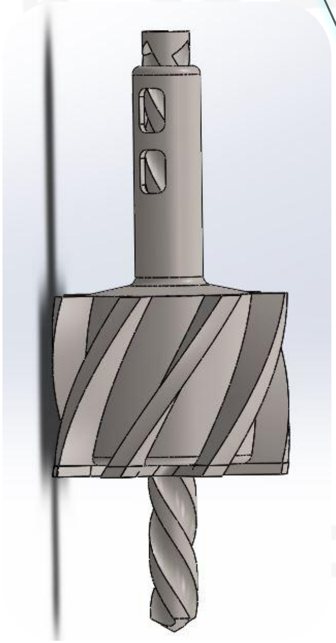




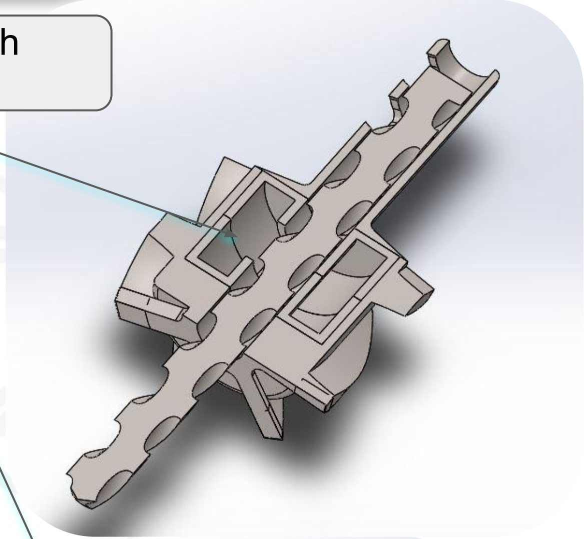
Subsystem - Mechanical (Excavation)

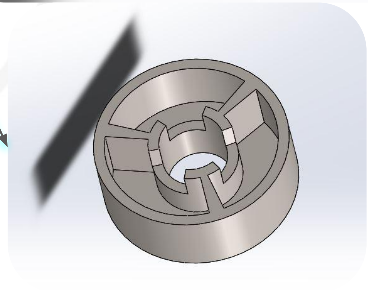
- ***Optimization of the design*** :





Sample collector with compartments





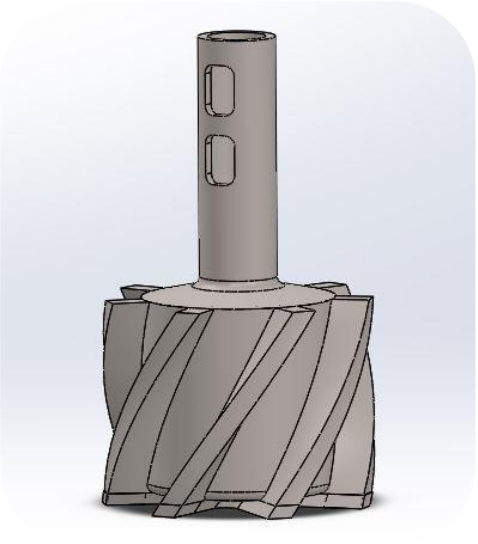
Combining both sample collector and bucket

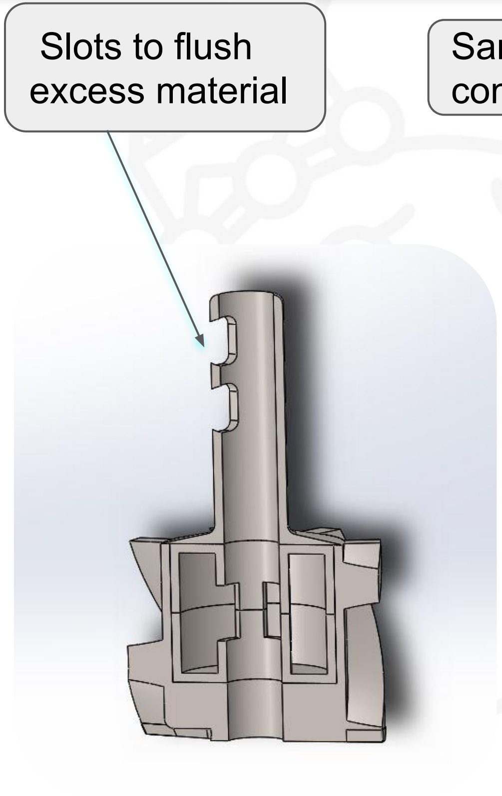
Subsystem - Mechanical (Excavation)

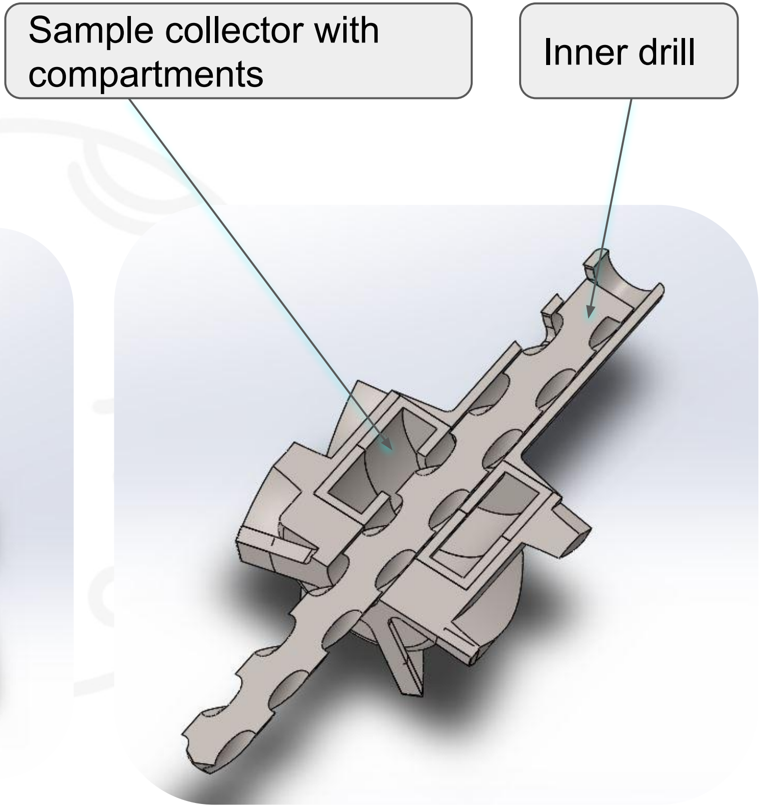
video credits : Aditya G

Subsystem - Mechanical (Excavation)

- ***Working***:







Subsystem - Mechanical (Excavation)

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- ***Dimensions*** :

	Inner dia	Outer dia	Height
Inner drill	__	5.6 cm	
Outer drill (counterbore part)	9 cm	28 cm	18 cm
Sample collector	6 cm	9 cm	15 cm
Inner spool	__	5.6 cm	__
Outer spool	6 cm	8 cm	300 cm

(Ref : These dimensions are based on the size constraints of the queen rover)

- ***Weight*** : Gross(total) = 30 kg
  Sample = 0.271 kg (considering density of regolith soil = 1.5 g/cm^3)

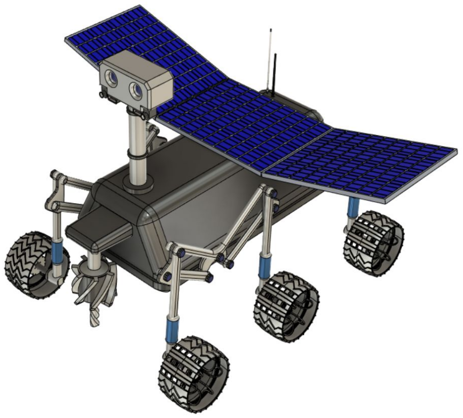
Subsystem - Mechanical (Excavation)

- ***Material selection*** :

1. Drill bit - The drill bit is made up of hy-tuf steel and tips are of tungsten-carbide .
2. Drill stem - The drill stem is made up from titanium

(Ref :The above materials have been chosen based on Apollo lunar surface drill (ALSD))

- ***Location of the drill tool on the rover*** :



SWARM COMMUNICATION

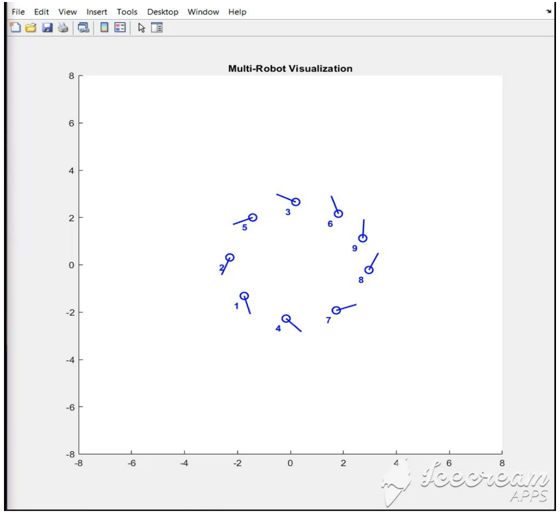
The behaviour of the swarm rover defines how the bots should organise itself with respect to its local neighbours and the specified goal. The behaviour can be observed in nature like the ants forming a colony to perform difficult tasks or like the birds flocking to avoid getting lost during migration. Some basic spatial organisation are **aggregation**, **dispersion**, **pattern formation**, **self assembly** and **clustering**. Depending upon the application the behaviour is chosen and coded into the bots.

Picture source: Internet

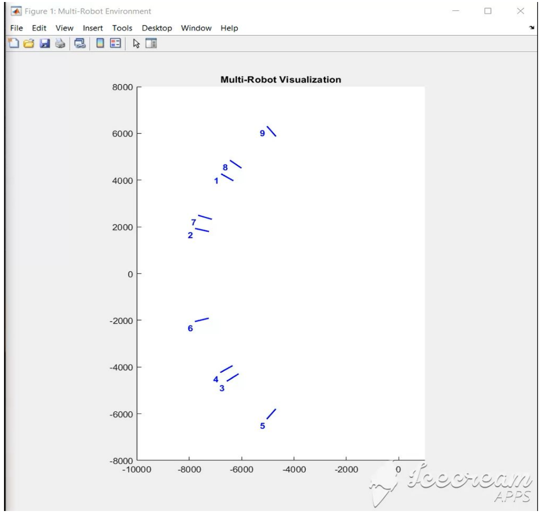
SWARM COMMUNICATION

Upon several studies the dispersion behaviour was chosen for implementation of swarm on the moon. This behaviour can maximise the exploration area at the moon. Among its advantages are concurrent execution of subtasks in task-decomposable application domains, robustness against system failure, scalability, flexibility in adapting to a different domain through reconfiguration, and cost effectiveness.

As you can see in the screenshots, the behavior was modelled in MATLAB using robotics toolbox.



Picture credits: Asvanth



Picture credits: Asvanth

Subsystem - Compute Module

Modern Day CPU

(>)[1] Billion

TI - 74

>>

Saturn V and Apollo Computers

Source : Internet

Subsystem - Compute Module

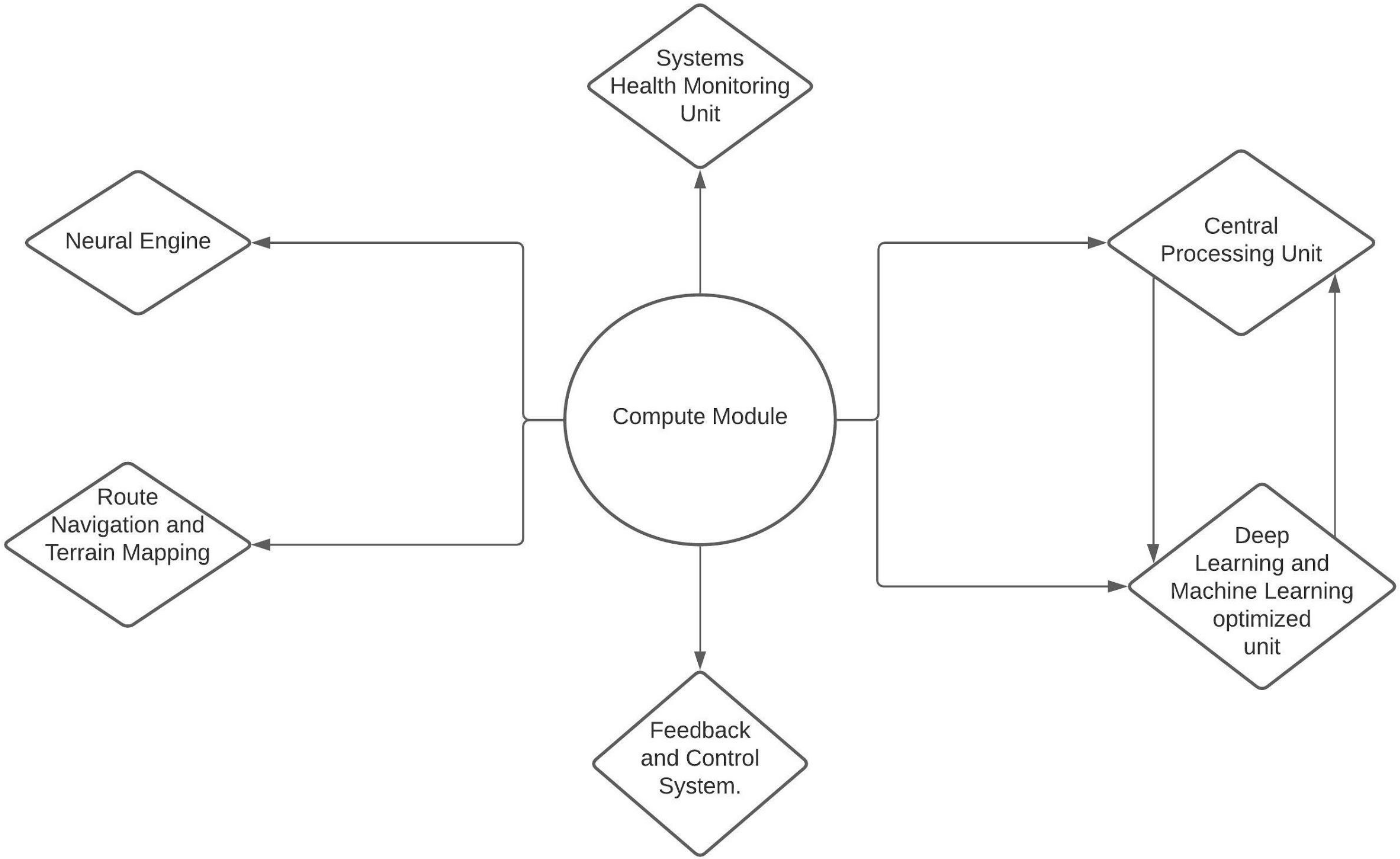
Objective

- To utilize the potential of today's computing power to the lunar rovers to perform complex analysis and experiment on the moon which has been never done before.
- Implementing autonomous navigation among the main rover and among the swarms.
- Performing in-situ experiments like soil analysis and lunar rock analysis.

Why on-board computing?

- A 1.25s time lag does not allow split second decisions to take place.
- Rough terrain can be handled better if on board decision making takes place.
- Reducing possible human errors by automating movements and actions.

Subsystem - Compute Module



Subsystem - Compute Module

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All our SoCs in the main as well as swarm rovers are **radiation hardened**.

Central Processing Unit

- **700 MHz** primary CPU coupled with **400 MHz** CPU for parallel processing
- Above unit is paired with a **300 MHz** CPU for redundancy.
- For **Main Rover**: **4GB** of flash memory paired with **512MB** of DRAM of shared memory
  For **Swarm Rovers**: **2GB** of flash memory coupled with **256MB** of DRAM of shared memory.

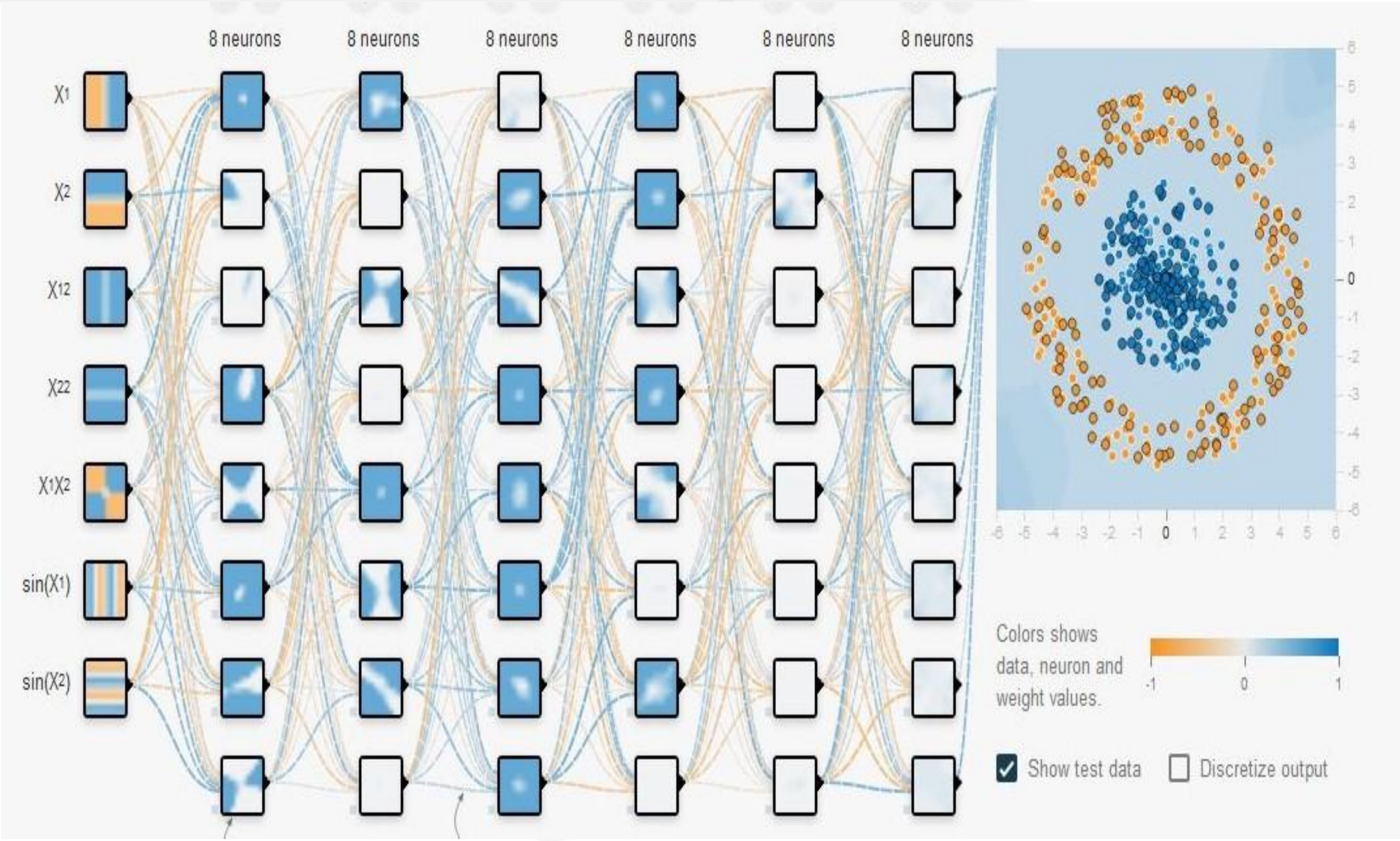
Smart Computing Unit

- Smartly assigns tasks to all compute model components and to the swarm rovers.
- Redirects power to components under load and shares processing load among various components.

Deep Learning and Machine Learning Unit

- Has **250 MHz** processing unit coupled with **1GB** of RAM.
- Optimised for Deep Learning and Machine Learning tasks for soil analysis.

Subsystem - Compute Module



The size of the activation layer is 336.

Credits : Srinivas and Siddhaanth

Subsystem - Compute Module

Neural Engine

- Responsible for improving image and video quality of the rovers.
- Also responsible to increase efficiency of soil analysis.

System Health Monitoring Unit

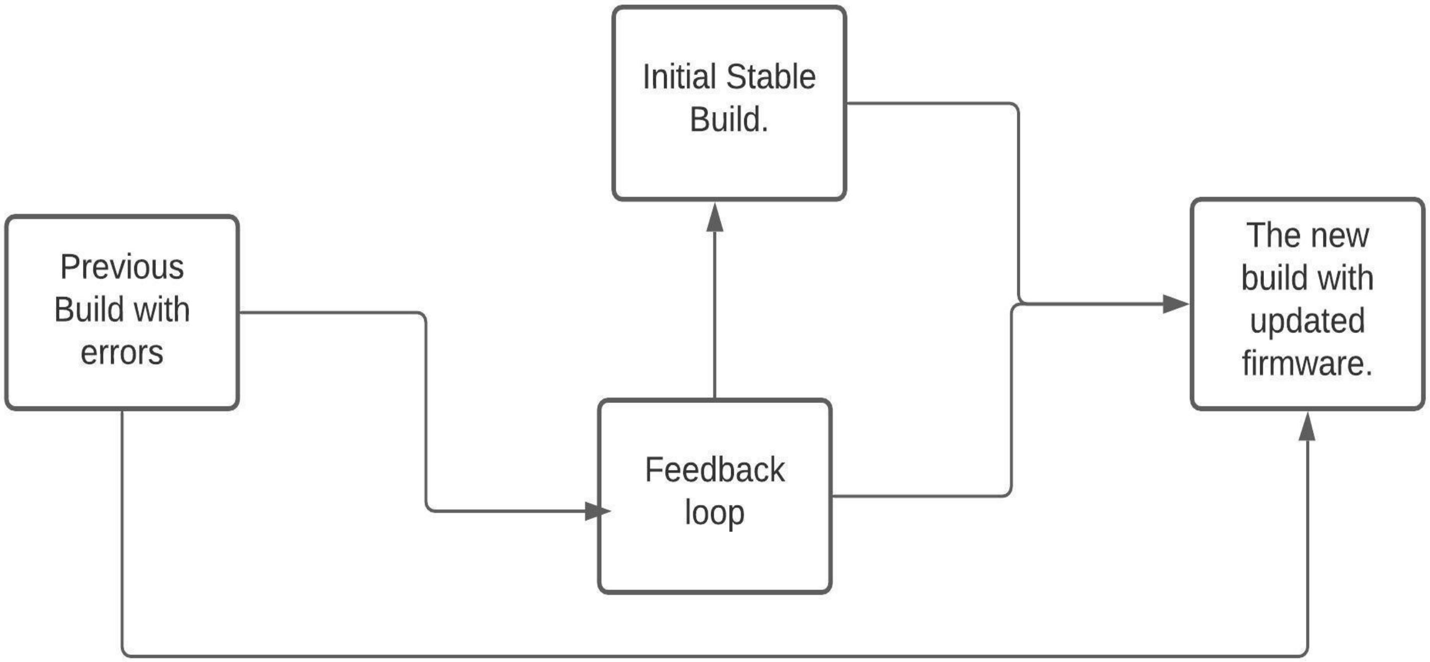
- Monitors the health of the rover under periodic time intervals.
- Checks status of all rover components and instruments.
- Performs a continuous chain of rigorous tests for each and every component.

Feedback and Control System

- Works with the Health Monitoring Unit to analyse results and correct any malfunctioning systems.
- Unit will be running in continuous loops under various arguments for getting optimized results - a feedback loop.

Subsystem - Compute Module

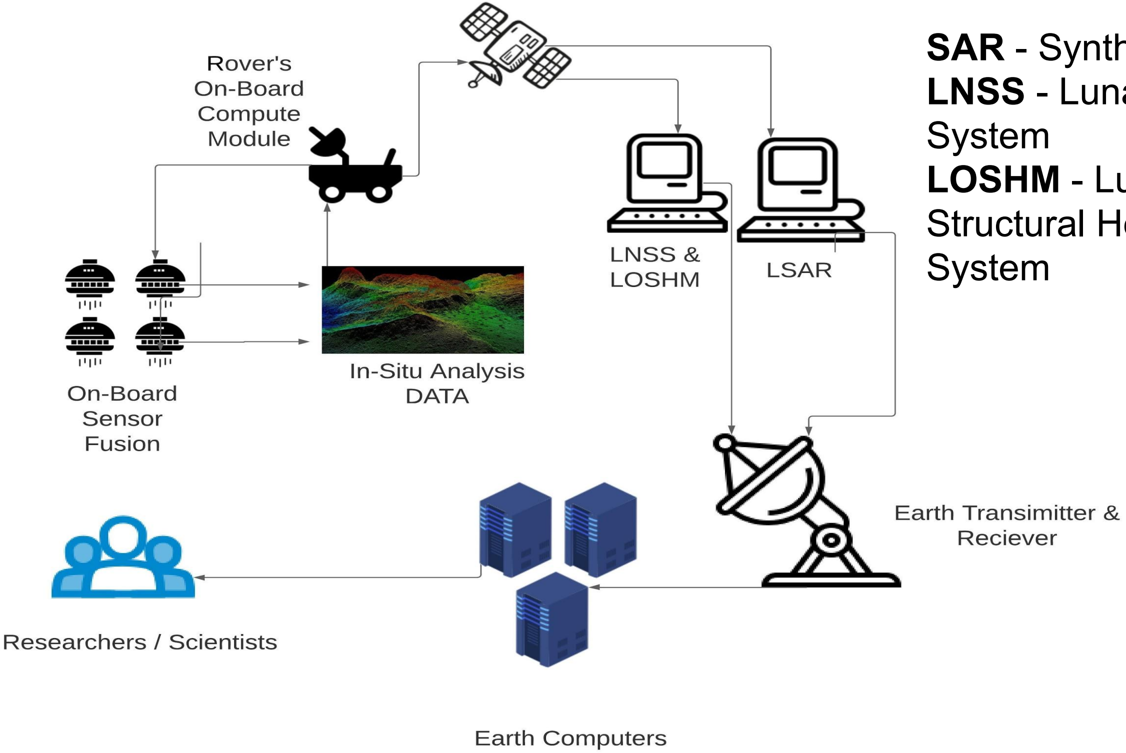
Feedback and Systems Health Monitoring Unit.



Credits : Srinivas and Siddhaanth

Subsystem - Compute Module

Working of the Rovers

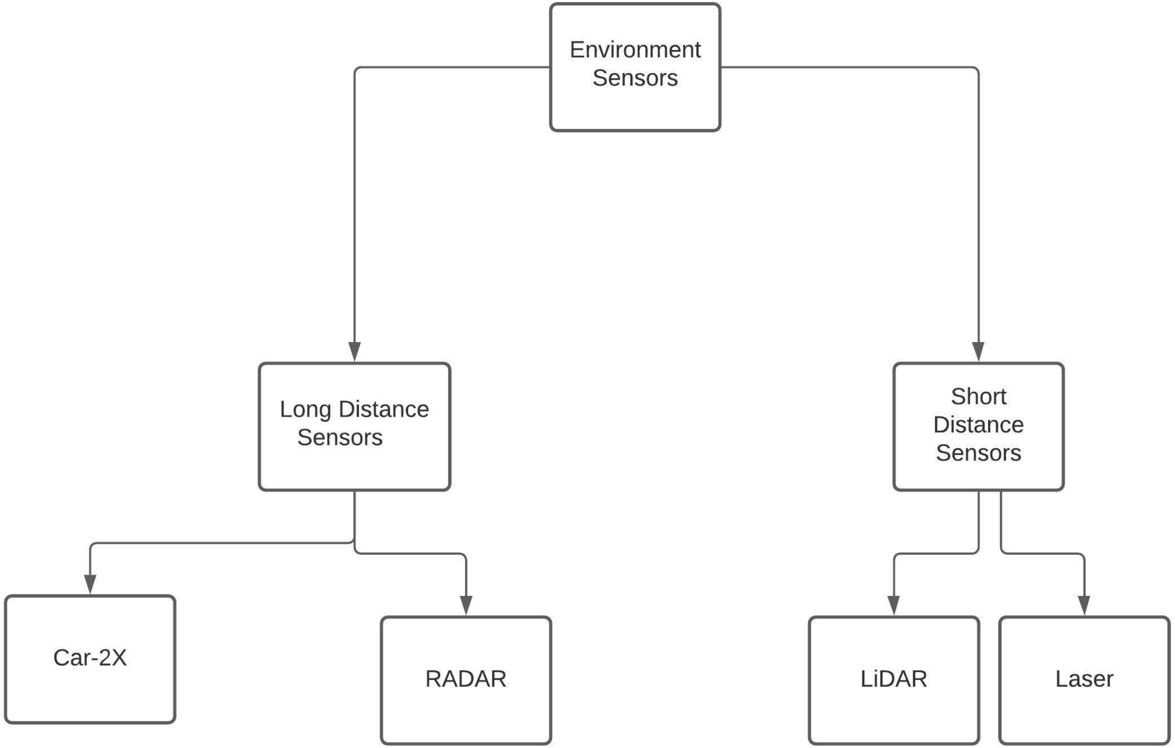


SAR - Synthetic Aperture Radar
LNSS - Lunar Navigation Satellite System
LOSHM - Lunar Observation for Structural Health Monitoring System

Credits: Srinivas and

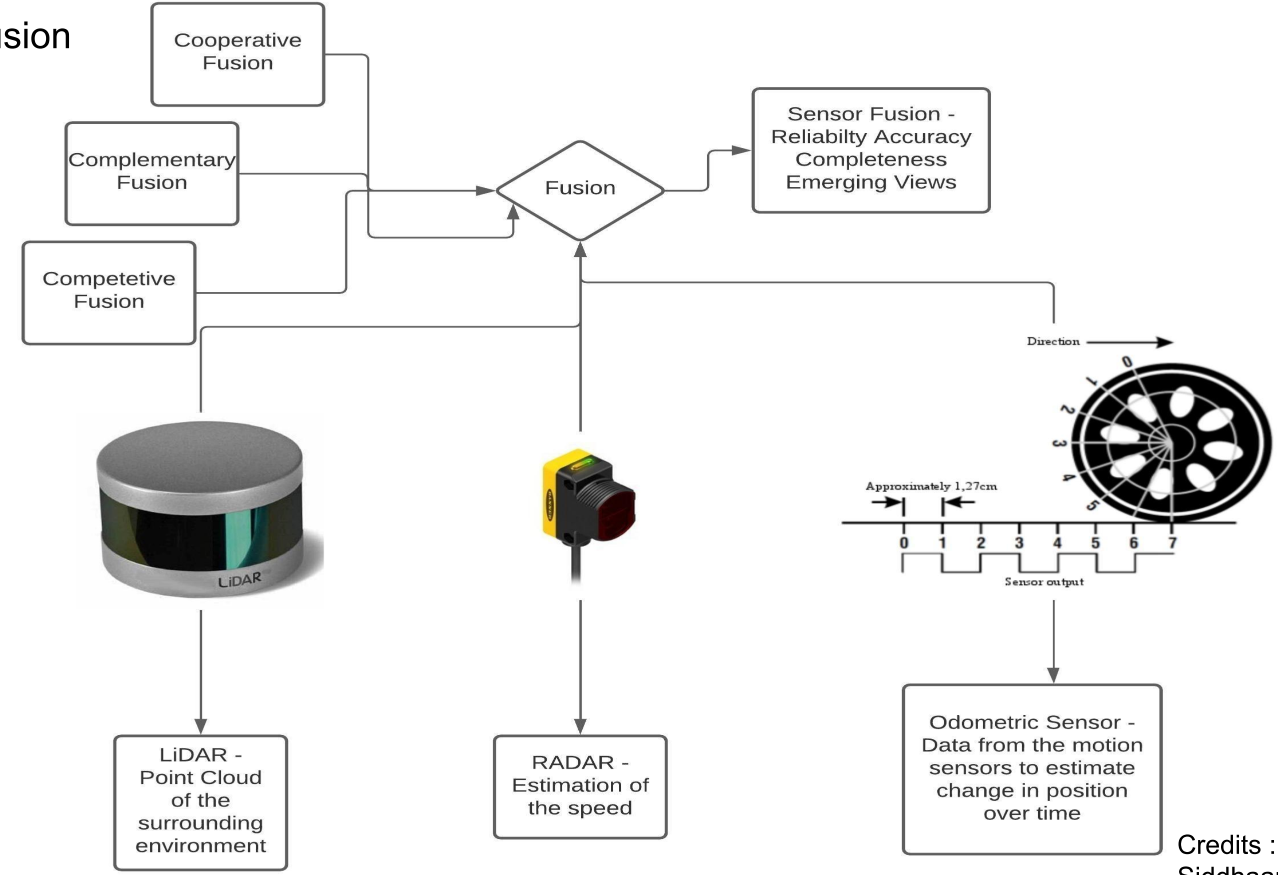
Subsystem - Compute Module

Autonomous Navigation and Terrain Mapping Unit.



Subsystem - Compute Module

Sensor Fusion



Credits : Srinivas and Siddhaanth

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OBJECTIVE

- To supply power to the swarm rover mechanism on the lunar surface wirelessly from a cube satellite.

BASIC PRINCIPLE OF WPT

- Power transmission through electromagnetic wave propagation.
- Two categories based on range of transmission
  - Near/Reactive field
  - Far/Radiative field (if $R \geq 2L^2 / \lambda$)
- Power beaming technique using microwave and laser.
- Power and efficiency calculation using **Friis equation**,

$$P_R = \lambda^2 G_R G_T / (4\pi D)^2 = A_R A_T P_T / (\lambda D)^2$$

$$\eta = 1 - e^{-(\tau^2)} \text{ where, } \tau^2 = A_T A_R / (\lambda D)^2$$

Subsystem - Communication (WPT)

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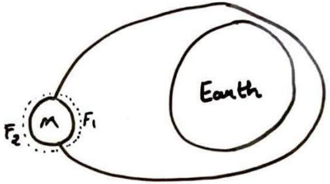
Cube Satellite Orbital Calculation:

- F_1 persists for the complete Moon Orbital Time Period $T_M = 27.322$ days

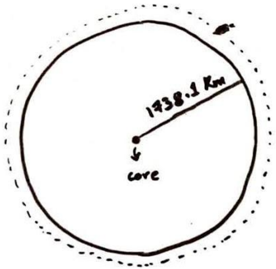
Hence Rotation $r_o = T_m$ [Due to earth gravitation the F_1 is tidally locked]



F_1 = near View

F_2 = Far View.

* Gravitational force $g_m = 1.62\ m/s^2$; * Mass $M_m = 7.35 \times 10^{22}$ Kg



Radius $R_m = 1{,}738.1$ Km [Equitorial Radius]

Rotational Time Period $\Rightarrow r_{om} = 27.3$ days. $= 655.2$ hours

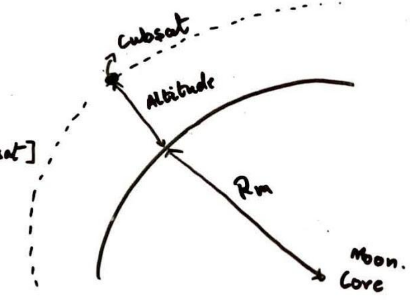
Semi-Major Axis $\Rightarrow a_m = 3.844 \times 10^8$ m

Universal Gravitational Constant $= G = 6.67 \times 10^{-11}\ N \cdot m^2/Kg^2$

$F_1 \Rightarrow$ Visible face for total time period T_M

$F_1 \nRightarrow \infty$ face visibility.

$F_g = ma_c \Rightarrow [a_c = r\omega^2] \Rightarrow F_g = mr\omega^2$ [ω = Angular Velocity of Cubsat]



$$\Rightarrow \omega = \frac{\text{change in Angular Position}}{\text{Change in Time}} = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T_m} = \frac{2\pi}{655.2} \times \frac{1}{(3600)} = 2.663811435 \times 10^{-6} \text{ rad/sec}$$

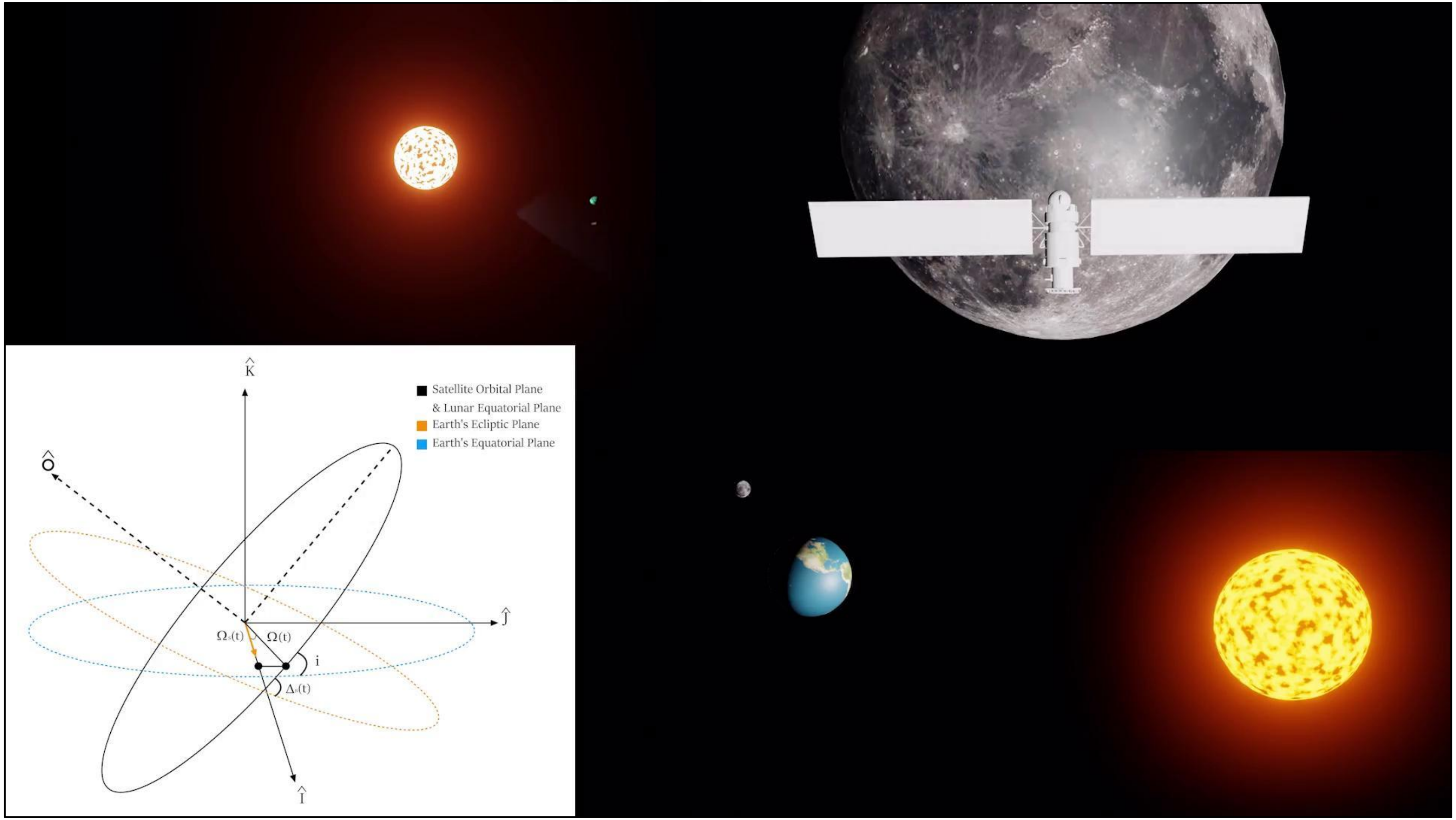
$$\therefore \frac{G M_m m_s}{r^2} = \cancel{m_s} r \omega^2 \Rightarrow r = \sqrt[3]{\frac{G M_m}{\omega^2}} = \sqrt[3]{\frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{2.663811435 \times 10^{-6}}} = 88403353.2 \text{ m} = 88403.3532 \text{ Km}$$

[m_s = Cubsat mass]

$$\text{Altitude} = r - R_m = 88403.3532 - 1738.1 = \underline{\underline{86{,}665.2532 \text{ Km}}}$$

Subsystem - Communication (WPT)

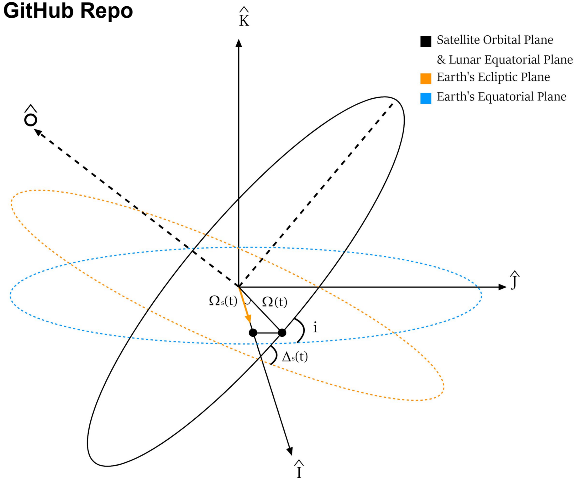
Cube Satellite 3D Simulation:



Subsystem - Communication (WPT)

GitHub Repo

Cube Satellite Beta Angle Calculations:



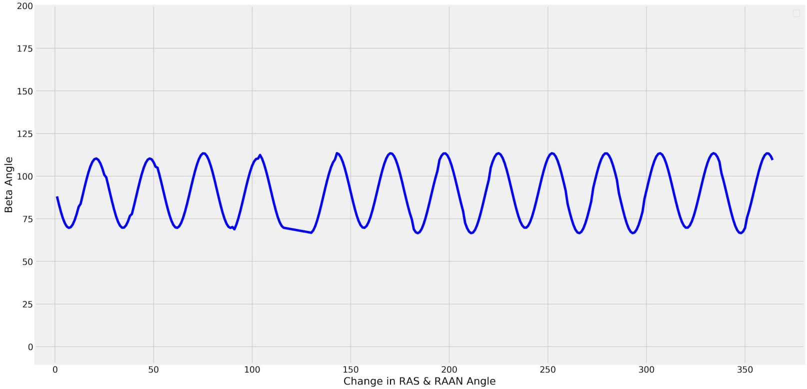
Satellite class to compute Beta Angle

In [3]:
```
class Satellite:
  def __str__(Self):
    return 'Enter the necessary parameter of the satellite.\n Various parameters must be given in degrees '
  def __init__(self):
    self.Gaama_st = 0
    self.Inclination = 0
    self.Omega_t = 0
    self.Omega_st = 0
  def BetaAngle(self):
    Beta = math.asin((math.cos(math.radians(self.Gaama_st))*math.sin(math.radians(self.Inclination))*math.sin(math.radians((self.Omega_t-
self.Omega_st))))+(math.sin(math.radians(self.Gaama_st))*math.cos(math.radians(self.Inclination))))
    if Beta<0:
      ans = abs(Beta+1.570796327)*(180/np.pi)
      return ans
      # print(str(Beta+1.570796327)+' Degrees')
      # print(str(ans)+' Radians')
    elif Beta>=0:
      ans = (Beta)*(180/np.pi)
      return ans
      # print(str(Beta)+' Degrees')
      # print(str(ans)+' Radians')
```

In [4]:
```
#Parameters for calculating Beta Angle

satellite = Satellite()

satellite.Gaama_st = -1.548      #Angle of declination of Sun
satellite.Inclination = 21.902 #Angle of Inclinaton of orbit with respect to Equatorial plane of Earth
satellite.Omega_t = 4.308      #Right Ascension of Ascending Node (RAAN)
satellite.Omega_st = 0         #Right Ascension of Sun
```



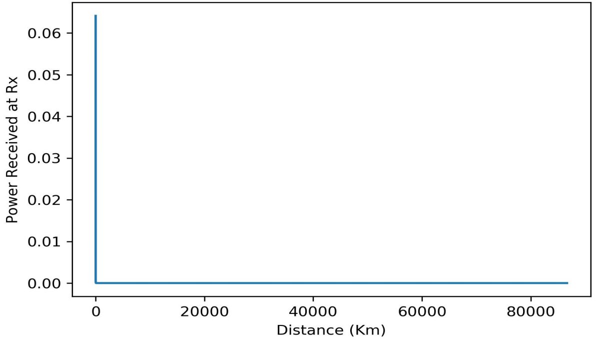
Calculating the positive half-cycle and the negative half-cycle of the orbit

In [5]:
```
halfdays = []
for i in range(1,366):
    if i%13==0:
        halfdays.append(i)
halfdays.insert(0,1)
len(halfdays)
```

Out[5]: 29

FUNDAMENTAL CONSTRAINTS

- Transparency of the atmosphere to the used wavelength
- Possibility for directional emission
- Possibility to convert the energy from the form of its source (solar, electric, heat) to a transmittable form (e.g. microwave, laser, acoustic)
- Possibility to convert the transmittable energy form back into a useful form of energy (e.g. electricity, hydrogen).



LPT(Laser Power Transmission)

- High intensity laser power beam for directional transmission with smaller aperture.
- Conversion using photovoltaic cells (Si) at the receiving end.

Subsystem - Communication (WPT)

CHAAND

Collective Hive of Advanced Autonomous Navigation & Design

LIMITATIONS

- This is a budding mechanism which needs a lot of research and development to achieve required goals
- Excavation Equipment needs extra power in addition to the power for basic functions of the rover.

FUTURE SCOPE

- Important field of research
- Sustainable source of energy
- SBSP (Space Based solar power), UAVs (Unmanned aerial vehicles), Household power distribution, etc.

Future Prospects

- Setting up a 3D printing hub for building.
- Extracting water ice from the lunar surface.
- Using said water ice for growing plants, extracting hydrogen for rocket fuel and oxygen for breathing.
- Extracting useful minerals and elements to build a thriving 'CHAAND City'.

Source: Internet

Vote of Thanks

A huge vote of thanks to the administration team of **SSERD** who gave us the opportunity to come together as a team and work for a period of forty one days.

Thank you for all the assistance especially **Pavan Kumar** who was ready to mentor us whenever we needed guidance and **Prateek Boga** who was an amazing coordinator.