University of Southern California

RASC-AL 2023: Multiuse Platform at L1

Satellite Base At Lagrange 1: SBAL-1

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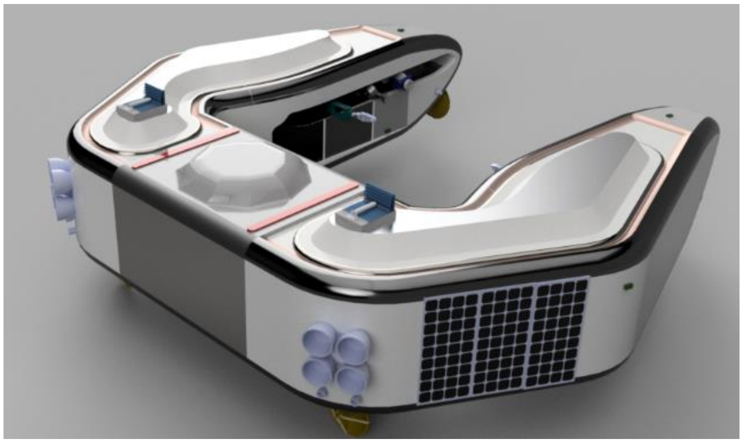
Multi-use Platform at L-1:
Satellite Base at Lagrange – 1

Mission

Dimensions: 7x7x1.5 m (L x B x H)
Weight: 507 kg

The satellite base at Lagrange aims at providing reliable and constant repair and upgradations to satellites in the cis-lunar space. The Lagrange 1 point being stable supports the base like structure and allows restricted movements about the yaw and pitch. Being the only such entity in the cis-lunar space SBAL-1 aims at improving efficiency of existing satellites and increasing the lifetime of satellites.

CAD



Objectives

1. An innovative satellite base that provides services to cis-lunar space satellites.
2. Inspection for external damage
3. Repair external damage.
4. Refuel existing satellites with required type of fuel.
5. Replace/Upgrade internal components of existing satellites.
6. Reduce cost of launch of large satellites by providing an intermediate stop to fill partial fuel and mount components externally.

Key Innovative Design Aspects

1. Using functioning parts of EoL satellites for new and functioning satellites.
2. Ability to act as a intermediate station for heavy satellites.
3. Designed after studying, fuel needs, dimensions and sensors existing in cis-lunar space.

Schedule

June ’23 - Approval by stakeholders
Dec ’25 – SRR
Dec ’29 – CDR
April ’32 – Precursor Mission Launch
April ‘35 – Main Mission Launch
June ’35 – Servicing Starts
June ’45 – Scheduled system check
July ’50 – End of Life

Cost

Development & Manufacturing Costs: $102 million
Estimated Cost during Lifetime: $180 million
Estimated Cost per ton of propellants: $ 1.0-1.2 m/t

1. Mission Summary


Figure 1: System Overview

Our mission on Satellite Base at Lagrange1 (SBAL-1) aims at refueling, repairing and upgrading satellites in the cis-lunar space. The platform weighing 507 kg and having dimension 7 x 7 x 1.5 m floats at the L1 Lagrange point to carry out its functions. Existing satellites in the cis-lunar space including LunIR, Themis, Danuri as well as future satellites would benefit from SBAL-1. SBAL-1 will include supplemental fuels such as Monoprop and cold gas thrusters, Hydrazine, Water steam in quantities proportional to the needs of expected satellites. Given that SBAL-1 will use different thrusters like RCS, cold gas thruster, electrodeless plasma thruster; these fuels would also help fuel these various thrusters to help in Attitude and Orbital Control. The platform at Lagrange communicates with the assisted satellite for repair using 'S' band frequency antennas. Simultaneously, it also communicates this information of the ground station using 'Ku' band frequency. The SBAL-1 is equipped with a camera for inspecting exterior of satellites coming for servicing. The range of camera 10m helps closely observe the satellite for physical damage and anomalies from different angles. SBAL-1 is also capable of dismantling and storing useful functioning components of satellites reaching their end of life. This helps to accumulate spare components that may be required for replacing components on other satellites during future repair. The SBAL-1 reduces cost of launch for heavy satellites by providing means to mount few common components into the satellite and providing supplementary fuel.

2. Stakeholders:

The mission of the RASAC-AL 2023 is to have a satellite base in the Lagrange 1 point that is capable of repairing and refueling the satellites. The problem statement itself gives us an idea of who can become a possible stakeholder. Satellites that are currently orbiting or have an intent to orbit in the cislunar space, satellites that are going far beyond the lagrange1 can use this base for refueling, Space exploration missions that plan on combining certain parts of satellite in space can use the base for storing and connecting parts. Current non-functioning satellites with working systems that can be removed and reused can also be considered as stakeholders

3. System Introduction:

SBAL-1 structure allows client satellite to dock itself in such a way that the accessibility of client satellite is higher. The satellite is oriented such that the solar panels protrude along the vertical axis of the satellite base. Robotics links with a 2 Degree of Freedom (DOF) then enter the space in between and repair the damages as per the communicated information as well as the data collected upon inspection by external cameras. The system comprises of 4 such links that have different end effectors attached based on the type of repair that each of them perform. A communication link is established between SBAL-1 and client satellite to share information regarding the damages and the upgrades made to the system for future reference. SBAL-1 is also constantly communicating with Earth at a different frequency that does not interfere with the client satellite communication. After servicing the client satellite, it is attached to the repositioning mechanism. This mechanism provides initial torque and momentum to the satellite to place it back into its orbit.

The mission aims at providing various in-space satellite servicing to update and upgrade satellites. The various services include:

A. Refueling satellites
B. Repairing damages
C. Way-point for big satellites
D. Dismantling satellites
E. Inspection and details

These services are described in detail in the fourth-coming sections of this proposal. The Figure below depicts SBAL-1 servicing a GPS satellite. The purpose of Satellite is to navigate in the cis-lunar space. Assuming a damage in transponder system. SBAL-1 is showing the servicing for replacing the faulty component. The payload for such a satellite is the navigation system. As we can observe in Fig 2a., the GPS satellite is approaching the satellite base. While it is approaching, SBAL-1 inspects the satellite for any external damages. It is then docked a t the docking station along the central axis. The end effectors then extend to perform necessary repairs which are described in detail in the later scope of this proposal. After the servicing is completed, the satellite is provided with calculated torque based on its dimensions, weight and destination orbit distance from L1 point.

Figure 2a: Incoming GPS satellite

Figure 2b: Docked satellite

Figure 2c: Re-inserting satellite into its original orbit to reduce fuel used.

4. Services offered at by SBAL-1

4.1. Refueling Satellites:

The platform contains various types of fuels used for different thrusters. The fuels included on the satellite include, water steam, solid iodine propellant, hydrazine and mono propellant hydrazine. Since the SBAL-1 also contains various types if thrusters to maintain its position at L1 point it also uses these fuels on board. After the satellite has been refueled it is then launched towards its defined orbit. The mechanism provides an inertia to the satellite to the so that it does not have to use its fuel to reach its orbit. The mechanism to place the satellite into the orbits is a circular rotating disk. The satellite attaches itself to the disk after servicing using the attachments. The internal gear mechanism provides the requires torque to launch the satellite based on its weight, size and destination orbit. The platform has the ability to move about its yaw for efficient placement into the orbit. Table [1] shows the existing satellites in cis-lunar space and their respective dimensions.

Table 1: Cis-Lunar Satellites and Dimensions

Sr. No	Name	Dimensions
1	Argo Moon	12cm x 24cm x 36cm
2	Capstone	34 x 34 x 64cm
3	**Chandrayaan - 2**	**3.2 x 5.8 x 2.2 m**
4	**Danuri**	**3.18 x 6.3 x 2.67 m**
5	Equuleus	10cm x 20cm x 30cm
6	Lunar Ice Cube	10cm x 20cm x 30cm
7	Lunar Polar Hydrogen Mapper	10cm x 20cm x 30cm
8	Lunar Reconnaissance Orbiter	390 cm x 270 cm x 260 cm
9	LunIR	10cm x 20cm x 30cm
10	Themis	

The design comprising of a 4m hollow space in the center allows client satellite to orient themselves for repair and servicing. The gap between the satellite and the inner side of satellite base is utilized by rods that slide out of SBAL-1 for repair.

4.2.Repairing damages:

Based on data we collected on existing satellites and system requirements the SBAL-1 is designed to perform repairs such as replacing components. Table [] gives detailed information about the purpose of the current cis-lunar satellites. Based on the data collected the tentative components that affect the payload include the transponder subsystem for Capstone satellite. These components include PCBs for communication system, transponder system which includes multiplexer, modulators, frequency translator, etc. It would be capable of welding any external damages made to the satellite. Similarly, cameras used for observing various parameters in the cis-lunar space for different satellites such as Argo Moon and Danuri, hydrogen sensors used on Lunar Polar Hydrogen Mapper, radiation measurement used on Equuelus, etc. The table below represents the existing satellites in the cis-lunar space and their purpose.

Table 2: CisLunar Satellites with their purpose

Sr. No	Cis-Lunar Satellite	Purpose
1	Argo Moon	Imaging satellite used to observe CubeSat and perform proximity maneuvers in deep space.
2	Capstone	Used for communication based applications and as a base for rovers
3	Chandrayaan - 2	Used to study the surface of the moon and determine the presence of water.
4	Danuri	Observe Lunar resources and lunar geology
5	Equuleus	To measure distribution of plasma around the Earth and conduct several lunar flybys within the Earth-Moon Region
6	Lunar Ice Cube	The science goals are to investigate the distribution of water and other volatiles, as a function of time of day, latitude, and lunar soil composition.
7	Lunar Polar Hydrogen Mapper	LunaH-Map's maps hydrogen upto 1 m below surface lunar south pole.
8	Lunar Reconnaissance Orbiter	Mapping of safe landing sites, tentative resources to be found on moon and observing the radiation environment on and around the Moon.

4.3.Waypoint for large satellites:

Being a repair and refueling station for existing satellites the SBAL is equipped with technologies that allow it to join various satellites parts. For this reason, it can as a joining station and docking station for large satellites that can be joined in space. It can also be used as a refueling station for long distance travelling satellites. This in turn can reduce satellite launching costs by reducing the weight of carrier vehicle.

4.4.Repurposing of nonfunctional satellites:

Often, satellites that have reached their End-Of-Life contain functioning sensors and other components. SBAL-1 has the necessary technology to take these functioning parts of satellites, store them and later repurpose them for other satellites.
For example: Argo moon will soon reach its End of Life. SBAL-1 can take the working parts of Argo Moon such as cameras, proximity sensors, etc. and store them. These parts can be used when any other satellite that comes for servicing has a requirement of any of these parts.

4.5.Inspection and details:

SBAL-1 provides inspection facilities to satellites. Satellites can pass through SBAL to have their external structure checked. There are 6 cameras placed along different angles along the inner trail of SBAL that are capable of taking high resolution pictures of satellites with low noise. Through communication between the satellite and the base, assessment and replacement of satellite's interior parts can be done.

5. Sub system Overview:

The detailed outline of the subsystems used to make SBAL efficient and effective to perform all its tasks are shown in the Fig 4 below:

5.1.Observation and Communication:

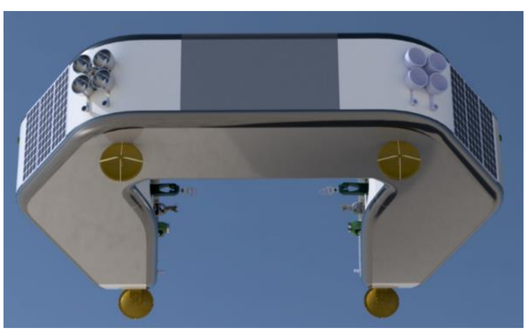


Figure 3a: Antennas to communicate with Ground Station operating in Ku band

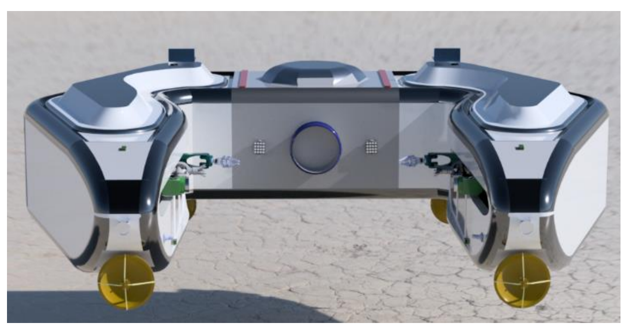


Figure 3b: Antennas to communicate with client satellite operating in C band.

The subsystem focusses on establishing stable and constant communication with Earth Ground Station. It also allows communication of the client satellite incoming for repair to communicate with SBAL-1. The frequencies of communication are tabulated below:

Table 3: Antenna Frequencies

Sr. No.	Communicating w.r.t SBAL	Frequency
1	Upstream communication to Earth	14.0-14.5GHz(Ku Band)
2	Downstream Communication from Earth	11.70-12.20 GHz(Ku Band)
3	Upstream Communication with client	5.9 -6.4 GHz(C band)
4	Downstream Communication with client	3.7-4.2 GHz(C band)

As we can observe in Fig [], the satellite base station comprises on 4 different antennas operating at 2 pairs of upstream and downstream frequency. One pair is dedicated for in-space communication between SBAL-1 and the client satellite approaching the base for service. The other pair of antennas are used.

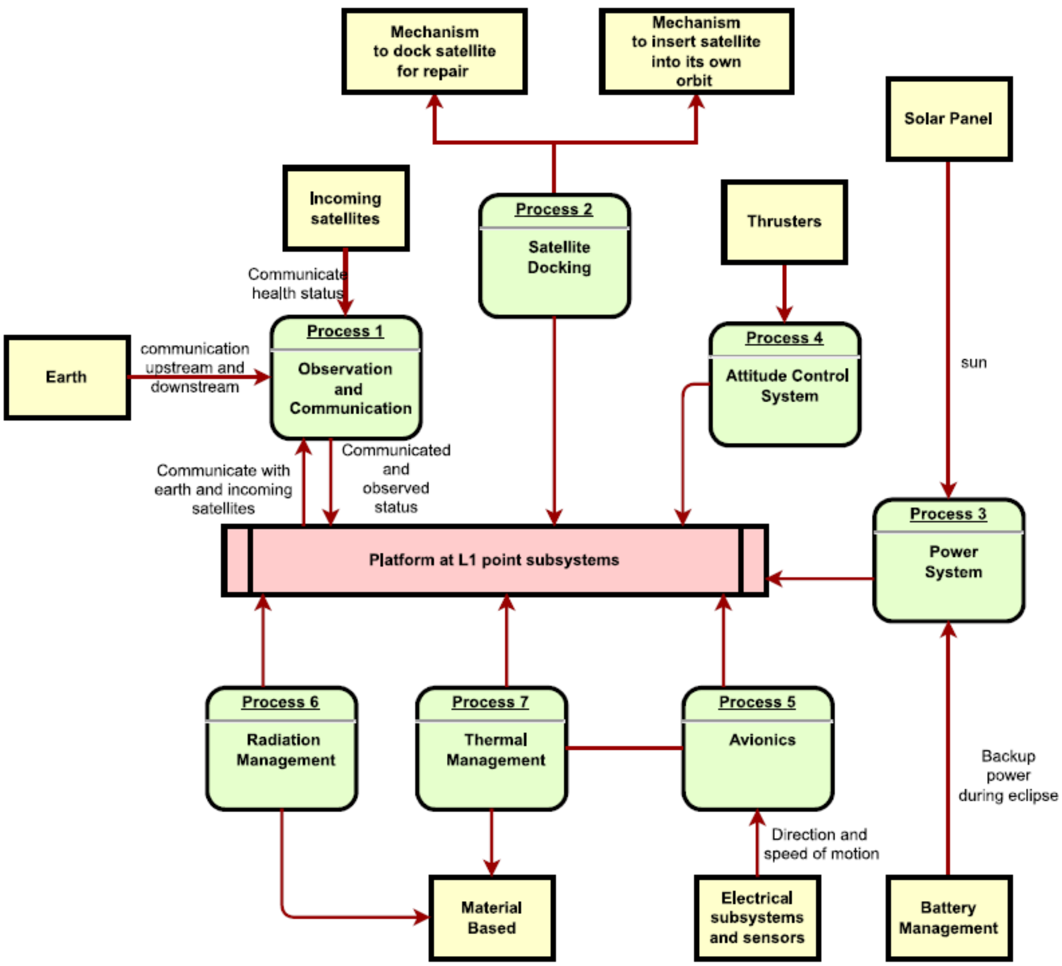


Figure 4: Subsystem Overview

5.2.Satellite Docking:

SBAL has provision to hold satellite in position(dock) while being serviced. After the service is complete it will provide inertia to the satellite such that it can be placed back into its orbit. For this purpose we have designed a circular vacuum grip that hold the client for repair and refueling. It then rotates about its pitch to provide torque and momentum in the direction of the clients orbit to place it into the orbit with minimal use of satellite fuel.

Figure 5a: End Effectors

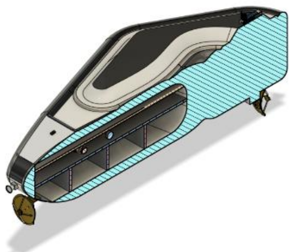


Figure 5b: Internal comparts for fuels

5.3.Power System:

Given that the SBAL-1 is situated at Lagrange 1 point. It is direct line of sight of the Sun. It does not face any issues due to obstruction or eclipse. However, as a safe back-up we have a battery back along with solar panels. Based on the weight, size and sensors requirements the size of solar panels is calculated as follows:

The system requirement is assumed as 1100 W based on power rating of the sensors and actuators present in the system

We know that,

Power = и*Solar Intensity*Solar Irradiance*Effective Area

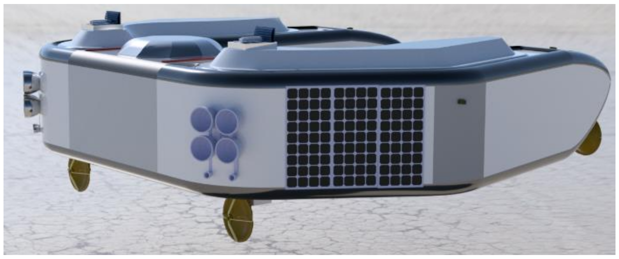


Figure 6: Solar Panels

Where: и = efficiency; Solar Intensity = 0 or 1; Solar Irradiance = in W/m^2 ;Effective Area = measured in m^2

Now, for Lagrange 1 point:

$$I = \frac{P}{4*pi*r^2} \text{ in W/m}^2$$

Here r = radius of the sun

Total Solar Radiance (I) = 1360.8 W/m^2; Radius of the sun = 696347.055 km;

Power from the Sun core = 3.86*10^{26} W

Therefore, Intensity at surface r is:

$$I = \frac{3.86*10^{26}}{4*3.14*696347.055^2} \text{ in W/m}^2$$

Using the above relations, the intensity at L1 point can be calculated using Inverse Square Law; Intensity at L1(LI) is given by:

LI = $\frac{I}{45478}$. Hence; **LI = 1.3929 * 10^9 W/m^2**

At 1 AU; solar irradiance is 1360.8 W/m^2. Since L1 is at 0.99 Au solar irradiance is calculated as 1350.8 W/m^2. Efficiency of the silicon solar poly and mono crystalline = 16%

With an area of 6m^2; output power = 1296.8 W/m^2

Solar panels degrade and the efficiency drops over a period of time. Silicon crystalline solar panels retain 88% of the original performance after 15 years, **hence end of life efficiency is 24.6%**

Thus, Output power after 15 years = 1141.2 W.

To meet the above requirements the theoretically required area A is given as:

$$A = \frac{1141.2}{0.2*1350.8*1} = 4.22\ m^2$$

But, we have **chosen 6m^2 as the area of solar panels** to compensate poor solar efficiency and End of Life Degradation

5.4.Attitude and Orbital Control:

While communicating with the Telemetry Tracking and Command at the Ground Station, we are aware of the exact position of SBAL and if there are any deviations from Lagrange 1 point. Thrusters are used to set the base back in its original position.

Satellite gyroscope: To maintain the stability of the base we have chosen to use Microelectromechanical system Gyros. Microelectromechanical systems Gyros have tiny electrical and mechanical devices that are etched with silicon. Microelectromechanical system gyros have been used in past NASA project “Space Technology 6”. The gyroscope uses a 3 axis MEM’S assembly that incorporates tuning fork gyro sensors with mixed signal application specific integrated circuits. These gyro electronics are designed to operate with approximately 12 off-chip components at a power draw of 75mWatts. EMS assembly includes data acquisition electronics that will provide angular rate, temperature, and health and status data to the processor. These components are small in volume, mass, and have high resistance to radiation and vibration.

A. SAS (solar aspect sensor):

SAS has a field of view is approximately 60 degrees and it has a resolution of better than 0.1 degrees. The SAS is designed to be reliable and accurate in harsh space environments, and can withstand high levels of radiation. It has a mass of approximately 0.5 kg and consumes less than 2 watts of power. Its dimensions are 7.62 cm x 7.62 cm x 6.35 cm.

SAS works by measuring the position of the sun relative to the sensor's field of view. The SAS consists of a detector that receives light from the sun, and a processor that calculates the position of the sun based on the intensity of the light. The detector is typically a silicon photodiode or a photomultiplier tube, which converts incoming photons into electrical signals.

It also has a set of baffles and a pinhole that help to prevent stray light from entering the detector and interfering with the measurement. The baffles are designed to block light from sources other than the sun, while the pinhole limits the size of the field of view and helps to increase the accuracy of the measurement.

B. Satellite Proximity Sensor: It is used to know the proximity of other satellites we are going to use Geiger-mode Avalanche Photodiode (GmAPD) LiDAR sensor.

The Geiger-mode Avalanche Photodiode (GmAPD) LiDAR is a type of LiDAR sensor that utilizes a Geiger-mode avalanche photodiode detector to measure the time-of-flight of emitted laser pulses. This type of LiDAR is capable of producing high resolution 3D maps of the surrounding environment with high accuracy and precision. The GmAPD LiDAR typically operates in the near-infrared range of wavelengths (around 1.5 microns) and can achieve high range resolution (less than 10 centimeters) and high angular resolution (less than 0.1 degrees).

The GmAPD LiDAR typically consists of a laser transmitter, a receiver telescope, and a detection unit. The laser transmitter emits a series of short laser pulses towards the target area, and the receiver telescope collects the reflected light from the target. The detection unit then processes the received signal to determine the time-of-flight of each laser pulse, which can be used to calculate the distance to the target. The GmAPD detector used in this type of LiDAR is able to detect single photons with high efficiency, allowing for high sensitivity and low noise performance.

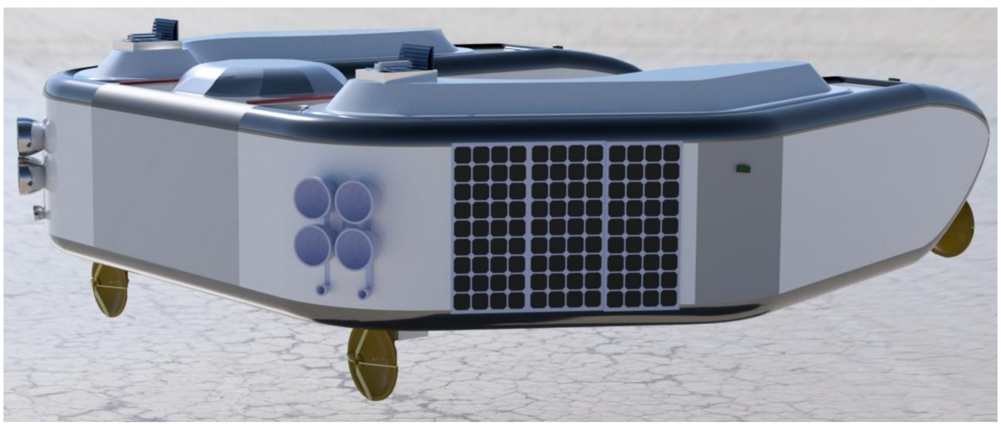


Figure 7: RCS Thrusters

5.5.Avionics:

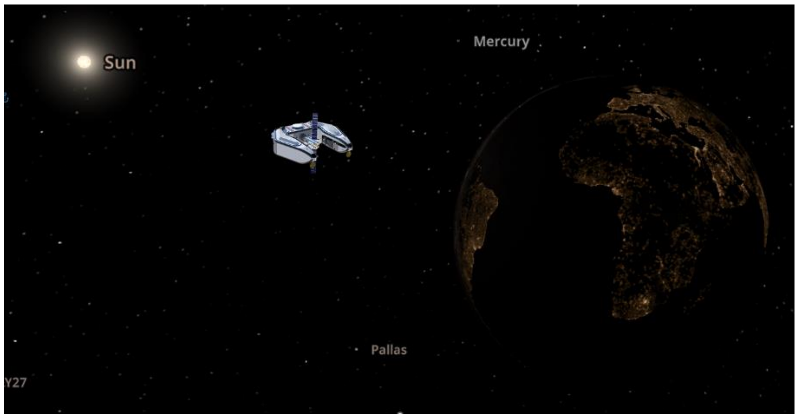
SBAL performs several motions such as avoiding collisions from debris in space, re-inserting client satellites into their orbits, etc. The avionics subsystem calculates the required amount of speed and torque required to move the SBAL in space.

5.6.Radiation Subsystem:

The radiation subsystem is responsible for protecting the satellite base and its components from the harmful effects of radiation in space. This can include both cosmic radiation and radiation from the sun, which can cause damage to sensitive electronics and other systems on the spacecraft. To address this challenge, the radiation subsystem typically includes a number of components, such as radiation shielding and monitoring systems, as well as redundancy in critical systems to ensure that the base can continue to operate even if some systems are impacted by radiation exposure. To minimize the radiation, Kevlar coating is going to be applied on the base.

5.7.Thermal Subsystem:

The thermal subsystem is responsible for managing the temperature of the satellite base, which can be challenging due to the extreme temperature fluctuations that occur in space. To address this challenge, the thermal subsystem typically includes a number of components, such as insulation and heaters, as well as temperature sensors and control systems. These components work together to maintain the temperature of the spacecraft within a safe and stable range, which helps to ensure that critical systems and components are able to function effectively. To maintain an ambient temperature for sensors to function properly with minimal damage a mixture of thermal sensors and heat sensors are going to be used.



SBAL-1 placed in space simulation

6. Sensors:

The SBAL-1 contains the following standard sensors. The description and specifications for each of them is briefly described below:

Imaging Sensors: The satellite Base should be capable knowing what's wrong with the satellites that are approaching it. Having high resolution multiple imaging sensors is key to knowing what exactly needs to be repaired or replaced. To achieve this goal we are using tow high resolution imaging sensors CCD55-20 and Gecko Imager.

CCD55-20: The CCD55-20 has a resolution of 2048 x 2048 pixels, which allows for high-quality imaging of a wide range of targets. It also has a high quantum efficiency, which means that it is highly sensitive to light, making it ideal for low-light imaging applications. it has a wide operating temperature range, which allows it to function effectively in extreme temperatures. It is also designed to be radiation-hardened, which means that it can withstand exposure to high levels of radiation without experiencing degradation in performance.

Other specifications of the CCD55-20 include its pixel size, which is 12 microns x 12 microns, and its full well capacity, which is 130,000 electrons. These specifications help to ensure that the sensor is able to capture high-quality images with a high level of detail and accuracy.

Gecko Imager: The Gecko imager is capable of capturing images with a resolution of up to 4K.The imager features a high signal-to-noise ratio, with values ranging from 50dB to 66dB depending on the imaging mode.The imager is designed to be radiation-hardened, with a radiation tolerance of up to 100 krad(Si) for total ionizing dose and up to 100 MeV-cm²/mg for single-event effects.The imager has a wide dynamic range, with values ranging from 55dB to 85dB depending on the imaging mode.It also has a high frame rate, with values ranging from 30 frames per second (fps) to 120 fps depending on the imaging mode.It is also highly configurable, with a variety of options for controlling its imaging parameters such as gain, exposure time, and binning modes.

The sensor is used to detect the orientation and rotation of a satellite relative to a reference frame, such as the Earth's magnetic field or the position of the sun. These sensors are critical for maintaining the stability and accuracy of the satellite's instruments and navigation systems. For our satellite base we are going to use Solar Aspect Sensor

7. Cost:

Total Estimated Cost: $152 million

Development and Manufacturing Costs: Satellite Bus: $45 million Payload: $35 million Integration and Testing: $22 million	**Ground Infrastructure Costs:** Communication Equipment: $3 million Ground Station: $6 million Data Processing and Storage: $2 million
Launch Costs: Launch Vehicle: $22 million Pre-Launch transport: $4 million	**Operations and Maintenance Costs:** Personnel: $6 million Facilities and Equipment: $4 million Fuel and other maintenance: $3 million

8. Risk matrix

The system comprises of various sensors and several tons of fuel. In case of solar-storm we may face disruption in the communication system. This may include the communication link between SBAL-1 and the client satellite or the communication with earth. Moreover, collision with space debris does pose a threat to the system. To overcome this, the SBAL-1 is equipped with proximity sensors that will allow it to detect any incoming debris in its surrounding. On detection of such objects. The SBAL-1 will rotate about its axis to deviate its position away from collision with the use of thrusters.

1. Thruster anomaly. Mitigated by redundancy in attitude control systems (RCS, cold gas thruster, and electrodeless plasma thruster).
2. Communication anomaly. Mitigated with redundant antennas; Earth communication possible over S band.
3. Inspection camera failure. Mitigated with redundancy; six cameras available.
4. Mechanical anomaly of robotic arms. Mitigated with redundancy; four arms available.
5. Repositioning mechanism failure.
6. Refueling mechanism anomaly. Mitigated by using high-heritage robotic refueling technology demonstrated on the ISS [cite https://nexis.gsfc.nasa.gov/rrm_refueling_task.html]
7. Docking system failure.
8. Collision with space debris. Mitigated with proximity sensors and on-orbit detection and collision avoidance.
9. Solar Fare.

Table 4: Risk Matrix

Likelihood/Severity	Marginal	Moderate	Critical
Improbable		1,2,8	7
Possible		3,4	5,6
Probable	9		

9. Prototype:

The SBAL-1 after rigorous CAD designing was 3D printed at the 3D4E lab at the University of Southern California. Shown below is the various images captured while prototyping the design.

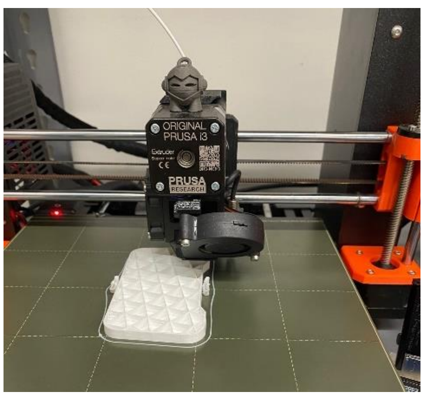


Figure: 3D printing the centre

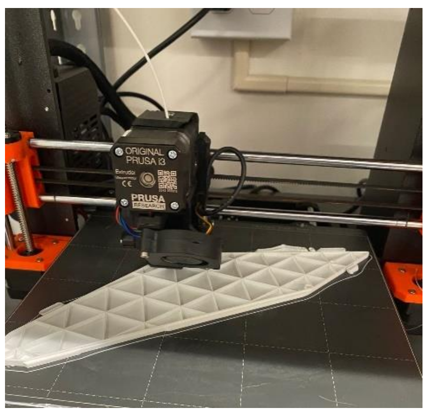


Figure: 3D printing SBAL-1 links

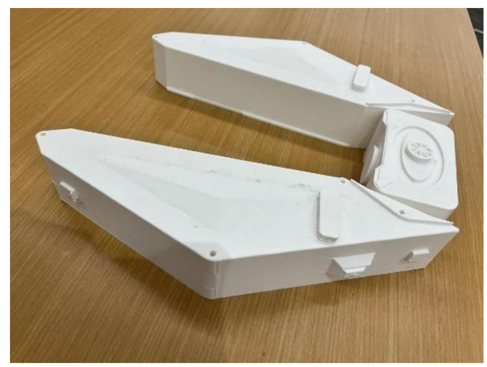


Figure: 3D printed prototype

10. Conclusion:

SBAL-1 is capable of performing in space missions from the year 2035 if we work as per schedule. The SBAL-1 provides a stable, sturdy, cost effective and innovative solution that help saving cost of launch and increasing lifetime of satellites. The design being scalable and dynamic in nature to cater to the needs of various types of satellites.

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Solar Power Panel Size, Type & Energy.

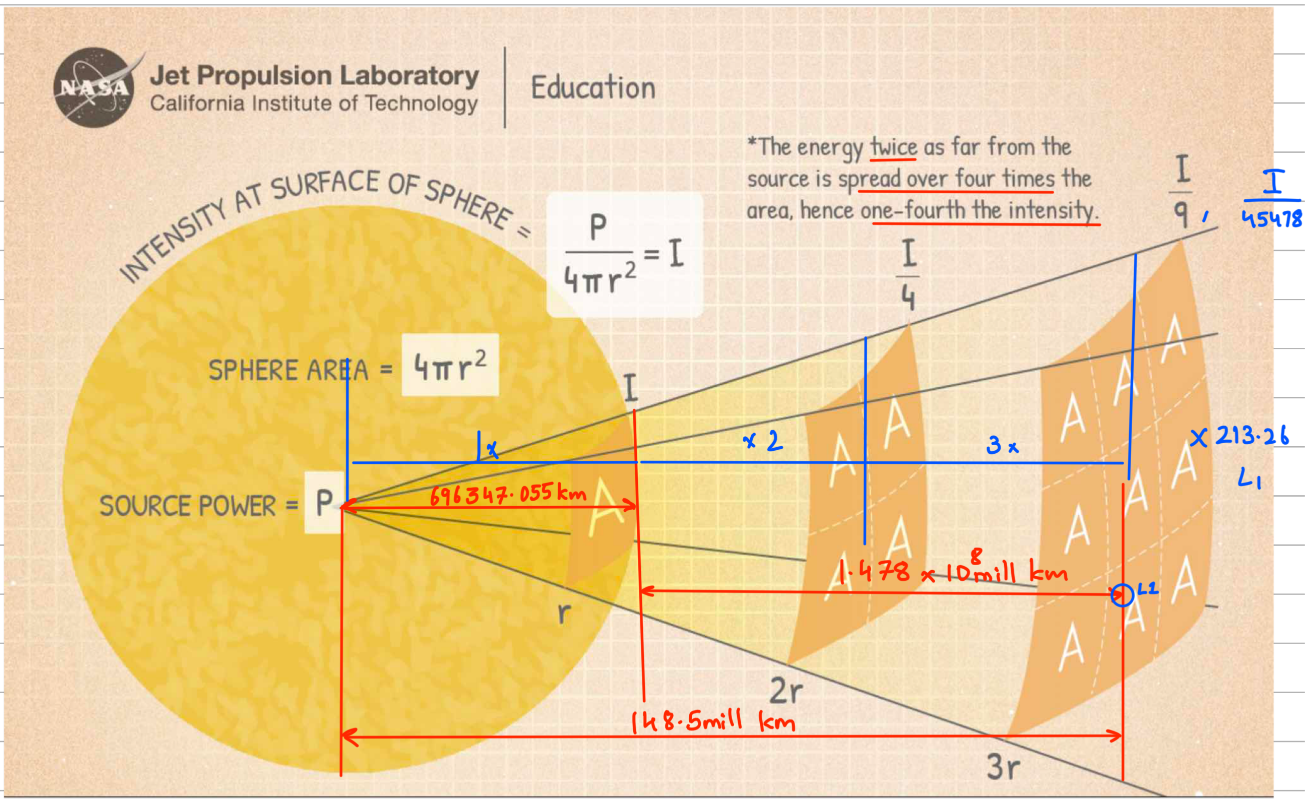
1) Required Power

- Sensors, Electronics = 100 W
- Motors Etcetra : 1000 W

1100 W

1100W is an estimate which can be adjusted later.

✱ Power = η (%) × Solar Intensity (0 or 1) × Solar Irradiance (W/m^2) × Effective Area (m^2)

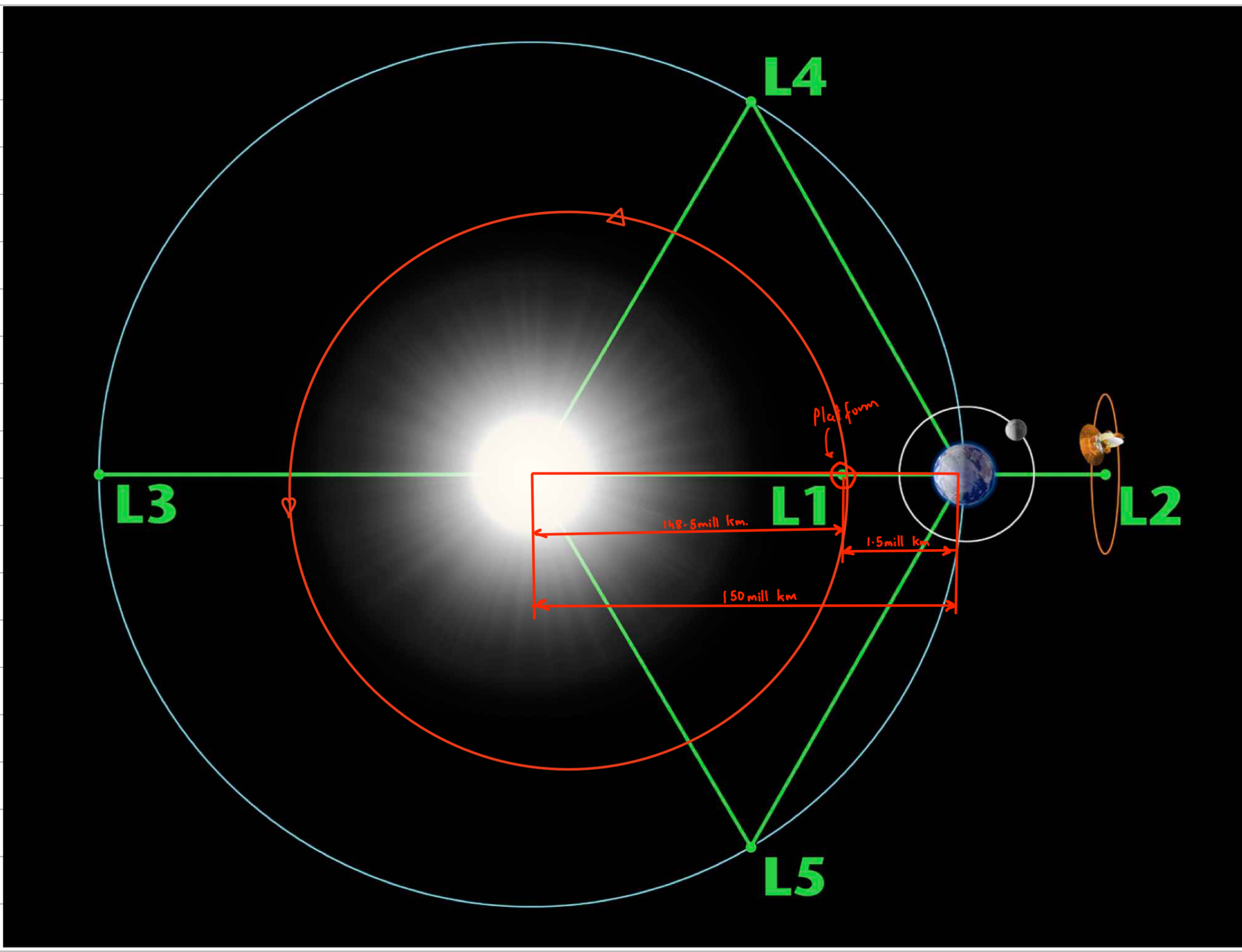


✱ The above image gives us the intensity of the suns power at L1

$\left(\frac{W}{m^2}\right)$ $I = \frac{P}{4\pi r^2}$

I : Intensity
r : Sun Radius.
P : Sun Power at core

✱ TSI total solar radiance = 1360.8 W/m^2 at 1 AU or 149,597,871 km.



Radius of Sun, r = 696347.055 km

Power from Sun Core P = 3.86×10^{26} W

Intensity at Sun Surface (r)

$$I = \frac{P}{4\pi r^2} = \frac{3.86\times10^{26}}{4\pi(696347.055)^2}$$

$$I = 6.3347\times10^{13} \text{ W}$$

Intensity at L1

$$r \text{ Factor} = \frac{148.5 \text{mill km}}{696347.055} = 213.26r. \text{ (at L1)}$$

$(213.26)^2 = 45478$ = Area covered at L_1

∴ Using Inverse square

Intensity at $L_1 = \frac{I}{45478}$.

$I = 6.3347 \times 10^{13}$ W/m² (at sun surface 'r')

$L_{1i} = \frac{6.3347 \times 10^{13}}{45478}$

$L_{1i} = 1.3929 \times 10^{9}$ W/m² (Intensity at L_1)

Solar Irradiance at L_1 (W/m²) → Light energy from disk of sun measured at Earth

At 1 AU = 1360.8 W/m²

L_1 lies on 0.99267 AU = ?

Solar irradiance at L_1: 1350.8 W/m²

Using inverse square law amount of sunlight received at L_1;

$1/d^2$ d → Platform dist from Sun

$= 1/(0.99267)^2$ = 148500000 km : 0.99267 AU.

= 100% sunlight

∵ ∴ at L_1 100% of solar energy received at earth reaches the platform.

So 100% × 1350.8 W/m²

Solar Irradiance on Platform = 1350.8 W/m²

Efficiency of Silicon Solar poly & Mono crystalline = 16%

$\eta = \frac{o/p}{i/p}$

With an area of $A_{sp} = 4m^2$

We get = 4 × 1350.8 m²

= 5403.2 W

Output = 16% = η = 0.16 × 5403

= 864.51 W → Not sufficient.

$A_{sp} = 6m^2$

O/P power = 1296.8 W → sufficient

Solar panels degrade over time $ conversion efficiency drops over the years.

- For Silicon Poly Crystalline Solar panel
  - ↳ Retain **88%** of original performance after 15yrs

End of life efficiency = 24.6%

$= 0.88 \times 1296.8W$

O/p power at 15yrs = 1141.2W → Sufficient

★ Theoretical Area Reqd.

$1141.2 = 0.16 \times 1 \times 1350.8 \times \text{Area}$

$$\text{Area} = \frac{1141.2}{0.2 \times 1350.8 \times 1} = \boxed{4.22 m^2}$$

But we have chosen $6m^2$

so, $6 - 4.22 = \boxed{1.78m^2}$ is needed to compensate for bad solar efficiency $ EOL degradation.

Note :. = Current transmission losses also have to be taken into account.