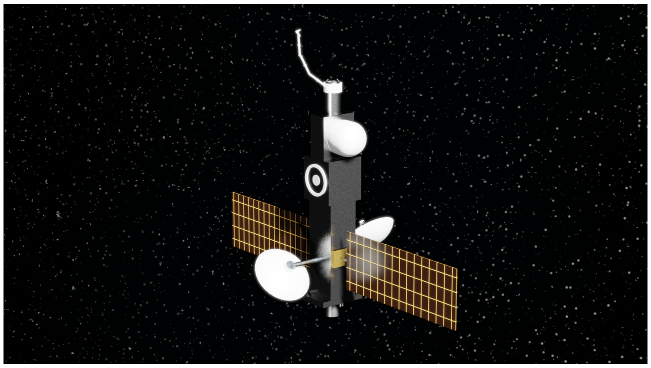
Intelligent Relay Inspection and Storage Station Proposal (IRISS)

RASC-AL: Multi-Use Platform at L1 Proposal

University of Colorado Boulder

Colorado Space Grant Consortium



Team Members

Ashley Withnell - Mechanical Engineering - Undergraduate

Evan Poon - Computer Engineering - Undergraduate

Luján Leal de Ibarra - Aerospace Engineering - Undergraduate

Mauricio Zambrano Diaz - Computer Science - Undergraduate

Table of Contents -

Competition Guidelines

This is our proposal for NASA's 2023 RASC-AL design competition. This year's challenge prompted us to design a concept for a platform operating at the first Earth-Moon Lagrangian Point (L1). This platform has to perform a combination of services to assist space travel, scientific research, and communications. Designed to reach orbit with a single rocket launch, the platform will deploy its systems after arrival. Within this report, we were asked to explain the chosen systems and discuss the conceptual design regarding the mass, power, geometry and data. We also lay out a plan for the lifetime of the platform, launch considerations, deployment and sustaining operations. It is designed to utilize both modern and pre-existing technologies to create a state of the art space platform which will complement future lunar missions. Finally, the following plan for this platform should encompass a mission lifetime of at least 10 years.

To start the research process, we identified the station's possible functionalities and allocated responsibilities amongst the team to thoroughly research each of the station's features. By supplementing this research with advice from professors and professionals in the aerospace industry, we narrowed down the list of functionalities to only those which were feasible. Features that were too expensive or lacked the proper technological grounding were among the items that were removed. In the end, the subsystems we selected looked to maximize the value that our craft contributes to future lunar missions. This proposal acts as our team's first submission, though a finalized and more complete submission is in the works. This means that although the current platform design is not fully developed, all of the finishing details are planned for the final paper.

The following is our proposal for IRISS, the Intelligent Radio Inspection and Storage Station.

Introduction and Objectives

This proposal details a plan for the development and deployment of an uncrewed multi-use platform at the Earth-Moon LaGrange point 1 (L1). Situated between the Earth and the Moon, L1 is the most logical location for the strategic placement of a platform to benefit and support future lunar missions and operations. Here, the gravitational pull of the two large masses (the Moon and the Earth) are equivalent and therefore work against each other equally to form a location with zero gravitational acceleration. L1 affords an uninterrupted view of the sun (NASA, 2018). IRISS is designed to provide radio signal relay, cargo storage, and real-time video scanning of docked spacecraft.

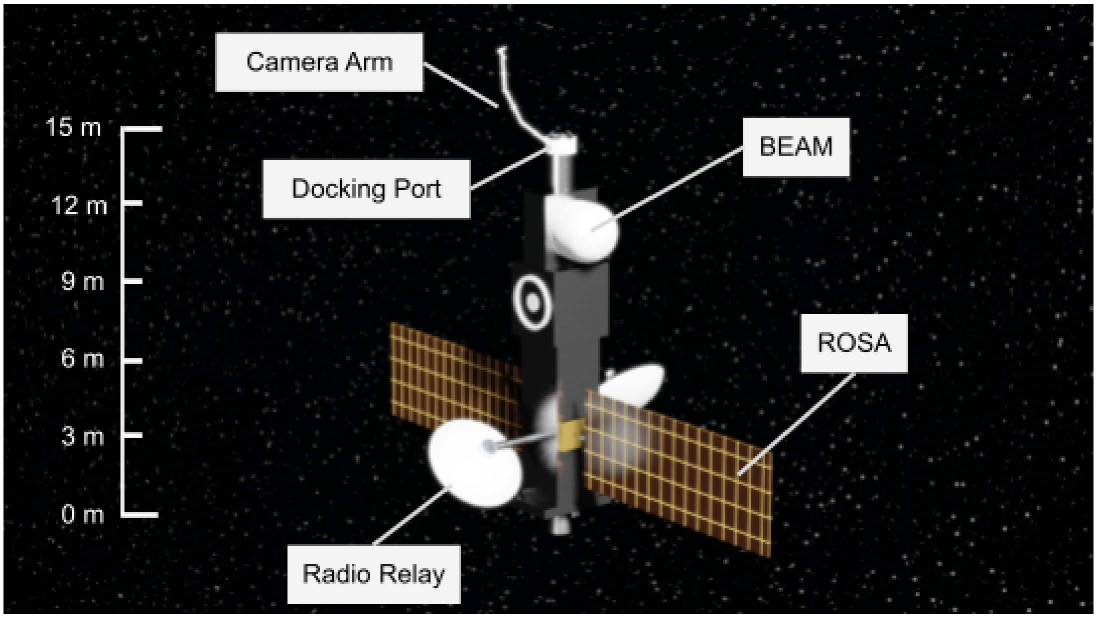


Figure 1: 3D render of general IRISS design

As a result of L1's constant view of both the Earth and Moon, this position is ideal as a communication relay. To leverage this advantage, the IRISS will make use of a radio relay system which will boost the signal integrity between lunar missions and the ground base on Earth to ensure reliable and efficient communication. The IRISS will also make use of Bigelow Expandable Activity Modules or BEAMs (Mahoney, 2015) to store numerous different items including mechanical parts, materials for lunar or nearby missions, or collected samples waiting to return to Earth. Utilizing the International Docking Standard set by NASA (Garcia, 2015), spacecraft can dock with IRISS and easily stow or retrieve their items. The third major component of the platform is a camera, mounted near the docking port, capable of scanning both docked spacecraft and the platform itself for damage. This scanning mechanism consists of an arm with 8 axes of rotation with a camera attached to the end. Leveraging both computer and mechanical control, ground crews can visually inspect docked craft. Power will be supplied by Redwire Space's Roll Out Solar Array or ROSAs (Redwire Space, 2022) for the full ten year mission. Finally, the platform's propulsion system is based on the systems of NASA's Orion (Garcia, 2015) and Gemini missions (Dunbar, 2015) and will allow for effective course adjustments, orbital maneuvers, and attitude control.

IRISS presents an exciting opportunity for supporting further exploration and utilization of cislunar space. By leveraging modern technology and strategic location, the platform can support a range of missions and activities, and ultimately contribute to humanity's continued advancement in space exploration.

Technical Approach

Radio Relay

IRISS looks to extract complicated communications from future lunar missions by relaying radio signals between the Earth and the Moon. L1 has a permanent, unobstructed view of the Earth, the Moon, and the satellites orbiting the Moon. L1's positioning, along with its vicinity to the Moon, makes L1 the perfect radio relay spot to retransmit data back to Earth at much higher rates and with higher data integrity compared to what can be achieved with the limited hardware on a rover or lander. Transmitting radio waves from the Moon to L1 takes 1/36th the power required to transmit the waves all the way to Earth because of its close proximity to the Moon. The intensity of a radio signal (I) is described by the following equation:

$$I = \frac{k}{r^2}$$

where k is the proportionality constant and r is the distance between the two objects. Reducing r greatly increases the signal intensity. This means future missions can cut costs, power, and volume requirements by having an alternative transmission target to L1.

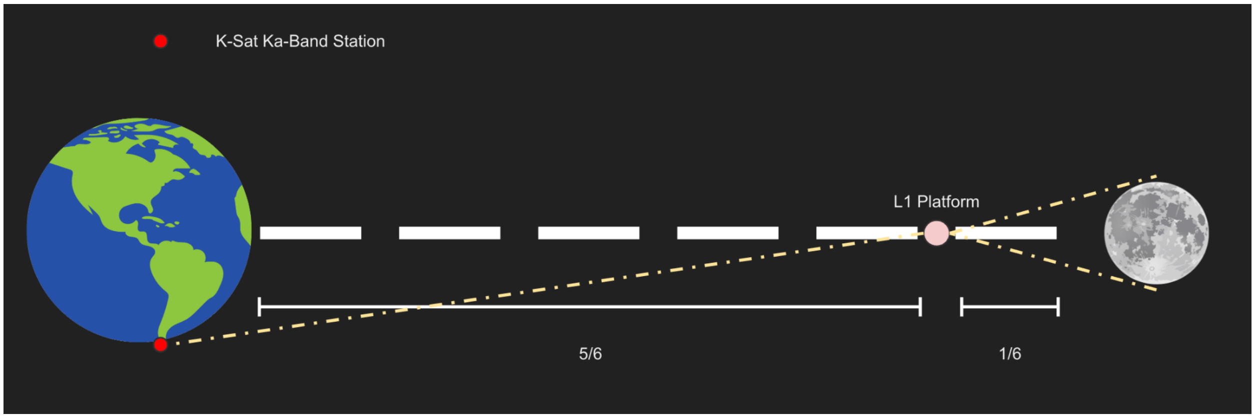


*Figure 2: Distances between Earth, L1, and the Moon. *Moon and Earth not to scale*

IRISS features two transceivers operating at two different frequencies each with its respective antenna, a high gain antenna with a 50-60 db gain, pointed at Earth and a 5 db gain antenna pointed at the Moon. Transmissions sent back to Earth are received by a single source and are sent through the high gain antenna. Transmissions received and sent from the Moon are administered by the low gain antenna. Both antennas will be Active Origami Reflector Antenna or AORA (Jape, 2020). This means they are made of a self-foldable memory polymer which is able to take any shape from a two-dimensional sheet. This allows for easier deployment as the antennas can be stowed in a flat sheet on the outside of the platform during launch. The antennas will be deployed once the platform reaches L1.

IRISS' high-gain antenna, used to communicate between the platform and the Earth, will transmit at a Ka-Band frequency (26.5 GHz – 40 GHz) which allows for higher data rate transmissions to be possible. The station will include a DRC 3500 5 Watt Ka-Band Transceiver developed by Global Skyware (DRC 3500, 2023). The transceiver is connected to a 1.3 m diameter antenna. This allows the station to transmit around 200 mbps assuming a system loss of 2 dB.

The low gain antenna will operate on a Ku-band frequency (10.9 GHz – 17 GHz). For this antenna the platform will use a UET50A09A SATCOM Transceiver manufactured by Wavestream Corporation (UET50A09A, 2023). It operates on frequencies from 13.75-14.5 GHz and consumes 500 W of power connected to a 3.3 m diameter antenna which allows for 200 mbps between the Moon and L1.

When it comes to downlink, high gain communication from L1 to Earth, IRISS will transmit to Ka-band antennas operated by KSAT Kongsberg Satellite Services, a company that hosts multiple antennas in Antarctica (Kongsberg Group, 2021). Some missions might not need to stream their data back to Earth in real time, to address this, IRISS includes three NASA certified 8 Terabyte M.2 solid state drives produced by the Taiwanese company Phison (Phison, 2022). The solid state drives have built in radiation protection to prevent cosmic rays bit flips.

The future of lunar exploration will feature many small rovers which do not have enough space/power/capacities to efficiently transmit data at high rates back to Earth. IRISS will help these missions by providing the option to transmit to L1 instead. Some of these NASA missions include the Cooperative Autonomous Distributed Robotic Explorers or CADRE (Vitug, 2021) which looks to map the subsurface of the Moon with four shoebox sized rovers. There is also the Lunar Vertex mission led by Johns Hopkins, which features a small rover and a lander (Lunar Vertex, 2021). Other space organizations such as JAXA or LINX from the Mexican university UNAM have missions that would greatly benefit from the radio relay. COLMENA, the LINX's mission has many "bite sized rovers" that are an inch tall and have a limited power supply. (Colmena - LINX - UNAM, 2021).

Docking Port

One of the most versatile features of IRISS is the docking port located at the end of the station. This mechanism is utilized for both the storage and scanning functionalities of the platform. Referred to as the International Docking Adapter (IDA), this port is modeled to NASA's International Docking Standard used by the International Space Station. Figure 3 depicts this adapter. This standard allows any spacecraft mission to design a compatible IDA according to the pre-existing NASA-defined design. This system creates an airtight seal which ensures the platform's internal compartment is isolated from the vacuum of space and that the vessel's internal pressure is maintained. A part of the IDA is an airlock door which opens once a spacecraft has successfully docked with the station for cargo storage access.

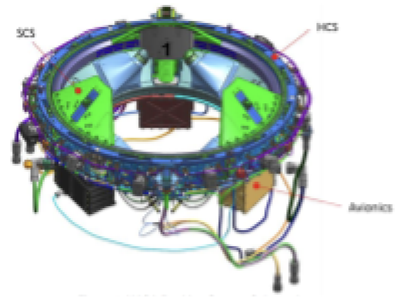


Figure 3: 3D model of International Docking Standard Port (NASA Technical Reports Server)

BEAM Modules

One of the two uses for IDA is a storage system utilizing new expandable module technology. This system introduces the possibility of an expandable habitat-like environment which inflates once the platform has arrived at its final destination, significantly increasing the volume of the platform usable area (depicted in figure 4). The walls of this module provide an extra degree of protection from radiation, space debris, atomic oxygen and more. IRISS will utilize Bigelow Aerospace's Expandable Activity Modules (BEAM) in order to achieve this portable and scalable storage. BEAM has proven to be a reliable and effective technology after its use on the ISS.

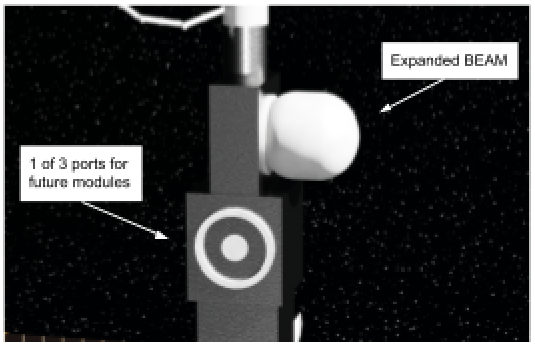


Figure 4: BEAM and ports

The cargo storage facility uses standardized containers that other missions will utilize, fill, drop off, and pick up from the station. These containers can store mechanical parts, experimental samples, and other (pre-approved) items clients would like to store in space for some given amount of time. This capability can be leveraged by several upcoming missions including construction and operation of the Lunar Gateway (Mars, 2016.) and future Helium 3 mining operations (The European Space Agency).

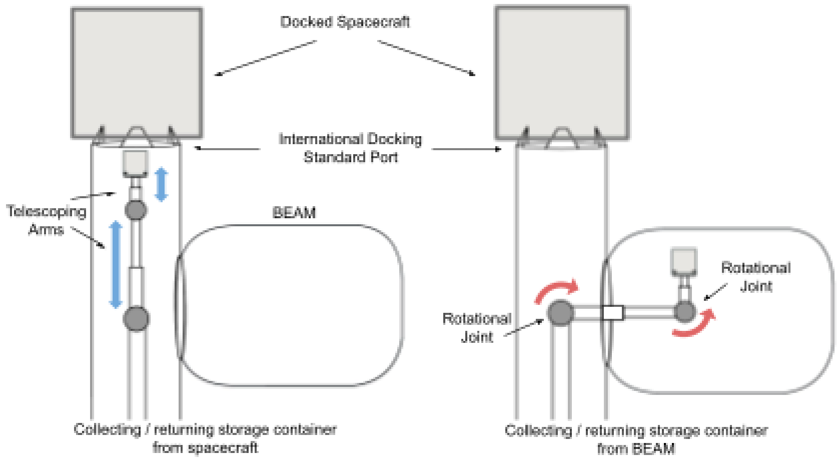


Figure 5: Basic Storage Container Mechanics Diagram

The mechanics of this storage system includes an arm that will carry the containers to and from the storage module. As depicted in figure 5, this arm will be mounted at the cross section of two BEAM module entrances, and will have several rotational and telescoping components that allow it to collect the container from the docked spacecraft and place it at the designated location in the BEAM module. It is understood that this arm must have several degrees of rotation along with a reach of around 4.8 meters to reach the docked spacecraft, and 4.5 meters to reach the far end of the beam module. Although the specifics of this mechanism have yet to be designed, a plan to design them is in place. The walls of the BEAM will be lined with a hook and loop fastener material which allows the container with a similar material to be attached and stored.

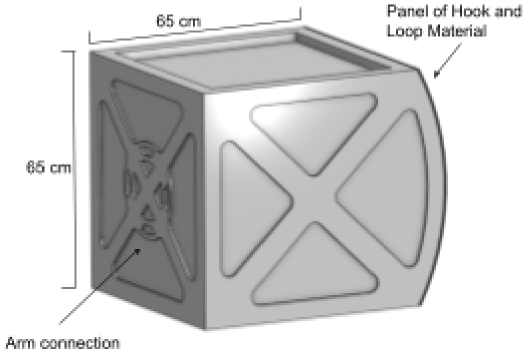


Figure 6: 3D model of storage container

The containers will be a 65 cm cube (figure 6), with one face that has a convex surface that matches the curvature of the box to stick to the walls. This container dimension will be configurable with the details solved for in the future. This curved surface is designed to fit perfectly along the walls of the round BEAM module, ensuring the fastening material has maximum contact surface area to extend longevity of the module as the material loosens. When the BEAM module has been completely filled with these storage containers, the containers themselves will be organized optimally to ensure the most efficient use of the provided space as possible, while still allowing each module to be accessible regardless of how many containers are on either side of it.

Although the plan is to launch this multi-use platform with only one BEAM module onboard, the platform contains three additional ports for BEAM expansion, depicted in figure 4, for future module additions. These ports enable future missions to deliver a BEAM model of their own to this platform.

The BEAM is currently being used and tested on the International Space Station, and will be applied in a similar manner on IRISS. When deployed, the module reaches a length of 4.01m and 3.23m in diameter. It has 16 cubic meters of storage volume and 1360 kg of mass. It is composed of two metal bulkheads, an aluminum structure, multiple layers of soft fabric and an airlock. On the inside, it will have air tanks that will help the structure expand to its maximum size and will also be working along the air tanks on-board the spacecraft to maintain a uniform pressure throughout the station. The connection between the BEAMs and the IRISS will remain open for the entire duration of the IRISS's deployment. In this current design, the BEAM is expanded through an air pressure system, however in a future model other unpressurized expandable options will be considered as an alternative.

Scanning Dock

Once a general spacecraft mission has launched and disconnected from the launch vehicle, the spacecraft deploys the components needed en route to its final destination, such as solar panels, and sends diagnostic data back to those monitoring it on Earth. The team then analyzes this data to determine if the spacecraft's functionality is working properly. If these numbers are not nominal, the team is left with few tools to diagnose what is wrong, and what the solutions should be. This lack of knowledge about the condition of a spacecraft mission can have detrimental effects on debugging, testing and data collection processes onboard the craft. To help mitigate this problem, the IRISS platform provides passing space missions the ability to perform a final check of their systems by scheduling a time to dock with the platform, and receive a visual inspection of their spacecraft before beginning the rest of their journey to their final destination.

To accomplish this, a camera arm, capable of rotating around the docking port and bending in multiple spots, will be used to provide a visual inspection of a docked spacecraft. The arm will also contain proximity sensors to prevent accidental collisions between IRISS and any docked spacecraft. Before arriving at this multi-use platform, an external spacecraft will have deployed the necessary appendages for space travel. This craft will then dock with IRISS, using the IDA. The platform will then deploy the camera arm and begin a livestream broadcast back to Earth, as depicted in figure 8. The beginning of this broadcast will mainly be predefined and standard camera maneuvers in which the camera makes a basic 360 degree pan around the spacecraft, and zooms in to standardized locations. However, once these maneuvers are completed, the ground crew of the docked spacecraft can input specialized maneuvers and movements to focus on specific aspects of their spacecraft if they need a closer look at a problem or location.

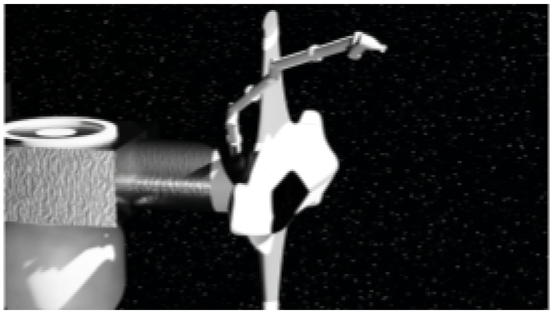


Figure 7: A 3D render of the scanning dock

Due to bandwidth limitations, the live video feed will be highly compressed and downscaled. If needed, once damage or any other problem has been identified, the camera is capable of taking higher resolution video, caching it into the solid state drives (SSDs) discussed above, and sending that video data back to the ground crew over a greater period of time.

The video stream from this system comes from a Toshiba True 1080p Hi Definition Camera (B&H Foto and Electronics Corp., 2023) chosen because of its similarity to the cameras currently used on the International Space Station for NASA's "High Definition Earth Viewing" stream. This camera captures a 1920 x 1080 video feed at 60 frames per second. This camera has been chosen for this initial proposal, however, it is understood that this camera does not meet all the requirements for a properly scanned image at a close range like what this camera arm requires for a good performance. When deciding on a final camera later in the design process, a camera with at least 8 megapixel resolution, along with a lens that can perform at that resolution 1 - 3 meters away from the target is desired.

This camera is attached to the platform's arm, which has 3 main linkages, and 9 total points of rotation. The arm itself is modeled after the ISS' Canadarm2 (Canadian Space Agency, 2018), though it is worth noting that it is about one sixth of the size, and half the diameter.

Similar to the Canadarm2, the main rotation locations are a rotation along the x axis at either ends of each linkage, and a rotation in the z direction half way along the length of the arm. IRISS' arm model for this platform has a total length of 5 meters, and connects to IRISS via a rotating ring located behind the docking mechanism. This ring allows the arm to swivel 360 degrees around the docking mechanism as seen below in figure 8.

When it comes to how the arm will maneuver the scanning sequences, a few software features come into play. To handle motion, the arm will utilize an inverse kinematics algorithm to determine how to move the camera arm into position without causing damage to either spacecraft. When a new spacecraft is docked with the platform, the volume and shape of the spacecraft will be uploaded to the platform's software system so the camera arm will have software hardstops preventing it from accidentally colliding with the spacecraft. The arm will also be equipped with proximity sensors to make sure no collision will be caused.The camera and arm system will be pre-programmed with default scanning and movement patterns to give general visuals of a spacecraft. If this is insufficient, the camera arm will have the ability to be manually controlled by a ground team.

Figure 8: Three possible camera angles for up close and farther away views of the docking area

Main Capsule

Propulsion System

The propulsion system for this platform mostly consists of a main thruster, a 200N Bi-propellant, and a reaction control system. This propulsion system is designed to exclude a large and powerful thruster because of the flight path IRISS will be taking to approach L1. Before the Falcon 9 (SpaceX, 2021), the chosen launch vehicle for this mission, makes its final separation from IRISS, it will orient the station with the correct attitude and with enough velocity to start this platform on the chosen flight trajectory. The planned trajectory takes a similar path to the one outlined in figure 9 (Parker and Rodney, 2013; and private communication with J. Parker). This path brings IRISS to L1 with little to no fuel consumption. Leveraging the gravity from both the Earth and the Moon IRISS arrives at L1 with close to no velocity. According to Parker and Rodney, this path is a low energy approach which requires 90 days to complete.

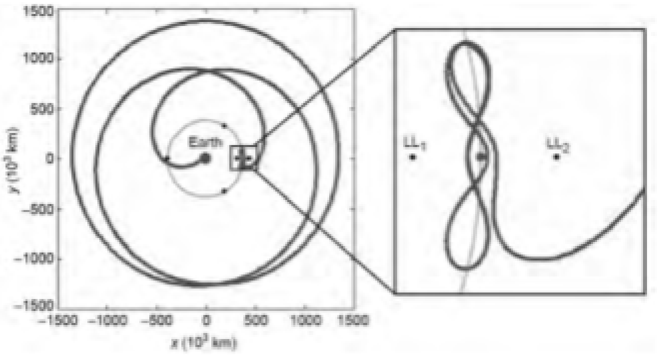


Figure 9: A low energy lunar trajectory (Parker and Rodney, 221)

Once at L1, the platform must be able to maintain its position for at least its 10 year mission. These small maneuvers will be accomplished with the main 200N Bi-propellant

Thruster from Ariane Group (ArianeGroup, 2020). This thruster is modeled from one of the thrusters used in the Orion mission. The attitude control system, designed after the Gemini mission, will supply adequate control over the platform's rotational and translational orientation. The Gemini's system consists of a combination of 110, 380, and 445 newton thrusters which are placed around the ship's hull. IRISS will look to do something similar to ensure complete rotational and translational control. Since the main thruster is bi-propellant, the attitude control system will be as well to reduce the number of necessary fuel tanks on board. With the capabilities of this bipartite propulsion system, IRISS will be fully capable of completing its mission objective.

To complete the maneuvers needed for the duration of this mission, IRISS will have a total change in velocity of 215 m/s. This accounts for the margin of error of the low energy approach to L1, launch vehicle clean up, establishing a launch period, the adjustment to maintain the location at L1, and an end of mission plan. This change in velocity number combined with the main thrusters' specific impulse and the total mass of the space station allows for the total fuel mass calculation to be made using the "rocket equation". The calculations for this equation are in appendix A. These thrusters utilize unsymmetrical dimethylhydrazine as the fuel and nitrogen tetroxide as the oxidizer with a 1.65 nominal mixture ratio. From here, the total amount of each fuel was calculated, along with the size of tank necessary to contain both.

Solar Panels

To power the various electrical components on the L1 platform, IRISS will be taking advantage of the newly developed Roll Out Solar Arrays from Redwire Space. These panels are designed to be highly compact and to allow for efficient transport into space. Several of these ROSAs have recently been implemented on the ISS, depicted in figure 10. Since they are able to roll up, less volume of the launch configuration is filled. When in this configuration, the panels will each have a diameter of about 1.25 meters giving them a "travel volume" of 4.54 cubic meters. To deploy, these arrays utilize the stored potential energy in the panels themselves to flatten out and extend the solar arrays, resulting in no consumption of power. Two of these ROSAs will be sufficient to supply power to the platform's various communication and electrical components. Upon departing from Earth's gravitational field and exiting the Falcon 9 rocket, the platform will immediately deploy its solar array and begin generating electricity for its features.

Although the total power needs of this station is not yet finalized, the only power draw that is constantly running comes from the radio relay station. Otherwise, operations such as the scanning arm and the storage box manipulation systems only use power when they are needed, and will not be operating for long periods of time. That being said, each panel will weigh approximately 120 kg and will provide a mass to power ratio of about 100 to 120 W/kg. This places the power output at approximately 12 kW per panel. Batteries onboard will store this power, though the capacity of these batteries is not yet determined. For the most part, the station will be in sunlight, except for when the sun is eclipsed by either the Moon or the Earth.

Figure 10: Fully extended ROSA on the ISS (Redwire Space, 2022)

Launch configuration

For the launch vehicle, IRISS will be utilizing the Falcon 9 reusable, two-stage rocket by SpaceX, whose payload fairing compartment is 13.1 m long and has a diameter of 5.2 m. For launch, the station will be packed to fit in this fairing volume. In the packed configuration, the BEAM will be collapsed to have the length of 2.16 m and a diameter of 2.36 m. Both ROSAs will be in the rolled configuration having a height of 8.5 m and diameter of 3.7 m. The camera arm will be in its folded and stored position with a length of 1.7 m, and a width of 0.6 m, and the AORA will be in their flattened origami shape (not depicted in figure 12).

Mass

The physical mass of this platform has not been completely determined, however, the numbers that are known are as follows. Since the SpaceX Falcon 9 is the launch vehicle for this station, the maximum mass IRISS can accommodate 25,000 kilograms. When accounting for a 25% margin, the total mass that the station can be is 18,750 kg. This 25% margin allows for future additions and scalability of the overall design of the IRISS station, since some of the current components and designs are not yet fully completed. To calculate the total mass of the station, a few more components are needed. Using the technology from the ISS to estimate the materials of the walls of the station, it is known that the walls themselves will be 10 cm thick. Within the wall are layers of light aluminum, kevlar, and high tech fabric. Knowing the density of the aluminum and the kevlar, the estimated mass of the walls is calculated to be 13535 kg. This wall mass is estimated from one that supports an internal habitat. IRISS will not have a life-supporting habitat so the final design will have thinner and lighter walls. Adding on the known masses of the other components of the station, the estimated total mass of the station is 16300 kg. Since the amount of fuel needed for this station is known, along with the type of fuel, the total mass of the fuel is 1350 kg (calculations in Appendix A). This brings the total wet mass of the station to 17615 kg. This mass estimate does not include the mass of the propellant system, avionics, batteries, or either arms on the station, though these will be needed for the final mass estimate.

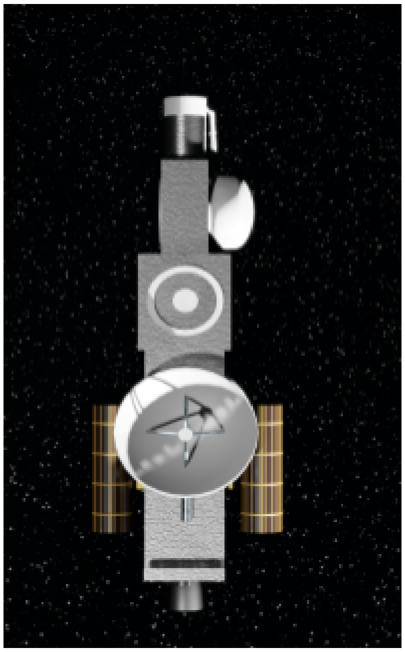


Figure 11: 3D model of IRISS in launch configuration

Cost

When it comes to the cost of IRISS, the specifics have not yet been determined, but reaching out to companies to get cost estimates is in the plan for future development of this platform. The main mission that has a comparable position and functionality to what is accomplished by IRISS is the Lunar Gateway mission by NASA. This mission costs approximately 779 million dollars. However, IRISS and the Lunar Gateway are different in a few ways, considering the fact that the latter is designed to be a crewed mission with on-board investigations and it will serve as a staging point for deep space exploration. Since IRISS is uncrewed and has different mission objectives, the actual cost will be greatly reduced from this estimate.

Adding up the currently known cost estimates for the different subsystems of IRISS (Appendix B) brings the cost of the mission so far to 115 million dollars. This total cost does not account for many different features on IRISS. Systems such as the scanning dock, and arm, fuel, fueling system, antennas and radio systems, and general labor costs are not accounted for in this estimate so far. To compensate for this, a margin of 150% brings the cost estimate to 280 million dollars.

Mission Timeline

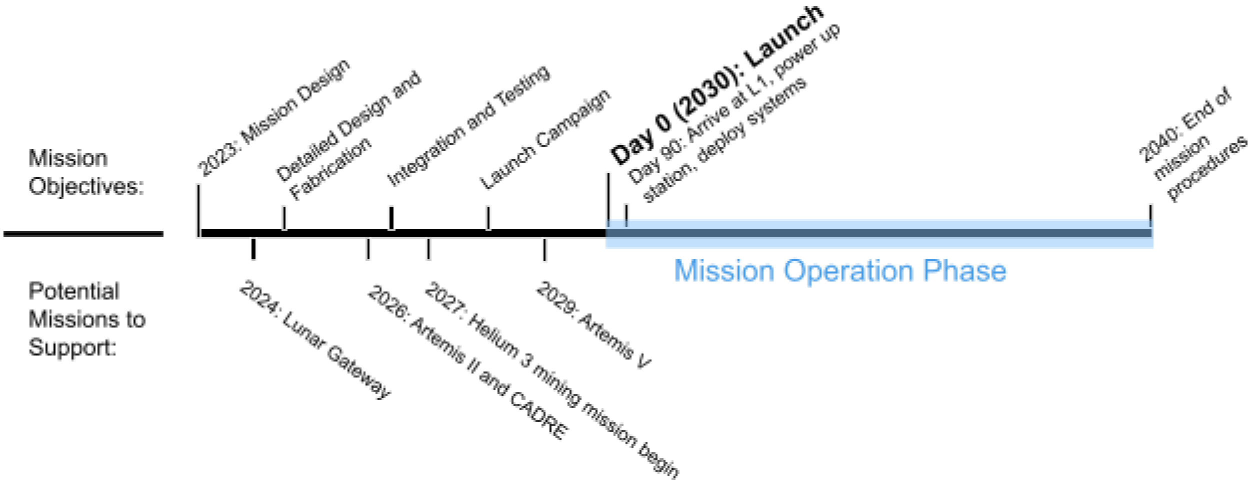


Figure 12: Mission Timeline

The above figure depicts the current time line of both the construction and launch of IRISS, along with when lunar missions, both rover missions and satellite missions, are planned to launch. These external missions can be potential clients of this multi-use platform. The construction missions such as the Lunar Gateway mission, and Helium 3 mining missions can store items or samples in the BEAM utilizing the storage containers. Passing missions can stop by the scanning port on the way to or from the Moon to get a visual inspection of their spacecraft. And lunar rover missions such as CADRE and the Lunar Vertex (launching in 2024) can utilize the radio relay aspect of this platform to boost signal integrity and cut down on on-board hardware requirements. Although these missions will be launched and operational before IRISS is operational, future missions with similar functionality can utilize this station during the entire mission operation phase. IRISS plans to stay at L1 for at least 10 years, and will support lunar missions through 2040.

Conclusion

With the help from new and upcoming technologies in the aerospace industry, IRISS will be enabled to support a new generation of Lunar space missions. With a radio relaying system to assist lunar rovers communication back to Earth, a docking station that provides a visual aid for any passing missions, and storage space to support construction and research missions, this Intelligent Radio Inspection and Storage Station will establish the infrastructure needed for future science, manufacturing and expansion into the cosmos.

Appendix

Appendix A

Rocket Equation: (University of Central Florida, 2016)

$$\Delta V = gc \times Isp \times ln(\frac{Mi}{Mf})$$

Where ΔV is the change in velocity number for that maneuver, gc is the acceleration due to Earth's gravity, Isp is the specific impulse of the thruster, Mi is the initial mass of the station before the mauver is made, and the Mf is the final mass of the station after that fuel has been expended.

Maneuver	Change in Velocity (m/s)	Shorthand label
Launch vehicle clean up	25	ΔV_1
Establishing launch period	30	ΔV_2
Navigation	10	ΔV_3
Lunar orbit assertion	30	ΔV_4
Station keeping	20	ΔV_5
Margin	100	ΔV_6
Total	**215**	$\mathbf{\Delta V_T}$

Known Dry Mass: 16400 kg

Specific Impulse of main thruster: 270 Ns/kg

Starting with the last change in velocity and working backwards:

$$\Delta V_6 = 100 = 9.8 \times 270 \times ln(\frac{Mi}{16400})$$
$$Mi = 17000\,kg$$

$$\Delta V_5 = 20 = 9.8 \times 270 \times ln(\frac{Mi}{17000})$$
$$Mi = 17128\,kg$$

$$\Delta V_4 = 30 = 9.8 \times 270 \times ln(\frac{Mi}{17128})$$
$$Mi = 17323\,kg$$

$$\Delta V_3 = 10 = 9.8 \times 270 \times ln(\frac{Mi}{17323})$$
$$Mi = 17388\,kg$$

$\Delta V_2 \ = \ 30 \ = 9.8 \ \times 270 \times ln(\frac{Mi}{17388})$

$Mi = \ 17586 \, kg$

$\Delta V_1 \ = \ 25 \ = 9.8 \ \times 270 \times ln(\frac{Mi}{17586})$

$Mi = \ 17752 \, kg$

Total Fuel Mass: 1352 kg

Final Wet Mass: 17752 kg

Appendix B

Known estimates for major costs:

Feature Name of Known Cost	**Cost (in millions of US dollars)**
Falcon 9 Launch	62
BEAM	17.8
ROSA	34
Total	113.8

Citations

Canadian Space Agency. “About canadarm2.” *Canadian Space Agency*, / Gouvernement Du Canada, 15 June 2018, https://www.asc-csa.gc.ca/eng/iss/canadarm2/about.asp.

“Colmena - Linx - UNAM.” *LINX*, 10 Dec. 2021, https://linx.nucleares.unam.mx/colmena/.

“DRC 3500.” *Skyware Technologies | SATCOM Transceiver*, Everything RF, https://www.everythingrf.com/products/satcom-transceivers/skyware-technologies/771-858-drc-3500.

Dunbar, Brian. “What Was the Gemini Program?” NASA, NASA, 23 Feb. 2015, https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-gemini-program-58.html.

Garcia, Mark. “Meet the International Docking Adapter.” NASA, NASA, 5 Oct. 2015, https://www.nasa.gov/feature/meet-the-international-docking-adapter.

Garcia, Mark. “Orion Spacecraft.” NASA, NASA, 15 Jan. 2015, https://www.nasa.gov/exploration/systems/orion/index.html.

Group, Kongsberg. “New KSATlite Ka-Band Antenna Operational in Antarctic Troll Station.” *KSAT*, 15 July 2021, https://www.ksat.no/news/news-archive/2021/new-ksatlite-ka-band-antenna-operational-in-antarctic-troll-station/.

The European Space Agency. “Helium-3 Mining on the Lunar Surface.” *ESA*, https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Space_for_Earth/Energy/Helium-3_mining_on_the_lunar_surface.

Jape, Sameer. “Self-Foldable Origami Reflector Antenna Enabled by Shape Memory Polymer Actuation.” IOPScience, IOP Publishing, 23 Sept. 2020, https://iopscience.iop.org/article/10.1088/1361-665X/abaac2.

“Lunar Vertex.” APL Civil Space, Johns Hopkins University, 18 Nov. 2021, https://civspace.jhuapl.edu/destinations/missions/lunar-vertex.

Mahoney, Erin. “Background and Frequently Asked Questions about Beam.” *NASA*, NASA, 17 July 2015, https://www.nasa.gov/feature/beam-facts-figures-faqs.

Mars, Kelli. “Gateway.” *NASA*, NASA, 17 Aug. 2016, https://www.nasa.gov/gateway/overview.

NASA Technical Reports Server (NTRS). https://ntrs.nasa.gov/api/citations/20180004167/downloads/20180004167.pdf.

Parker, Jeffery S, and Rodney L Anderson. *Low-Energy Lunar Trajectory Design* . Jet Propulsion Laboratory, 2013.

Phison. “Phison's 8TB SSD Ready for Historic Liftoff after Earning NASA Certification.” *PHISON Electronics Corp.*, 7 Dec. 2022, https://www.phison.com/en/company/newsroom/press-releases/general/3189-phison%E2%80%99s-8tb-ssd-ready-for-historic-liftoff-after-earning-nasa-certification.

“Redwire's Innovative Solar Array Technology .” *Redwire Space*, 26 May 2022, https://redwirespace.com/newsroom/redwires-innovative-solar-array-technology-powering-the-future-of-space-exploration/.

SpaceX. https://www.spacex.com/media/falcon-users-guide-2021-09.pdf.

“Toshiba True 1080p Hi-Def Camera.” *B&H Photo Video Pro Audio*, B&H Foto and Electronics Corp., https://www.bhphotovideo.com/c/product/686371-REG/Toshiba_IK_HR1D_True_1080p_Hi_Def_Camera.html.

“UET50A09A.” *Wavestream Corporation | SATCOM Transceiver*, Everything RF, https://www.everythingrf.com/products/satcom-transceivers/wavestream-corporation/771-778-uet50a09a.

University of Central Florida. “9.7 Rocket Propulsion.” *University Physics Volume 1*, 3 Aug. 2016,https://pressbooks.online.ucf.edu/osuniversityphysics/chapter/9-7-rocket-propulsion/#:~:text=mim).-,%CE%94%20v%20%3D%20u%20ln%20(%20m%20i%20m%20)%20.,m0%20down%20to%20m.

Vitug, Eric. “Cooperative Autonomous Distributed Robotic Exploration (Cadre).” *NASA*, NASA, 5 Feb. 2021, https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/CADRE.

“What Is a Lagrange Point?” *NASA*, NASA, https://solarsystem.nasa.gov/resources/754/what-is-a-lagrange-point/#:~:text=The%20L1%20point%20of%20the,the%20James%20Webb%20Space%20Telescope.

“200N Bi-Propellant Thruster.” *ArianeGroup*, 17 Nov. 2020, https://www.ariane.group/en/equipment-and-services/satellites-and-spacecraft/200-n-bi/.