TEAM 43: ARIST43US

ORBITAL MISSION TO IDENTIFY LUNAR-ICE

PDR SECTION 3 & 4 DRAFT

Section 3: Descent Maneuver and Vehicle Design

3.1. Selection, Design, and Verification

3.1.1. System Overview

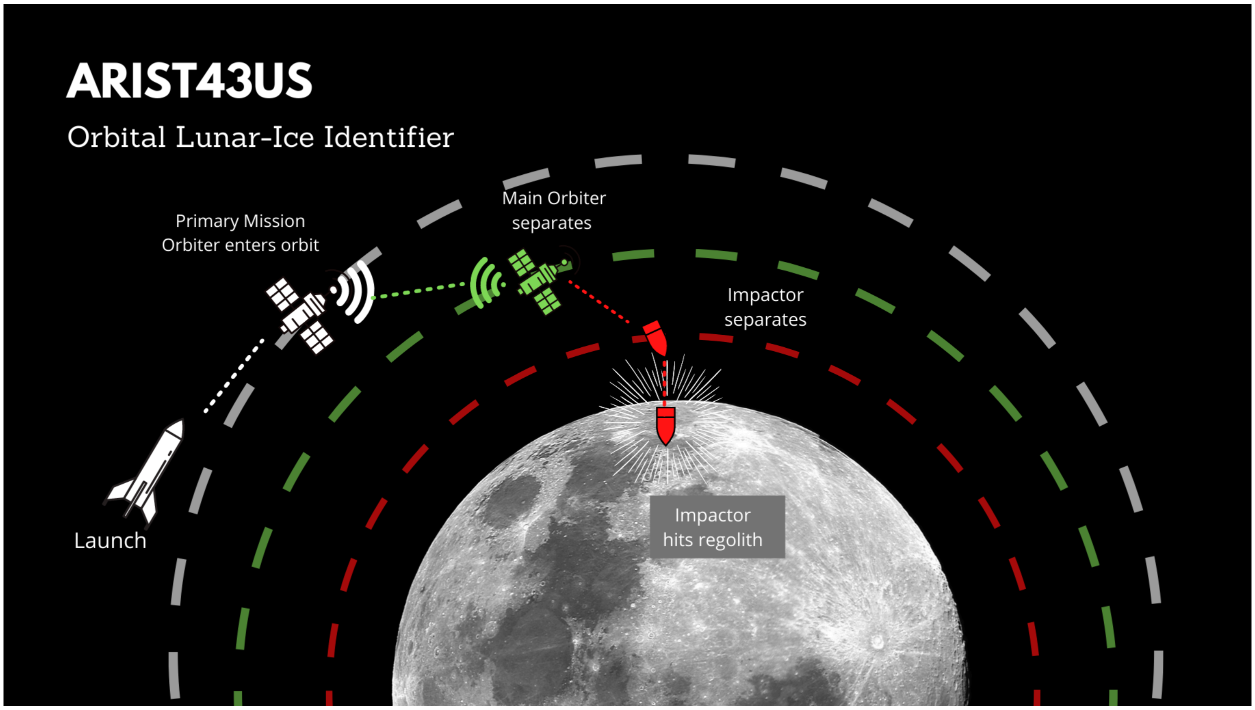


Figure 0. A diagram of the entry, descent, and landing path.

ARIST43US begins its standalone mission after separation from the primary payload at a 100km polar lunar orbit approximately 2 days after launch. The satellite will sustain its instrumentation and computers through energy derived from solar panels as well as a small backup battery in case of an emergency. The satellite is outfitted with its own xenon propulsion system which will be able to perform both major and minor adjustments to orbit and inclination. The satellite will perform these adjustments through the use of an Attitude and Determination Control System (ADCS) and a set of reaction wheels installed for all three axes. The mission also features a small impactor which will be able to separate from the ARIST43US craft and perform a controlled deorbit maneuver to impact and disturb the lunar surface within the PSRs.

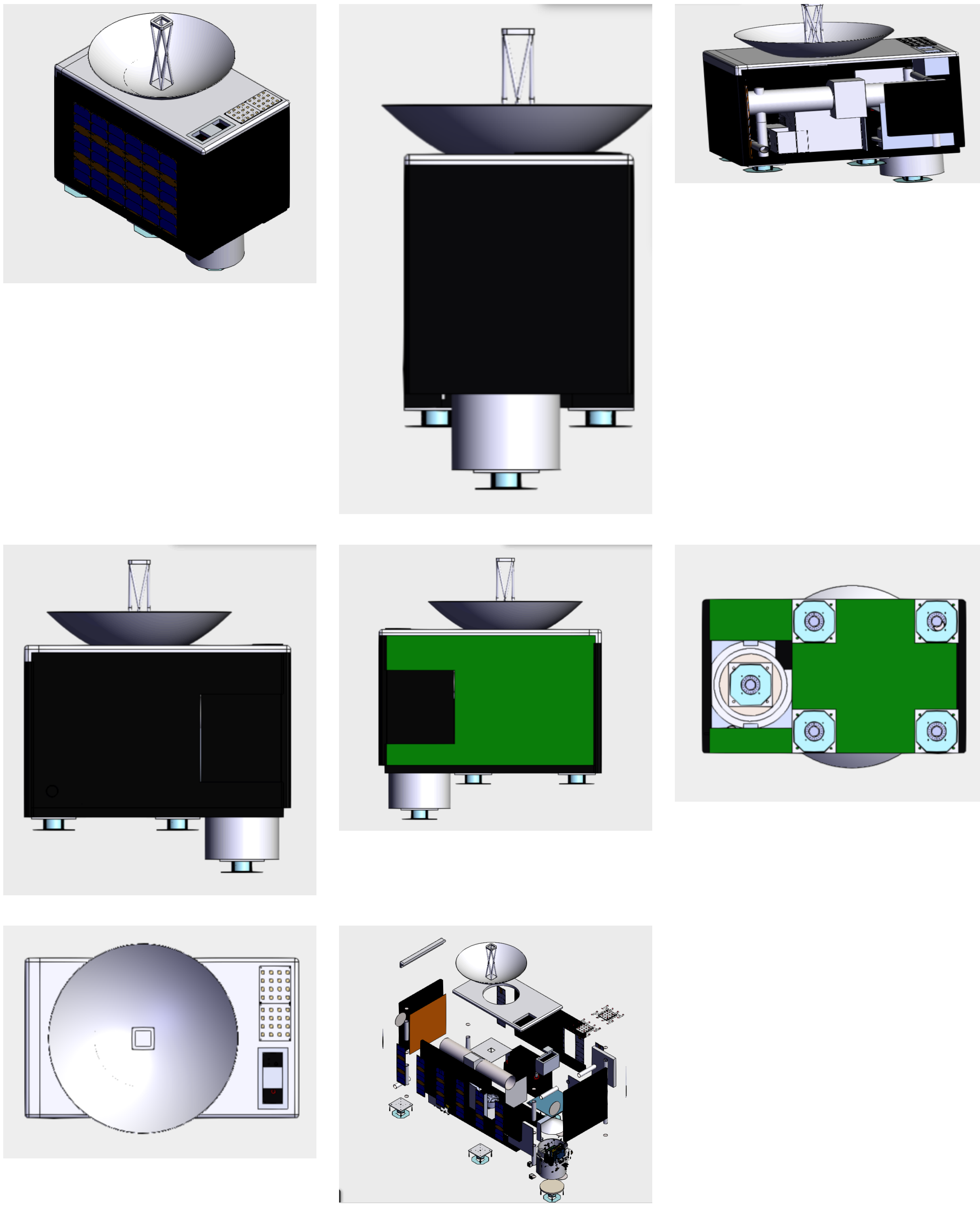
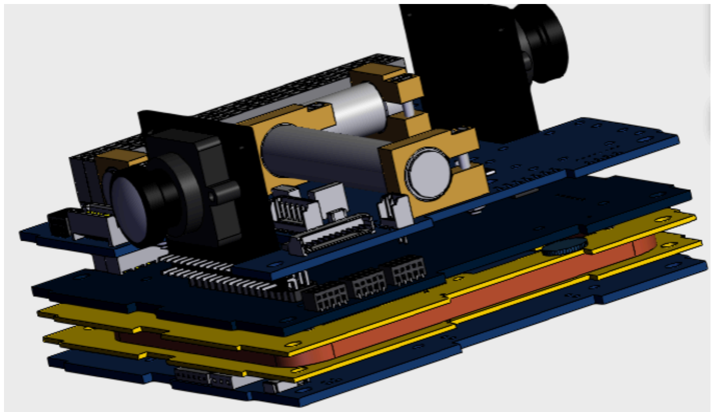


Figure 3.1: Orbiter Views: Mass ~= 141 kilograms

3.1.2. Subsystem Overview



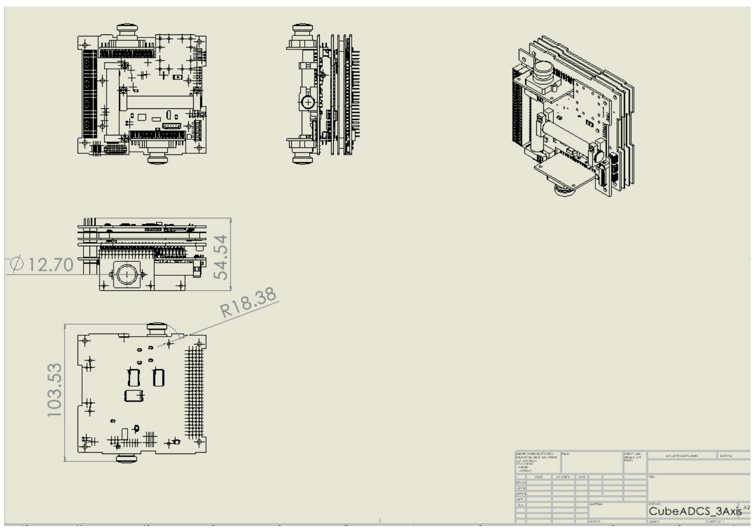


Figure . ADCS: The ADCS is one of two standard Cubesat ADCS'es that are used in both the impactor and the orbiter. It weighs 506 grams.

ARIST43US will also have its own attitude determination and control system (ADCS) featuring 3 reaction wheels for high precision and 3-axis of rotation. The ADCS is responsible for detecting and controlling attitude and orientation of the orbiter. The ADCS will provide pointing accuracy and stability for the satellite's radar antenna and infrared spectrometer which will play a critical part to the mission's success. Over time the reaction wheels may become saturated, at which point we may perform a small correction burn to compensate. This helps extend the lifespan of ARIST43US to outlast the initial mission plan and allow for future utilization of the craft.

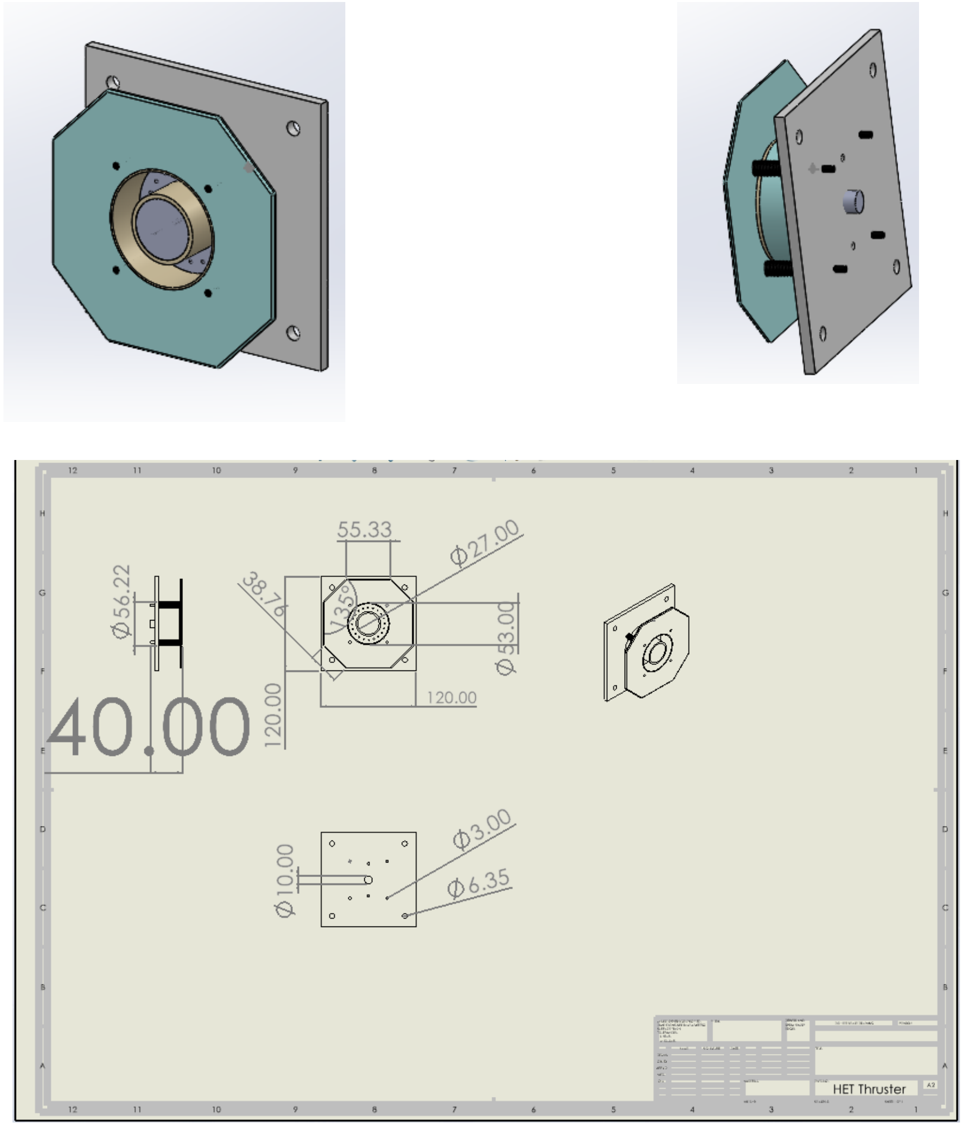
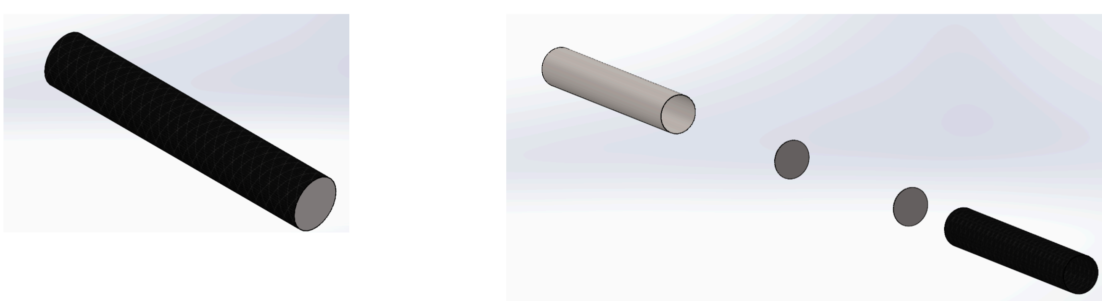


Figure . Xenon Thruster: This is the orbiter's one of five thrusters. It weighs 2.6 kilograms.



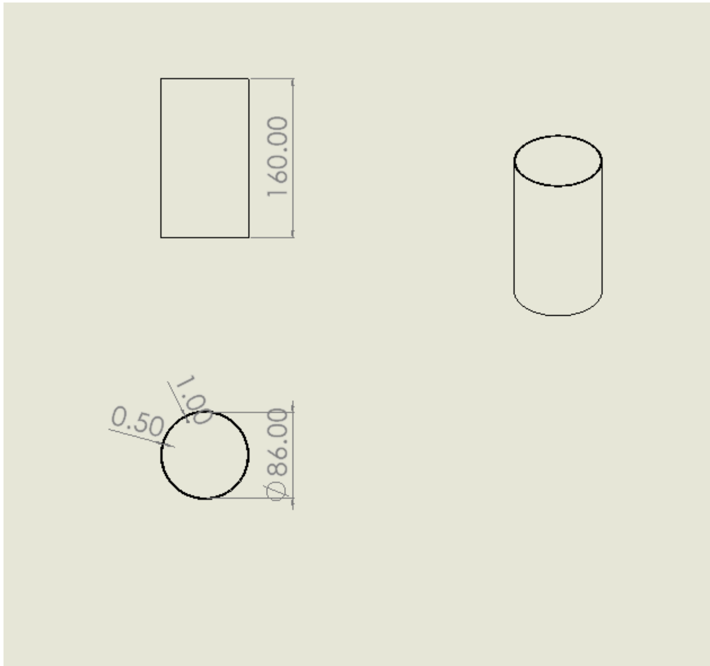
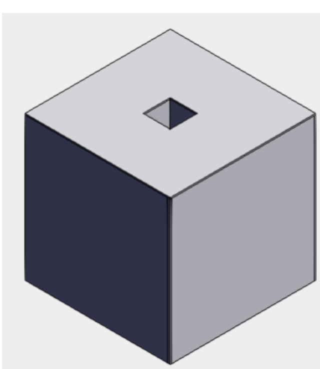
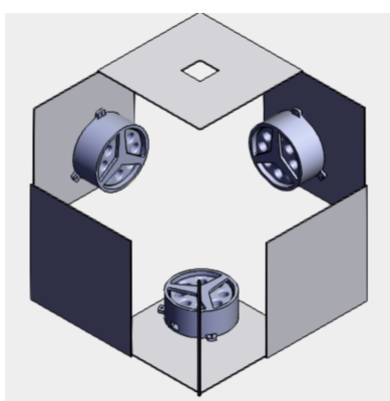
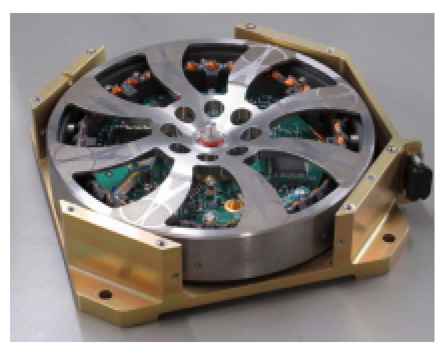


Figure . Main Fuel Tank(~6 liters of Xenon): This is the orbiter's main xenon fuel tank. It has a carbon fiber shell with titanium lining that weighs a total of 1368 grams with 6 liters of xenon gas.

ARIST43US will begin its mission at a 100km orbit, however by using the satellite propulsion system it will be able to perform any orbital adjustments in its inclination and orbital height. The propulsion system is made up of four Xenon-gas thrusters and a single fuel tank. The fuel tank is a 6 liter xenon gas tank that is composed of a carbon fiber shell with titanium lining. This will allow the craft to extend its functionality and future utility and make it far more versatile as a lunar research sate







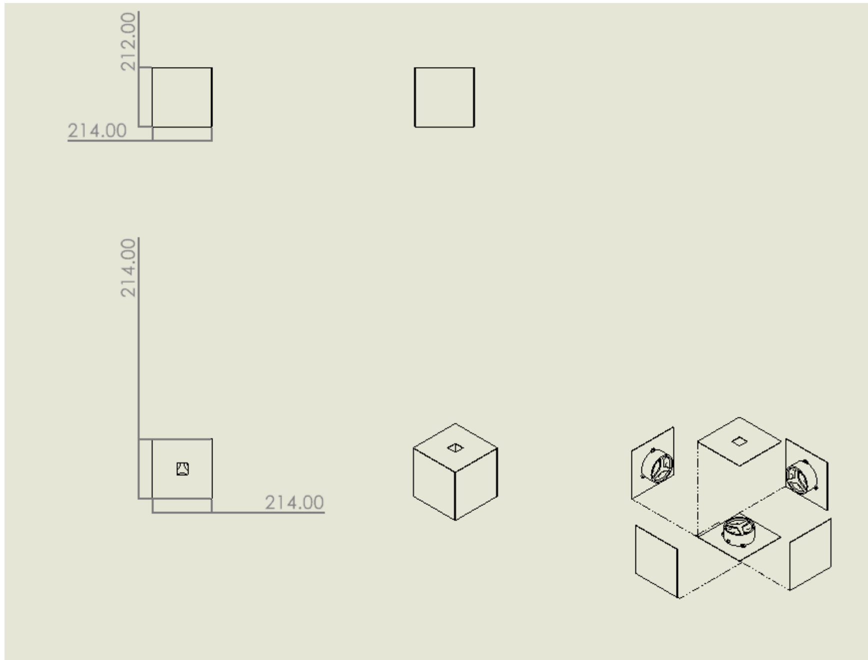
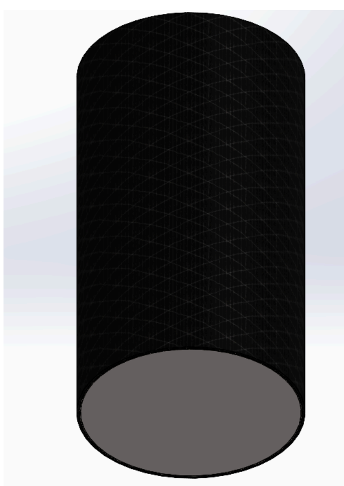


Figure . Reaction Wheel: This is the orbiter's reaction wheel cube composed of 3 reaction wheels inside an ABS plastic cube. It weighs 4.5 kilograms.



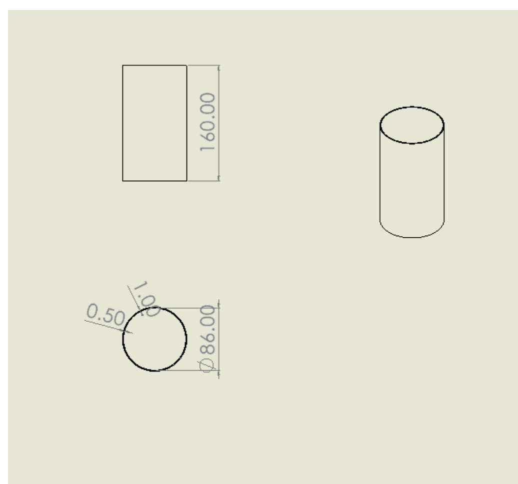


Figure . Impactor Fuel Tank (0.9 L): This is the impactor's fuel tank that is composed of the same material as the orbiter's fuel tank scaled down in size. It weighs 280.6 grams with 0.9 liters of xenon gas.

ARIST43US-I (Impactor) will contain its own guidance and propulsion systems which will be able to orient, aim, and perform a deorbit maneuver using the onboard thrusters. In order to accomplish this the Impactor requires its own miniature onboard ADCS reaction wheels or sphere and a small xenon-gas thruster.

3.1.3. Dimensioned CAD Drawing of Entire Assembly

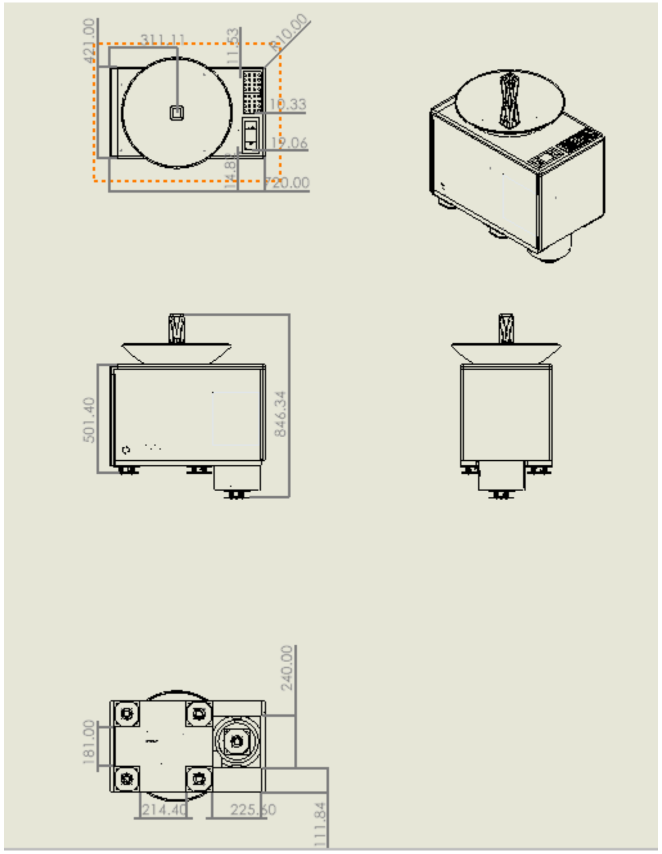


Figure 1. A drawing of a complete assembled model of the orbiter defined in millimeters.

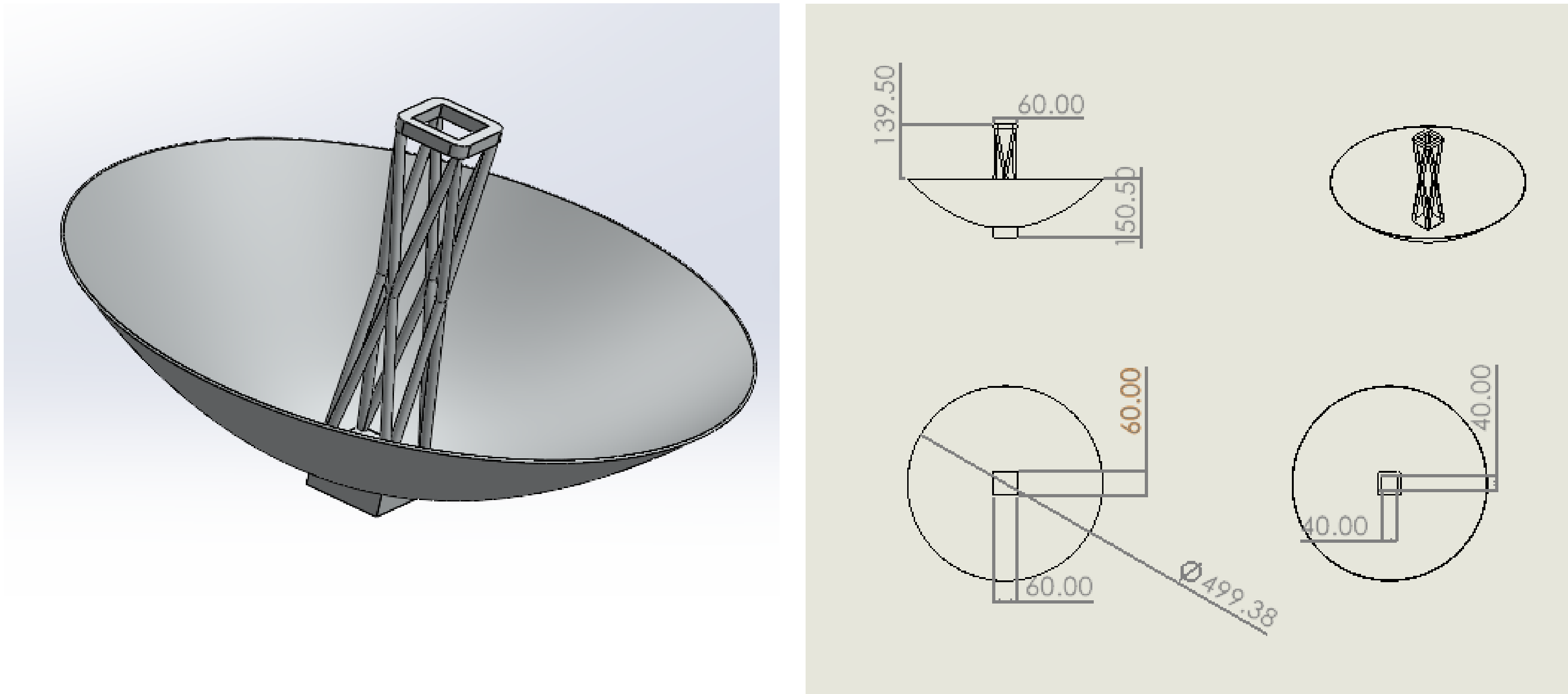


Figure 2. A drawing of the satellite dish, defined in millimeters.

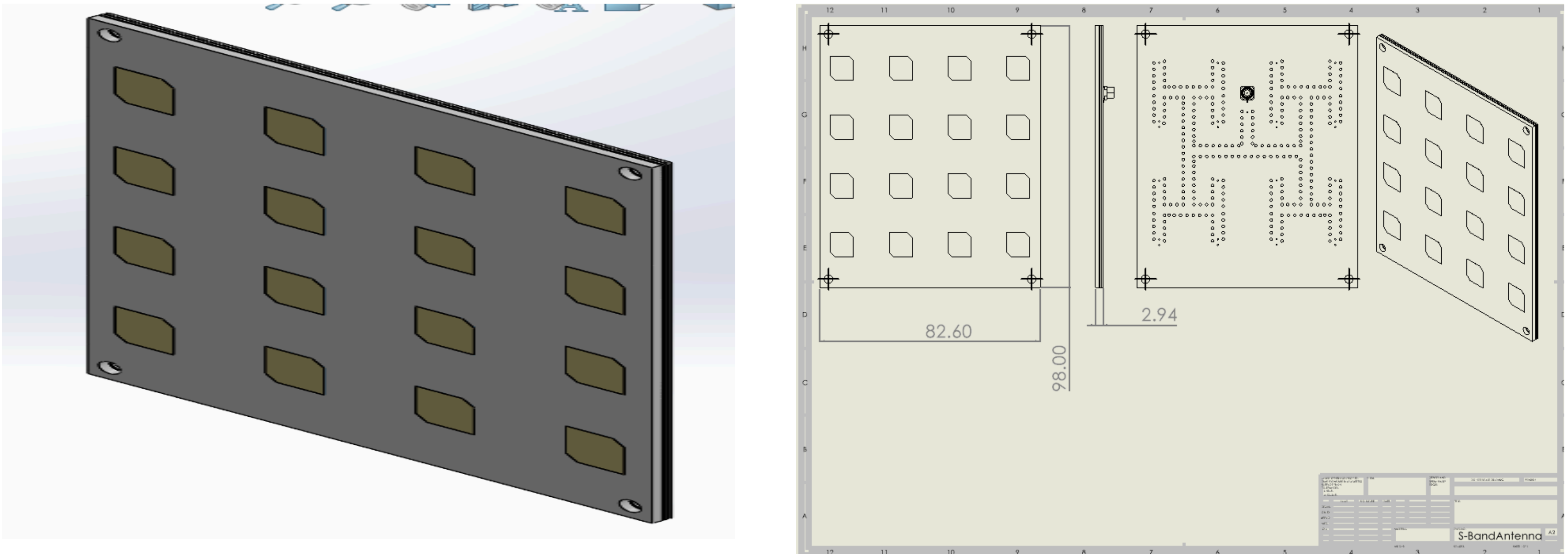


Figure 3. A drawing of communications S-band and UHF/VHF radio antennas.

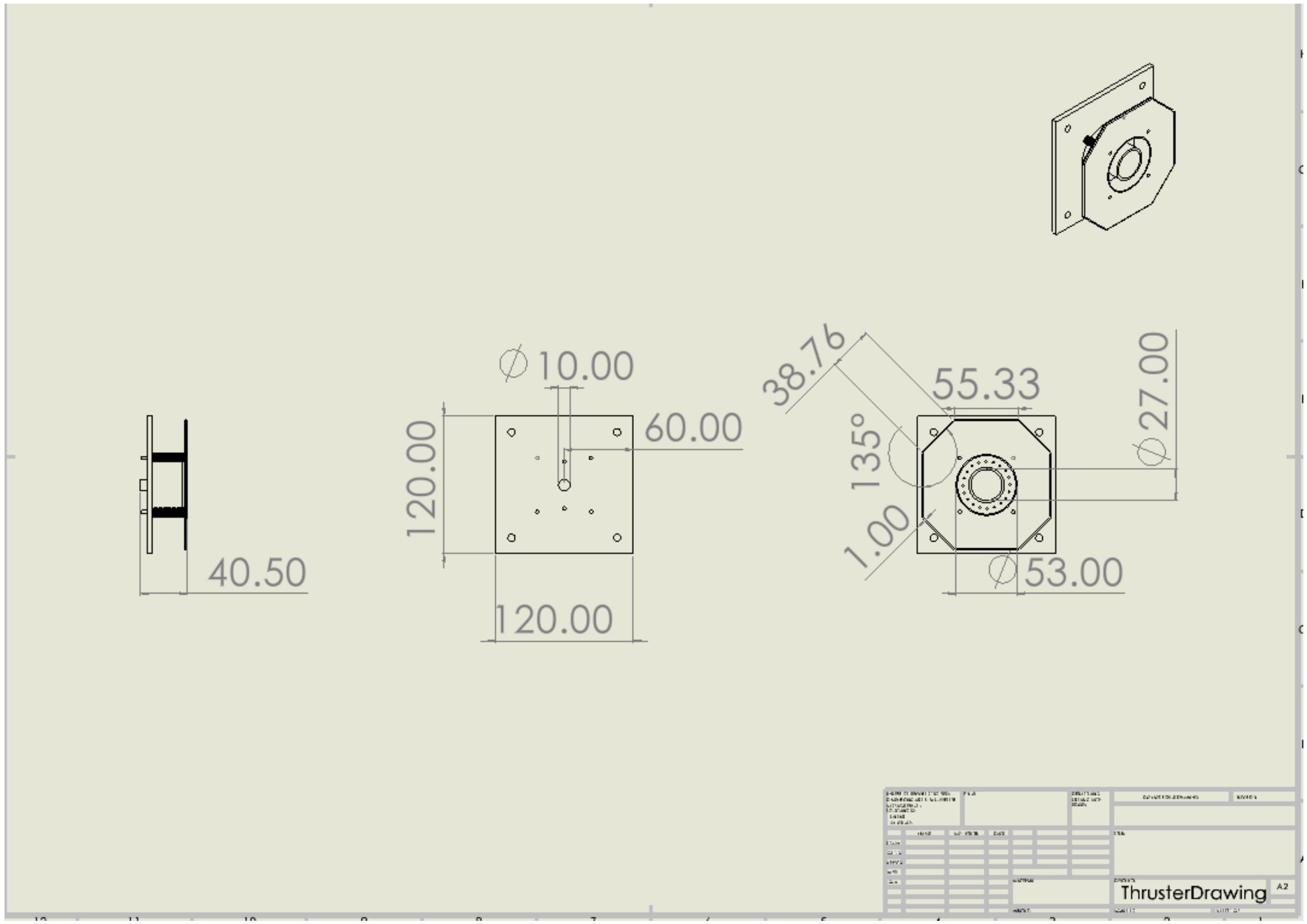


Figure 9. A drawing of a complete assembled model of the thruster defined in millimeters.

3.1.4. Manufacturing and Integration Plans

The scientific instruments on the orbiter will be outsourced to specialized companies and labs that develop such technology, such as the infrared spectroscopy and radar instruments. Throughout the prototyping and development process of all of the electronics, these off-the-shelf or custom manufactured items will be tested by the ARIST43US team scientists and engineers, who will test and communicate with the engineers of the respective contracted company. The framework of the orbiter and the impactor will be designed by the project engineers and will be manufactured off-site by a contracted company. Prototypes will be constructed in the earlier stages of the project by the contracted company, which the project engineers will test for integrity. Once this technology is well-developed and tested, the project engineers will need an on-site manufacturing lab to integrate the framework and all of the different instrumentation together. The resources needed to do so would include electronics fabrication supplies, computers, and controls engineering instruments. The project scientists and engineers working in this location will build and verify that the spacecraft is ready for launch.

As seen in the Project Schedule in Section 6, prototyping of the solar panels, energy backups, instruments, and other electronic components would begin only a few months after the start of the project. The fabrication of the framework of the orbiter and the impactor spans between 2022 and 2023. Through 2024 - 2025, this technology will be tested and validated for flight.

		Bill of Materials for ARIST43US								
				Part Mass (grams)	Total Mass (grams)	Yearly Cost	Total Cost	Manufacturer		
		Plastic		0.7 kilograms		$103	$309			
		Titanium Ti-8Al-1Mo-1V		13 kilograms		$532	$1,595			
		Carbon Fiber Hexcel AS4C (3000 Filaments)		0.5 kilograms		$467	$1,400			
	1	Aluminum Alloy		97 kilograms		$1,707	$5,121			
	2	Electrical Power System	1	400.00	400.00	$45,000	$135,000			

	3	Solar Panel Planes	12	270.00	3,240.00	$183,600	$550,800			
	4	Main Reaction Wheel	3	1,400.00	4,200.00	$240,000	$720,000			
		ADCS	2	506.00	1,012.00	$74,800	$224,400			
		Impactor Cube Wheel	3	60.00	180.00	$14,100	$42,300			
	5	Monostatic Radar	1(Manufactured Aluminum)	2,118.76	2,118.76	$1,758	$5,274			
	6	Thrusters	5	2,600.00	13,000.00	$25,000,000	$75,000,000			
	7	On Board Computer	1	130.00	130.00	$3,650	$10,950			
	9	Main Battery	1	12,247.00	12,247.00	$1,075	$3,224			
	10	Impactor Battery	1	1,034.00	1,034.00	$126	$378			
	11	S-Band Radio	1	250.00	250.00	$11,110	$33,330			
	12	UHF/VHF Radio	1	75.00	75.00	$10,069	$30,206			
	13	Communications Antenna	2	53.00	106.00	$15,200	$45,600			
		Temperature Probe	2	78.00	78.00	$21	$63			
	14	Thermal Silicon Heater(1224 cm^2,	1		61.20		$0			

		thickness 0.3cm)								
	15	Spectrometer	1		453.59	$50,000	$150,000			
n	16	Motors	15		0.00	$1,000	$3,000			
	17	Wires	20		0.00	$2,000	$6,000			
	18	Solder	10		0.00	$2,000	$2,000			
	19	Soldering Kits	5		0.00	$690.00	$690.00			
	20	Sensors	15		0.00	$300-$2000	$300-$2000			
		Impactor Xenon Fuel(0.9 Liters)	900g	900g	900g	$1,080	$1,080			
		Main Xenon Fuel(6 Liters)	6000g	6000g	6000g	$7,200	$7,200			
	21	Xenon Fuel	100g			$120	$120			
	22	Multi-Layered Insulation	1		3.5 kg	$11,667	$11,667			
					138,000.00					

	Manufacturing/Facilities/Transportation Costs for ARIST43US						
	Labor Costs/Salaries	**Quantity**	**Unit Price**	**Year 1**	**Year 2**	**Year 3**	**Total Cost**
1	Project Managers	2	$180,000	$360,000	$360,000	$360,000	$1,080,000
2	Engineering Manager	1	$140,000	$140,000	$140,000	$140,000	$420,000
3	Business Manager	1	$100,000	$100,000	$100,000	$100,000	$300,000
4	Chief Scientist	1	$140,000	$140,000	$140,000	$140,000	$420,000
5	Engineer	3	$90,000	$270,000	$270,000	$270,000	$810,000
6	Business Operator	2	$75,000	$150,000	$150,000	$150,000	$450,000
7	Scientist	2	$100,000	$100,000	$100,000	$100,000	$300,000
	Equipment						
8	Forklifts	3	$10,000	$30,000	$30,000	$30,000	$90,000

9	Electrical Pallet Jacks	4	$5,000	$20,000	$20,000	$20,000	$60,000
10	Machinery	5	$15,000	$75,000	$75,000	$75,000	$225,000
11	Welding Equipment Kits	3	$3,500	$10,500	$10,500	$10,500	$31,500
12	Tools	5	$1,200	$6,000	$6,000	$6,000	$18,000
13	Computers/Software	12	$2,000	$24,000	$24,000	$24,000	$72,000
	Facilities						
14	(Gas, Water, Electricity, Heating/Cooling, Internet)	1	$52,000	$52,000	$52,000	$52,000	$156,000
15	Property Lease	1	$335,500	$335,000	$335,000	$335,000	$1,005,000
16	Food/Water	1	$20,000	$20,000	$20,000	$20,000	$60,000
17	Office Supplies	1	$20,000	$20,000	$20,000	$20,000	$60,000
	Transportation						
19	Trucks(Diesel/Petro)	10	$30,000	$300,000	$300,000	$300,000	$900,000
20	Fuel	10,000	$5.00	$50,000	$50,000	$50,000	$150,000
	Total						$13,215,000

3.1.5. Verification and Validation Plans

The first verification tests are implemented to test whether the finished device meets the allocated requirements. The mission's spacecraft must have its dimensions measured to meet the volume constraint which is 23.7 inches x 28 inches x 38 inches. The spacecraft must be weighed to possess a mass of up to 180 kilograms. In addition to weight measurements, the orbiter should be calculated on a 3D CAD modeler to have a sufficient moment of inertia and center of gravity before the orbiter is assembled, as well as any materials and dynamics testing on the CAD modeling software.

The orbiter utilizes a battery system that must be tested to see if it can contain enough power to meet the amperage demands of the electronic devices contained within the spacecraft. This is checked with a Battery Discharge Test that uses a battery discharger to calculate the amperages available with the battery and the cell count to see if it can meet the current and power demands of the electronic devices. In order to simulate the conditions in which the spacecraft would be during and after launch, validation testing should be performed to simulate the environment. A Thermal Cycling test should be performed to observe whether the spacecraft's performance isn't hindered at varying temperatures which typically ranges from -30 degrees Celsius to 65 degrees Celsius with a temperature variation rate greater than 1 degree Celsius per minute. In an ideal situation, the team would be able to conduct more tests utilizing different facilities and equipment such as a thermal vacuum to test the spacecraft's performance at varying pressure and temperature rates, a Vibration Test System to demonstrate whether the spacecraft can survive the vibrations experienced during launch and deployment. Pyroshock testing is required to prevent the spacecraft from being damaged by Pyroshock, which is "a stress or shock wave propagates through the structure and into the electronic equipment contained within the structure" after different stages during spacecraft launch where components split off after explosive events. Based on multiple sources, Pyroshock can be best tested for at a Pyroshock testing facility that utilizes an array of different large and expensive electronics and sensors to test for pyroshock under varying frequencies. Other tests such as shock tests and drop tests can be conducted with more testing equipment to test the spacecraft's performance during flight as well as the impactors performance when dropped from a high altitude as it would be in orbit.

In addition to all these tests, we will also perform a static test for the thrusters that includes a dress rehearsal in a vacuum environment. This process begins with firing the engine at full thrust for about twelve to twenty seconds while the launch vehicle is firmly held to the launch mount. Then the test engine is ignited(startup) while measuring pressure, temperature, and propellant flow gradient. We can perform this test whether or not there is a payload on the craft. The data gathered from this test will be utilized to determine the criteria for the Go/No-go decision tree in the launch software used on launch day.

Finally, we will carry out hypervelocity impact testing to simulate the micrometeoroids and orbital debris's impact on the spacecraft shielding, components, materials, and various test configurations. To accomplish this, we would utilize two-stage light gas gun equipment. This equipment can fire projectiles at a speed of up to 24,000 feet per second. Also, swing drop test for water landings. In this test, the payload vehicle will be dropped vertically into the pool; this will help fine-tune how we predict how the spacecraft load landing.

3.1.6. FMEA and Risk Mitigation

Like most things, space exploration and the fabrication of the ARIST43US Lunar Orbiter encounter a multitude of risks and hazards that range in a variety of severity levels. Ever since the beginning of space exploration programs in the 19th-century, there have been many incidents in project development and operations that have cost billions of dollars and the death of many lives. In order to continue with the development of the ARIST43US, the risks and hazards must be analyzed. The purpose of this section is to introduce the Failure Mode and Effects Analysis (FMEA) and Risk Mitigation analysis of this project.

Failure Mode and Effects Analysis (FMEA) is defined as a structured approach to identify possible failures within a product or service by analyzing designs and processes (Quality-One).

In this analysis, “failure modes are the ways in which a process can fail and effects are the ways these failures can lead to waste, defects, and harmful outcomes for clients.” (Quality-One). Risk Management is “an organized, systematic decision-making process that efficiently identifies risks, assesses or analyze risks, and efficiently reduces or eliminates risks to achieving program goals.” By implementing FMEA and Risk Mitigation analysis, potential risks, hazards, and failures will be identified and analyzed before deployment of the ARIST43US Lunar Orbiter.

The ARIST43US Lunar Orbiter has ten main components which will be analyzed from there functions, failure modes, effects, causes, design controls (prevention and detection), and recommended actions. In addition, Risk Mitigation will analyze the likelihood and consequences of each component's potential risks and hazards. This section will allow project leaders and team members to continue with the development of the ARIST43US Lunar Orbiter.

LIKELIHOOD					
5					
4			7		4
3			6	1 5	2 9
2				8	3
1					
	1	2	3	4	5
	CONSEQUENCES				

Critically	**LxC Trend**	**Approach**
High	↓ Decreasing (Improving)	M-Mitigate
Med	↑ Increasing (Worsening)	W-Watch
Low	→ Unchanged □New Since Last Period	A-Accept R-Research

Rank & Trend	**Approach**	**Risk Title**
→1	M	Signals may not have enough power to transmit and create faults in communication systems.
↓2	A	Error in ADCS operation could lead to the orbiter missing a specified target.
→3	A	ADCS prevents energy from relaying to the rest of the orbiter.
→4	R	Electrical power system shorts and does not supply electric power.
↓5	M	Failure in these components operations could prevent transmissions of any kind including data, images, etc.
↑6	R	Failure in instruments results in false data collection.
→7	W	Potentially damages impactors from being deployed again
→8	W	Thrusters do not ignite and fail to push the orbiter.
↓9	R	Thermal energy not being distributed to the rest of the orbiter.

(2) CubeWheel										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To control the altitude of orbiter.	Improper configuration could provide incorrect navigation for orbiter.	Orbiter unable to operate.	9	CubeWheel improperly soldered or configured to radar antenna or navigational system.	7	Make sure components are compatible.	Run tests for Radar Antenna with Cube Wheel.	6	378	
To provide a mechanism for orbiter navigational system.		Orbiter goes out-of-range from Lunar orbit.	8			Test whether components operate together. Test navigation for low and	Run tests for CubeWheel and navigation system.	6	336	

						mid ranges.				
To inable ADCS operation.	Error in ADCS operation could lead to orbiter missing specified target.	Orbiter completely misses target.	9	CubeWheel improperly configured to ADCS.	7	Test CubeWheel and ADCS for several levels of targets.	Run tests for CubeWheel and ADCS.	6	378	1. Have multiple checkpoints in assembly. 2. Setup navigation checks in low and mid range. 3.Setup navigation checks in long range.

(3) ADCS										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To stabilise and point satellite to target.	Operations fail and do allow orbiter to reach target.	Orbiter unable to operate.	10	ADCS improperly fabricated.	5	Make sure ADCS is functioning properly.	Run tests on ADCS.	4	200	
To provide pointing accuracy for payloads and antennas.	Antennas and payloads not operating with ADCS.	Antenna prevents proper navigating and steering from CubeWheel and ADCS.	9	ADCS improperly configured with CubeWheel or Antenna.	5	Reassure ADCS and CubeWheel are properly configured.	Run tests with ADCS and CubeWheel assembly.	7	315	
To relay energy for electrical power system.	ADCS prevents energy from relaying to rest of orbiter.	Orbiter unable to operate	10	Electrical power system may be shorting.	5	Identify any errors in energy output from electrical power system.	Run tests on various components with the electrical power system and ADCS assembly.	7	350	1.Have multiple checkpoints with assembly. 2. Setup test with electrical power system and ADCS assembly. 3. Run tests with one or two more components before proceeding.

(7) Impactor										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To hit a body and reveal internal structure.	Misses target by deploying impactors too early or too late.	Prevents Orbiter from analyzing chemical compounds from target.	9	Errors in navigational system force impactors to deploy incorrectly.	5	Make sure proper assembly of components with Impactors.	Run tests on Impactor deployment with navigation system.	4	180	
To prevent orbiter from encountering potential physical hazards.	Potentially damages impactors from being deployed again.	Prevents Orbiter from accomplishing mission.	10	Brittle material from impactors reduces durability.	5	Make sure material is durable enough to encounter space hazards.	Test material with various trials.	5	250	1.Have multiple checkpoints with assembly. 2. Setup impactors and simulate potential space hazards 3.Make sure operations flow in rest of assembly.

(8) 2x2 Nano Thrusters										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To produce thrust, or propulsion, and push the orbiter.	Thrusters do not ignite and fail to push the orbiter.	Prevents orbiter from accelerating in space.	8	Error in thruster assembly or damages from space hazards.	6	Make sure proper assembly of components with thrusters and determine proper flow from fuel take to thruster.	Run tests to analyze thruster performance and troubleshoot where needed.	6	288	1.Have multiple checkpoints with assembly. 2. Run tests on thrusters and analyze performance. 3.Make sure operations flow in rest of assembly

3.1.7. Performance Characteristics and Predictions

The performance of the thrusters will be analyzed to see how much thrust is exerted in order to determine whether it can reach the orbit of Earth's moon and help the Impactor deorbit itself and impact the moon. All of the sensors and scientific instruments would adequately pinpoint the PSR's sources of lunar water and determine the composition of the lunar ice that is composed of water. The transmitters and transceivers would establish two-way radio with the main satellite and Earth to relay the required data.

BHT - 600 System Technical Specifications								
Throttle Range	**Nominal Discharge Power**	**Thrust**	**Specific Impulse**	**Propellant**	**Cathode**	**Cathode Location**	**Thruster Mass**	**Cathode Mass**
300W - 800W	600W	39 mN	1500 seconds	Xenon	BHC-1500	External	2.6 kg	0.2 kg

The normal operating temperatures of each subsystem onboard the satellite must be taken into consideration to ensure optimal performance while in orbit around the moon. Thermal components will be utilized to counteract the extreme temperature lows and highs the satellite will be subjected to. The table below shows the operating temperatures of the systems onboard the orbiter. '

Subsystem Component	LOW Operating Temperature °C	HIGH Operating Temperature °C
ADCS	10	60
Reaction Wheels	−40	70
S-Band Transmitter	−40	70
GPS Patch Antenna	-30	70

Infrared Spectrometer	−40	60
Solar Panels	-100	125
Batteries	-20	70

Maintaining each of these devices within the normal operating temperature will allow the science instrumentation to provide the best data for water abundance in the PSRs. The DWARF-Star NIR Spectrometer is expected to provide data from the lunar surface by taking measurements in the 900-1700nm wavelength range, achieving resolutions down to 1.25 nm. In addition the High performance InGaAs detectors with 1024 linear 25μm by 500μm pixels installed within the spectrometer are expected to provide maximum sensitivity. The monostatic radar will provide data by scanning deeper into the PSR regions.

3.1.8. Confidence and Maturity of Design

The Arist43us spacecraft will feature multiple instruments and subsystems, including data gathering, power systems, thermal management, attitude determination and control, satellite propulsion, and deployable mass impactor designed to enable long-term lunar observation. To enable longevity of the exploration, solar panels along with Lithium-ion batteries have been integrated to generate, store, and manage the power necessary for satellite functionality. Lithium-ion batteries have long been used in NASA missions and crafts, such as the International Space Station, due to their high density energy and have been designed to mitigate volatile chemical reactions.

Furthermore, to meet the design and mission criteria, primary instruments such as radar and infrared sensing instrumentation will be integrated into the spacecraft to enable the production of higher resolution models of the ice distribution located within the permanently shadowed regions. Infrared spectrometers were successfully used in the Deep Impact mission, in a very similar context. Like the Deep Impact mission, this mission aims to impact the surface to probe further into the regolith and analyze the composition with the spectroscope. Radar imaging is commonly used in satellites and has been successful in capturing and mapping surfaces, such as in the Spaceborne Imaging Radar C/X-Band Synthetic Aperture Radar.

Steps were taken to ensure that materials, part specifications, and unit performance meet the NASA Technical Standards and Engineering Policies with respect to manufacturing and designs. Additionally, these off-the-shelf or custom-manufactured items will be tested by the ARIST43US team scientists and engineers, who will test and communicate with the engineers of the respective contracted company if there be need for any modifications in the system. These projects scientists and engineers will ultimately verify that the spacecraft is ready for launch by carrying out a test for dimensions test. Each piece of equipment and material will also undergo thermal cycling tests to observe whether the spacecraft’s performance isn’t hindered at varying temperatures or reaches a failure point at certain temperatures.

Conclusively, the final check will then be the application of Failure Mode and Effects Analysis (FMEA) and Risk Mitigation steps. The FMEA is defined as a structured approach to identify possible failures within a product or service by analyzing designs and processes. Potential risks, hazards, and failures will be identified and analyzed before deployment of the ARIST43US

Lunar Orbiter. These processes will also analyze the likelihood and consequences of each component's potential risks and hazards.

3.2. Recovery/Redundancy System

In the situation that parts of the orbiter are damaged or are no longer functional, there are backup plans in place. There is no cost-effective and feasible way of repairing or replacing the components on the satellite if they malfunction; therefore each component must have redundant copies or be designed in such a way it protects from malfunction.

Electronics on the orbiter that are integral to the completion of the mission have backup, redundant components. The computers will use Triple Modular Redundancy (TMR) circuits to ensure one computer has redundant components and can handle the necessary computation in the event of failure of the other computers. To conserve energy, the computer used as the backup unit will lie dormant until it is needed. Each electronics component and instrument will each be individually routed to the control systems, such that if one malfunctions, it will not interfere with the others' performance.

Various mechanical components will be designed to be fault-tolerant, such as the actuators on the orbiter. There are high-redundancy actuators (HRAs) on the orbiter that release the impactor that rests inside the orbiter. In order to make sure the impactors can be deployed in the event the actuators do not function properly, the actuators are designed to have a structure of smaller actuators placed together in both series and parallel inside the actuator housing. If one actuator fails in this configuration, another actuator can complete the needed action.

Certain measures have been taken to avoid damage and the need for redundancy or recovery. Because the satellite dish is located on the outside of the orbiter, it has a greater chance to be damaged during the launch or separation from the payload. The satellite's antenna will be collapsed and folded at the start of the launch, and only emerge upon separation from the payload. It will also be held in a mount inside the orbiter that ensures the instrumentation has enough clearance to not impact any neighboring parts during heavy vibration or volatile motion. This is also the case for the rest of the scientific instrumentation, such as the spectroscopy, radar, and telemetry instruments.

3.3. Payload Integration

All components of the secondary payload spacecraft will be integrated to ensure optimal functionality of onboard instruments within the given 23.7 in x 28 in x 38 in volume constraint. The key science instruments on the orbiter include the monostatic radar dish with its antenna as well as an infrared spectrometer.

From an isometric point of view, the radar dish and antenna will be mounted on the top of the satellite. The top of the satellite is the optimal position as it will not interfere with the thermal radiators and solar panels on each respective side of the oribter, as well as the impactor bay at the bottom, where the surface impactor and thrusters are located. As the spacecraft is placed into its required orbit, the radar will rely on the Attitude Determination & Control System (ADCS) which powers the reaction wheels to obtain the correct orientation to begin scanning the PSR regions. The ADCS system is housed in a dedicated cube on the interior of the orbiter which has the reaction wheels mounted on three of the four sides for roll, pitch, and yaw control. Similarly to the radar, the infrared spectrometry sensors mounted below the radar dish rely on this system for its orientation.

Each of the other components such as the power systems box, electronics box, composed of the UHF/VHF transceiver and S-Band Transmitter, and the fuel tank for the thrusters are located within close proximity to each other on the interior of the orbiter. They will play a vital role in powering and orienting the science instruments to gain accurate data of water abundance in the PSRs.

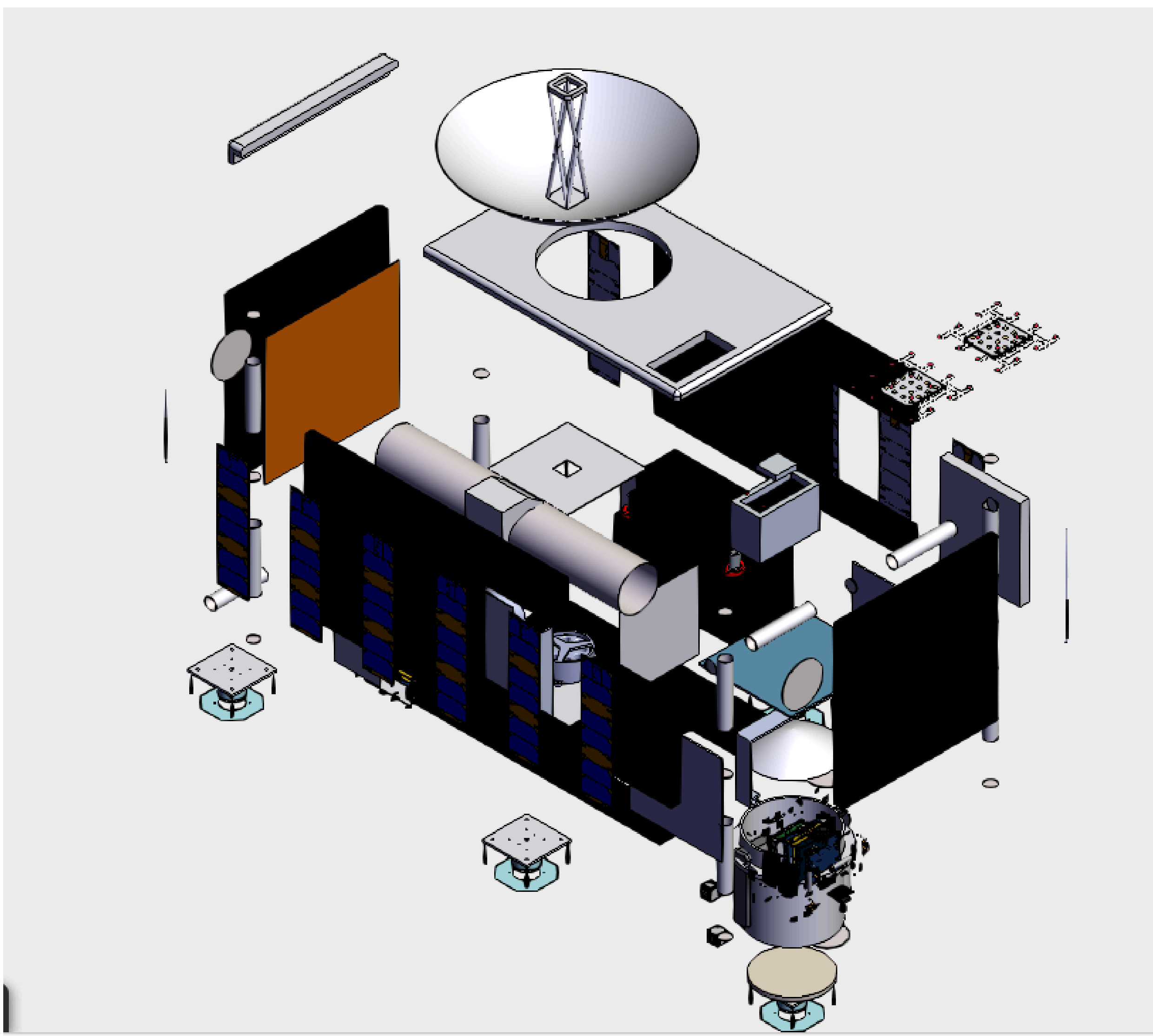


Figure . Exploded View of the Orbiter.

Section 4: Payload Design and Science Instrumentation

4.1. Selection, Design, and Verification

4.1.1. System Overview

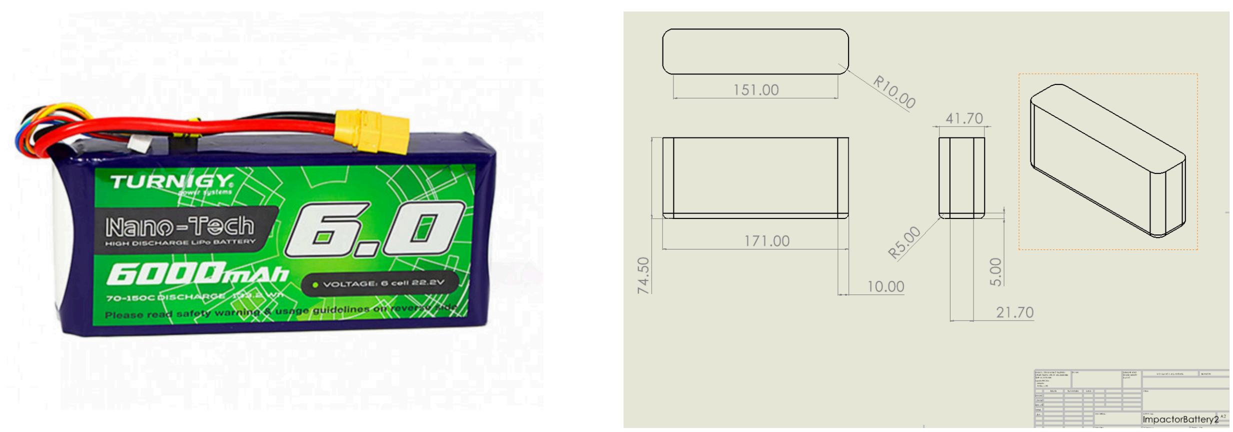


Figure . Impactor Battery: This is the lithium-ion battery that will power the impactor. It weighs 1034 grams.

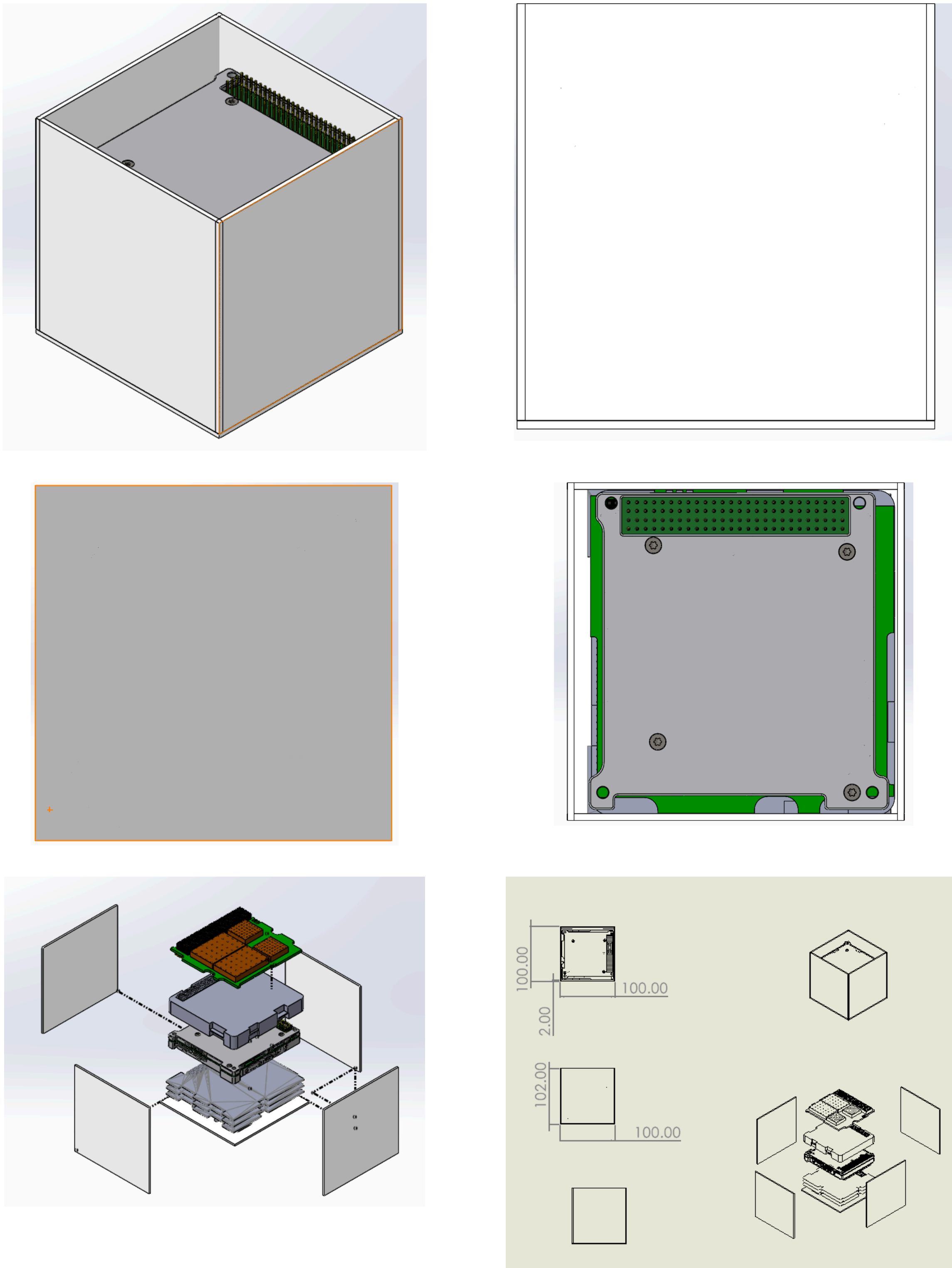


Figure . Main Electronics Box: The electronics box is composed of the On-Board Computer, S-Band transmitter, UHF transceiver, and the ADCS. It has an ABS plastic shell and the total mass is 1.06 kilograms.

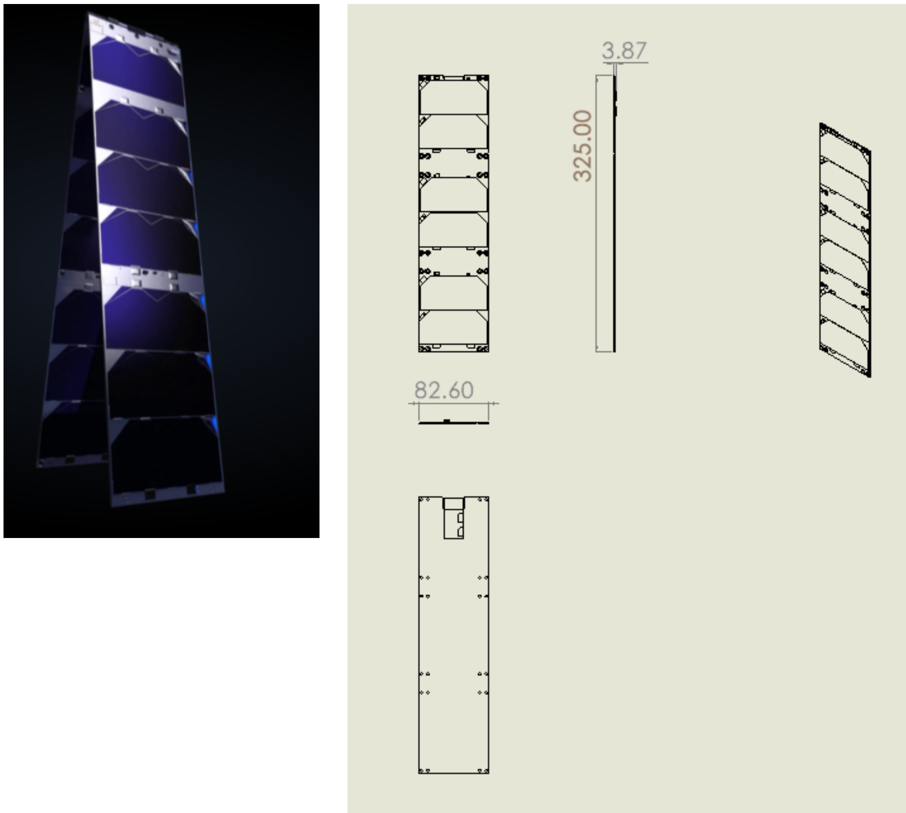


Figure . Solar Panel: This is the orbiter's one of twelve deployable solar panels that provides roughly 33.6 watts of power each. It weighs 270 grams.

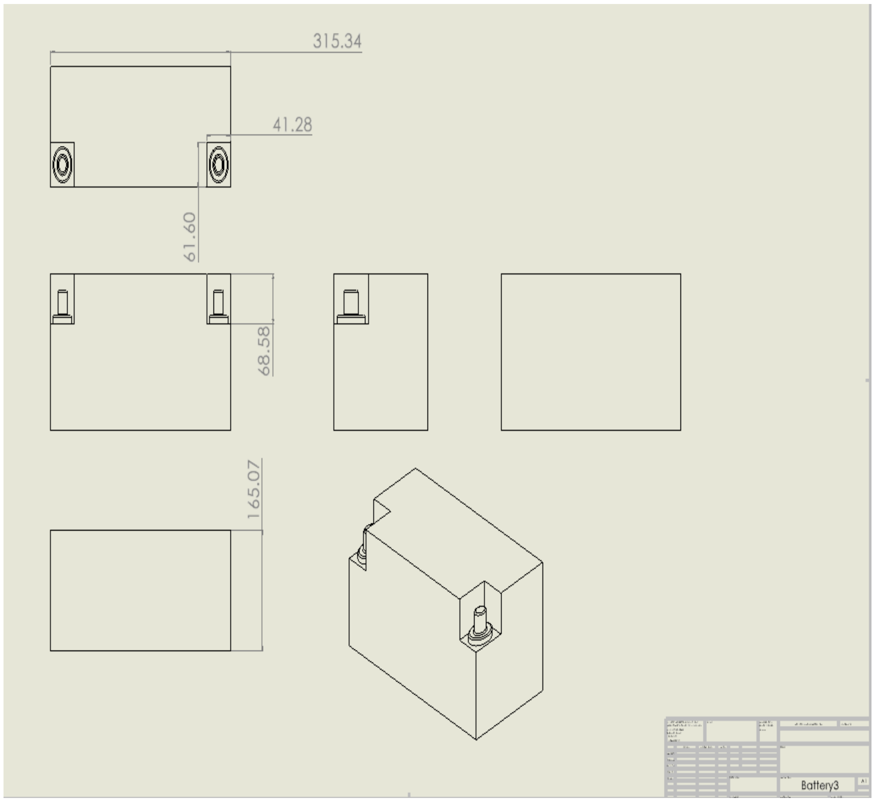


Figure . Main battery: This is the orbiter's main lithium-ion battery that provides 1.2 kilowatt-hours of power provided by the solar panels. It weighs 12.247 kilograms.

The Arist43us spacecraft will feature a number of instruments and sub-systems designed to enable long term Lunar observation; these systems include data gathering, power systems, thermal management, and deployable mass impactor. Among the systems aboard the Arist43us orbiter, data gathering and communication will be essential to this missions' success. The data for determining the abundance of water in the permanently shadowed regions of the moon will be found using radar and infrared spectroscopy. From there, the data will then be sent to the primary mission payload using an S-band radio. All of these will be powered by a battery which will be powered by solar panels. Aside from these data gathering components, the main battery system will power the deployable mass impactor as well as the reaction wheels and motors that control the direction of the solar panels and information gathering components. There will also be a thermal radiator on board designed to control the temperature of the spacecraft and its several components. In terms of the specific power usage of each component on the spacecraft, exact components have not been selected yet. However, approximate calculations from our research shows that the cube wheels will require at least 180 mW, the ADCS plate will require at least one watt, and the S-band transmitter will require at least 13 W.

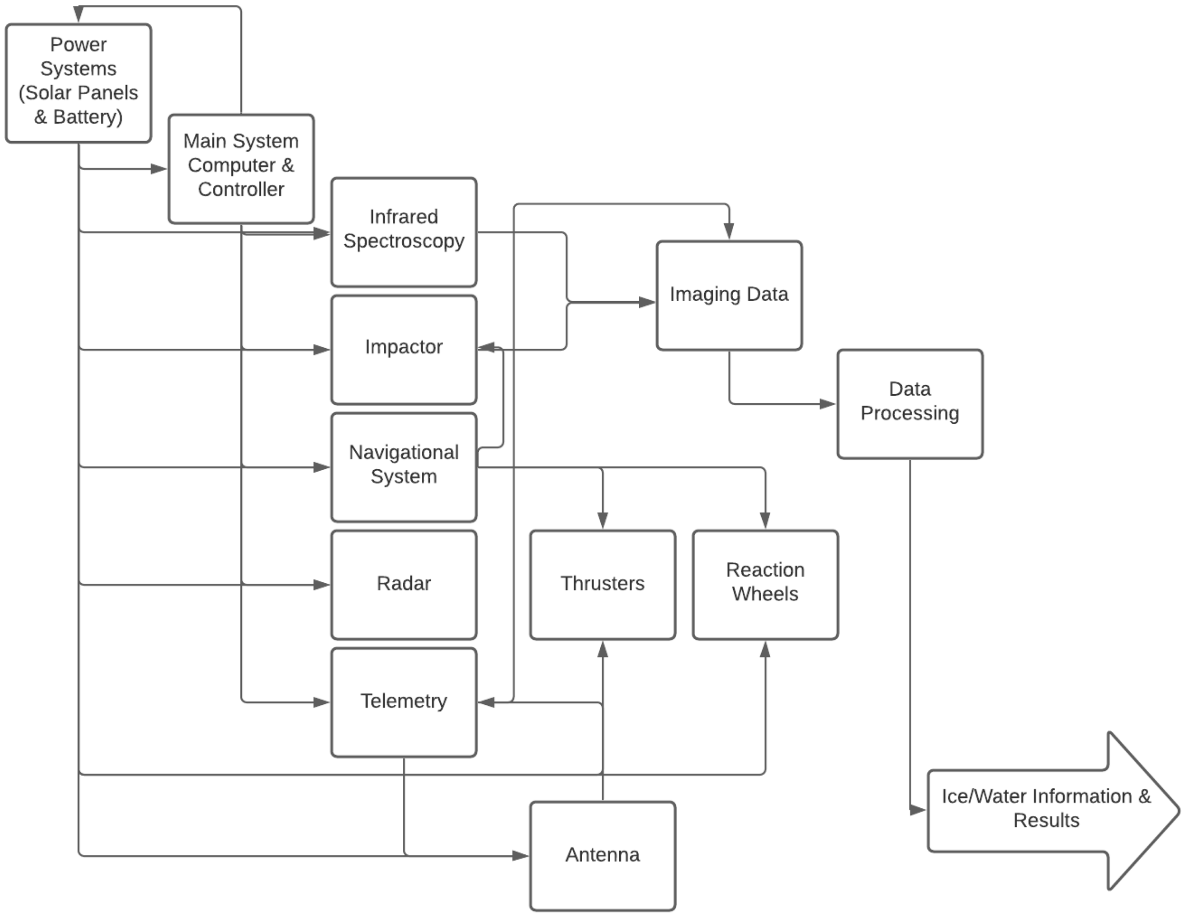


Figure 10. An N^2 chart of the interaction and dependencies between various systems.

4.1.2. Subsystem Overview

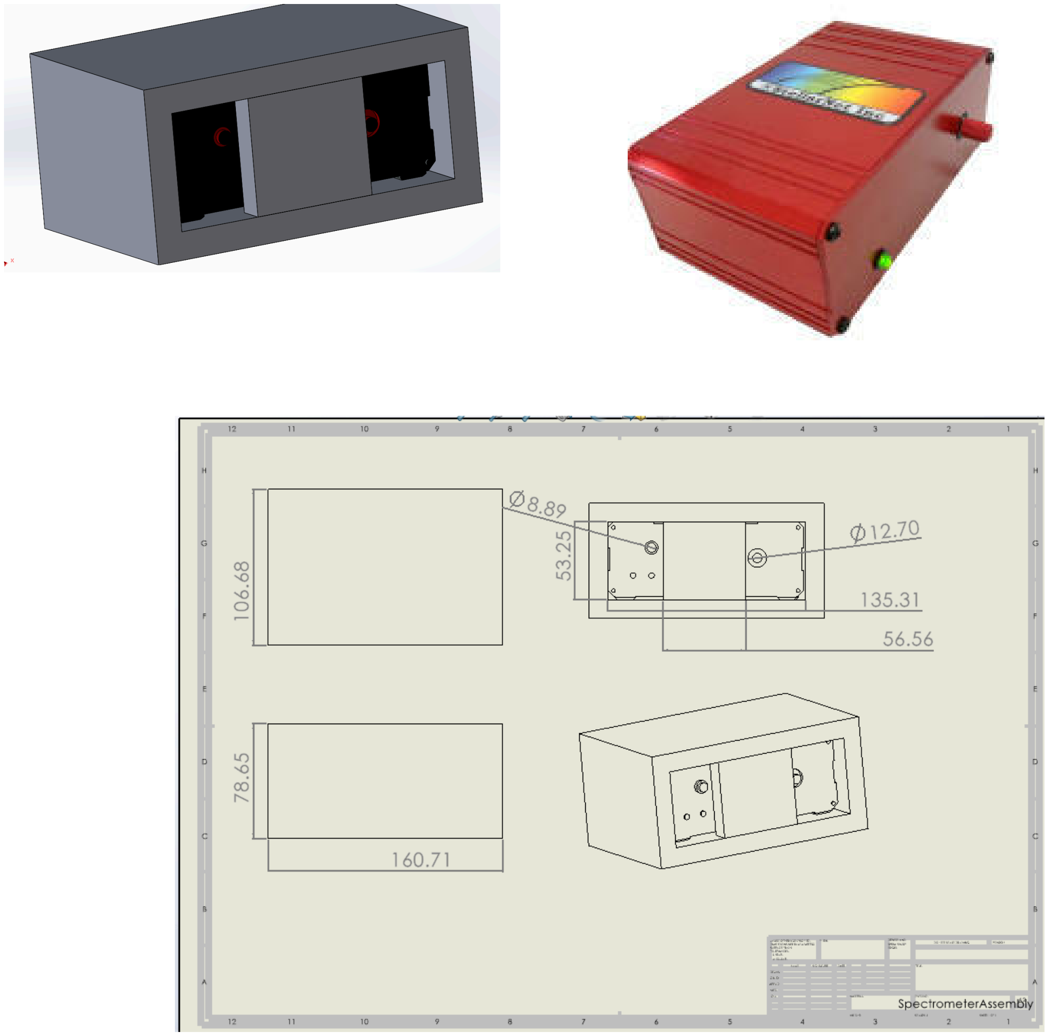


Figure . Spectrometer: This is the orbiter's spectrometer. It weighs 0.45 kilograms which will be placed in a 1060 aluminum alloy container..

The primary instruments of the craft are the radar and infrared sensing instrumentation which will be able to produce higher resolution models of the ice distribution located within the permanently shadowed regions. Among these two instruments, the infrared spectrometer will be able to receive measurements within a wavelength of 900-1700 nm. This is particularly useful because Arist43us will be able to study the PSR regions with near infrared light (NIR) along with shortwave infrared light (SWIR), therefore allowing the spacecraft to be able to discern between land and water lines while also studying the abundance of water in the regolith. Specifically, Arist43us will utilize wavelengths between 900-1,100nm to study NIR then a wavelength of 1,400nm to study the SWIR at the south pole due to water's tendency to absorb these wavelengths.

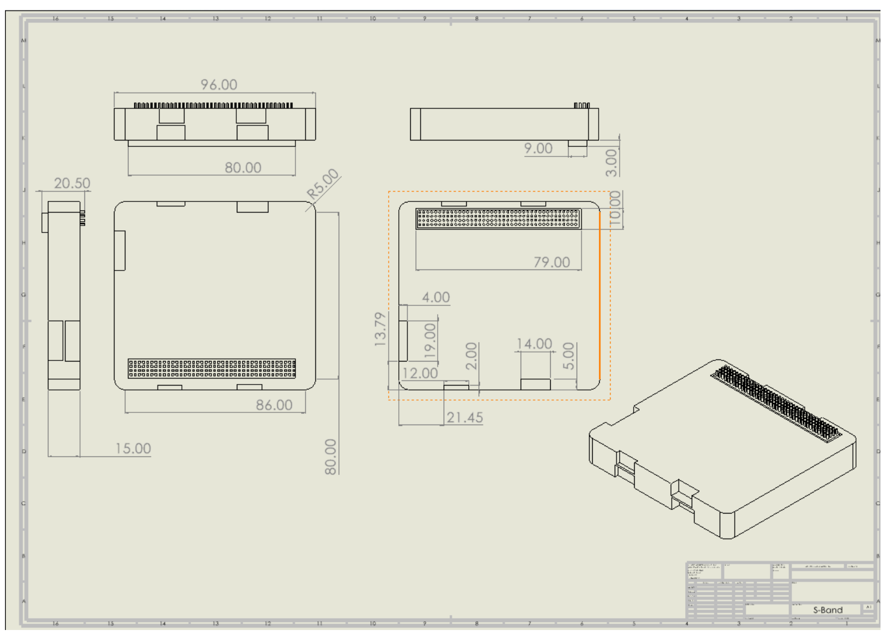
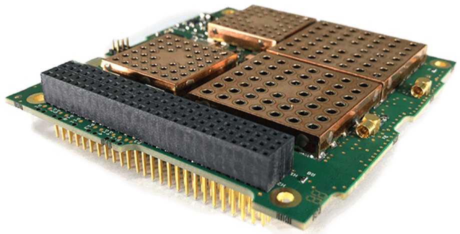


Figure . S-band transmitter: This is the S-band transmitter that will be placed in the electronics box. It weighs 250 grams.



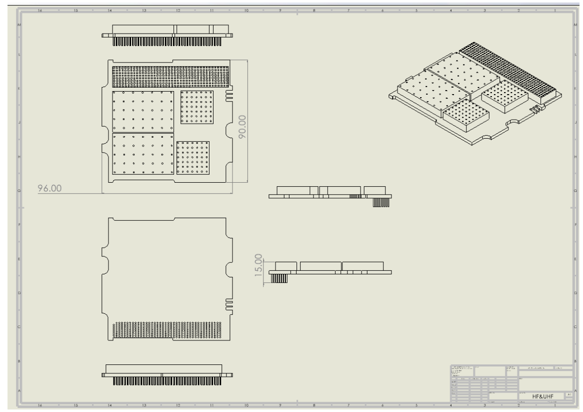


Figure . VHF/UHF transceiver: This is the UHF/VHF transceiver that will be placed in the electronics box that weighs 75 grams.

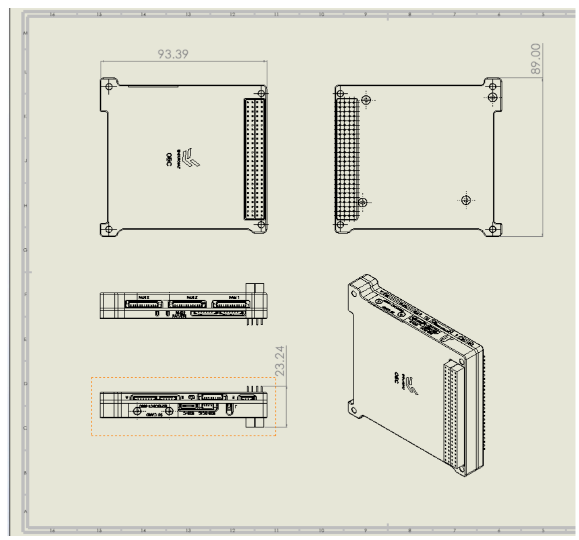
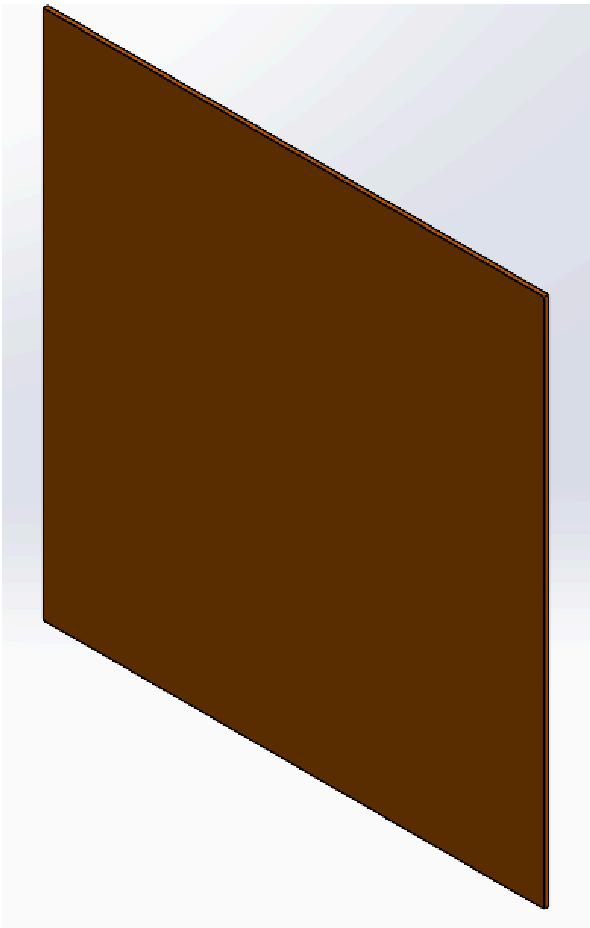


Figure . On-Board Computer: This is an On-Board Computer meant to program all of the Orbiter's electronic devices and pilot it throughout the mission from the electronics box. It weighs 130 grams.

The communications system will utilize an S-band transmitter to transmit data acquired from the orbiter's sensors back to Earth and a UHF/VHF transceiver to establish communications between the orbit and the other satellites as well as any user of the orbiter. These communication systems will be wired through the on-board computer that will also program all the sensors and thrusters on the orbiter. The UHF/VHF transceiver will have a volume of 52826.27 cubic millimeters and a mass of 75 grams. The S-band transmitter will have a volume of 127743.58 cubic millimeters and a mass of 250 grams. The communications systems will utilize 2 small patch antennas on the side of the orbiter where each antenna has a volume of 24126.89 cubic millimeters and a mass of 115 grams.

In order to generate, store, and manage the power necessary for satellite functionality. The craft will feature solar panels along with Lithium-ion batteries to store power.



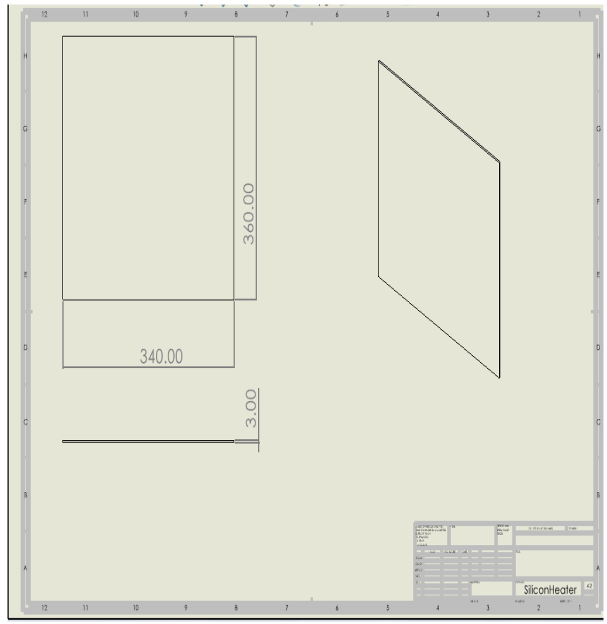


Figure . Silicon Heater: This is the orbiter's silicon heater wall that is composed of smaller strips of silicon heaters. It weighs 61.2 grams with an area of 1,224 square centimeters.

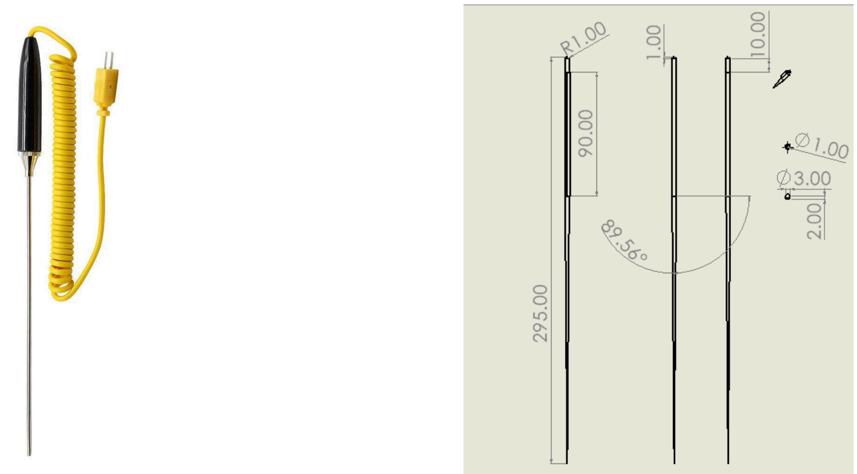


Figure . Temperature Probe: This is one of two temperature probes that will be placed in the edges of the orbiter’s internal compartment to make sure that all of the electrical devices are at their optimal temperature. It weighs 78 grams.

One challenge Arist43us will face is the thermal extremes it's lunar polar orbit. Temperatures in direct sunlight can reach 300℃ while in shadow it might drop below -250℃. The craft will use its radiator and thermal control subsystems to maintain acceptable operating temperatures across the craft. The thermal control of the craft will utilize both passive and active methods. The main passive thermal control system will be through the use of Multi-Layered Insulation or MLI. This thermal insulation will be used as a thermal radiation barrier from incoming solar or infrared flux and to prevent undesired radiative heat dissipation. The insulation will consist of at least 15 layers of aluminized kapton film which is 1.2 kilograms per square meter and will be mounted on the satellite using dual lock fasteners.The aluminized kapton film reflects the thermal radiation exposure away from the spacecraft and will protect the spacecraft from other space effects.The MLI will play an essential role in maintaining the temperature of the electronics and batteries onboard the craft. Since this passive system will not be sufficient to maintain the necessary thermal environment, one main active system will be used. An array of Ultra-Thin Flexible electrical resistance heaters controlled by a thermostat will help maintain the temperature for the batteries and other electrical components as well as prevent them from losing excessive heat during the cold cycles of the orbit. The DWARF-Star NIR Spectrometer will also use its own integrated thermal control system. The detector has an integrated thermo electric cooler (TEC) maintained at -15 degrees, stabilized within +/-0.1 °C.

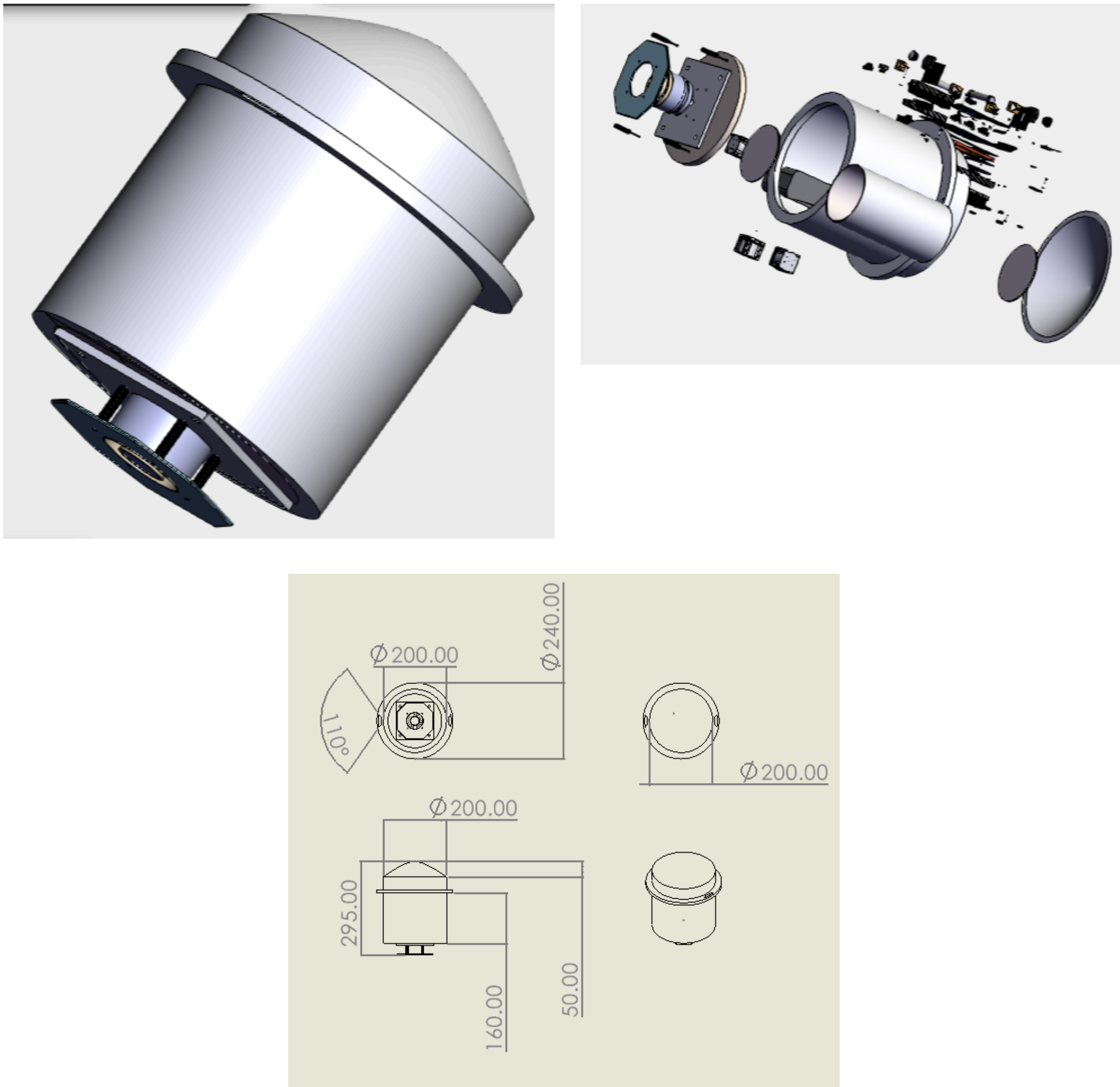


Figure . Impactor: This is the assembled impactor that will be dropped from the orbiter to guide itself to impact the moon. It weighs 7.4 kilograms and its structure is composed of 1060 Aluminum Alloy.

Finally ARIST43US is able to release a kinematic mass impactor designed to perform a controlled deorbit maneuver, impacting the lunar surface and generating enough impact force to uplift a portion of the top layer of regolith exposing possible ice or bedrock.

4.1.3. Manufacturing Plan

The spectroscopy and radar sensors and related instrumentation will be Commercial Off-The-Shelf (COTS) products. The Attitude Determination & Control System (ADCS), thrusters, and satellite reaction wheels will also be COTS technology. In addition, much of the telemetry, such as the S-band transmitter and frequency instrumentation will be COTS as well. Using COTS products gives the mission an advantage by saving time and resources. By using technology that has already been designed, manufactured, and tested for accuracy and efficacy, the scientists and engineers only need to dedicate themselves to incorporate the technology into the spacecraft and ensure its functionality to certain mission specifications. Each unit's manufacturer is listed in Section 3.1.4.

The framework will be designed by project engineers in CAD software; this design will be based on accommodating the necessary instrumentation as well as constraints and protective measures. The framework refers to the metal casing and parts of functioning mechanisms of the spacecraft, which will be outsourced to aerospace manufacturing companies with specifications to tolerances and materials. This fabricated framework will then be welded and assembled by the same companies.

The mission requires an in-house lab to ultimately incorporate each system into the spacecraft. The project scientists and engineers who designed and planned the use of various technologies will test these products in the lab and then integrate the electronic systems and instruments with the written code and the framework. This would require substantial wiring and programming, necessitating the use of control systems instruments such as servomechanisms, terminals, and computational and simulation software.

Delays in the shipping of or set-backs with COTS or outsourced products would impact the integration process by pushing back completion times for the spacecraft systems. The Project Schedule, as seen in Section 6, allows a healthy margin of time for such issues. There are one-week margins to account for delays in shipping. In addition, the Project Schedule tacks on an extra 10% of the time originally allotted for each stage of manufacturing.

Each unit upon arrival or completion in manufacturing will be tested to ensure it has no functional issues, meets quality standards, and passes each validation and verification test as outlined in later sections. Following the N^2chart, each unit will be integrated with other units it would regularly communicate or work with. Validations and verification tests will once again be performed on a system level. Upon passing all tests and quality inspections, the units and systems will be launch ready.

4.1.4. Verification and Validation Plan

Arist43us utilizes a multitude of instruments to conduct the research required for this mission. However, each instrument aboard the spacecraft must complete their own separate rigorous testing before launch. To begin, every component must undergo the “shake and bake” test in which they are exposed to extreme vibrations and temperatures therefore ensuring that they will survive the launch as well as the harsh climate of space.

The orbiter utilizes a battery system that must be tested to see if it can contain enough power to meet the amperage demands of the electronic devices contained within the spacecraft. This is checked with a Battery Discharge Test that uses a battery discharger to calculate the amperages available with the battery and the cell count to see if it can meet the current and power demands of the electronic devices. This test will be conducted first in regular conditions to ensure functionality, then will be tested in a thermal vacuum to confirm that it will also function in space.

The UHF/VHF transceivers and transmitters can be tested before assembly by using them at various ranges to simulate the distance it would be used at when in orbit. The communication systems will also be tested under a vacuum to ensure that the devices can withstand the temperature and pressures of space.

The thermal radiator would be tested to observe how much heat it radiates and how frequently in a cold environment during the validation stage.

Lastly, the spectrometer and the radar must undergo the temperature and vacuum tests along with their own vigorous tests. The spectrometer will be tested at a multitude of distances ranging from directly in front of the instrument to miles away. The spectrometer must be able to assess the abundance of water in these tests with an accuracy of at least ±5%. Next, the radar will be tested

4.1.5. FMEA and Risk Mitigation

Failure Mode and Effects Analysis (FMEA) is defined as a structured approach to identify possible failures within a product or service by analyzing designs and processes (Quality-One). In this analysis, "failure modes are the ways in which a process can fail and effects are the ways these failures can lead to waste, defects, and harmful outcomes for clients." (Quality-One). Risk Management is "an organized, systematic decision-making process that efficiently identifies risks, assesses or analyze risks, and efficiently reduces or eliminates risks to achieving program goals." By implementing FMEA and Risk Mitigation analysis, potential risks, hazards, and failures will be identified and analyzed before deployment of the ARIST43US Lunar Orbiter.

The ARIST43US Lunar Orbiter has ten main components which will be analyzed from there functions, failure modes, effects, causes, design controls (prevention and detection), and recommended actions. In addition, Risk Mitigation will analyze the likelihood and consequences of each component's potential risks and hazards. This section will allow project leaders and team members to continue with the development of the ARIST43US Lunar Orbiter.

LIKELIHOOD						
	5					
	4			7		4
	3			6	1 5	2 9
	2				8	3
	1					
		1	2	3	4	5
	CONSEQUENCES					

Critically	**LxC Trend**	**Approach**
High	↓ Decreasing (Improving)	M-Mitigate
Med	↑ Increasing (Worsening)	W-Watch
Low	→ Unchanged □New Since Last Period	A-Accept R-Research

Rank & Trend	**Approach**	**Risk Title**

→1	M	Signals may not have enough power to transmit and create faults in communication systems.
↓2	A	Error in ADCS operation could lead to the orbiter missing a specified target.
→3	A	ADCS prevents energy from relaying to the rest of the orbiter.
→4	R	Electrical power system shorts and does not supply electric power.
↓5	M	Failure in these components operations could prevent transmissions of any kind including data, images, etc.
↑6	R	Failure in instruments results in false data collection.
→7	W	Potentially damages impactors from being deployed again
→8	W	Thrusters do not ignite and fail to push the orbiter.
↓9	R	Thermal energy not being distributed to the rest of the orbiter.

(1) Radar Antenna										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To transfer the transmitter energy to signals in space with required distribution and efficiency.	Power system supply to Radar Antenna may short.	Orbiter unable to operate.	9	Wires may be improperly soldered or other electrical components not performing.	5	Follow technical manuals for proper configuration.	Test power system is relaying energy to Radar Antenna.	5	225	
To ensure that the signal has the required pattern in space.	Signal may not have enough power to transmit and create fault in communication systems.	Failure in communication systems may lead to transmission loss from ground operations.	9	Improper connection between Radar Antenna and communication system.	6	Reassure multiple team members are analyzing proper placement of wiring.	After 1st assembly, use low to midrange comm checks with ground operations.	6	324	1. Have multiple checkpoints in assembly. 2. Setup comm checks in low and mid range. 3.Setup comm checks in long range.
To provide the required frequency of target position updates.	Errors in Radar Antenna could lead to errors in navigation system.	Navigational systems may fail and compromise the entire mission.	10	Errors in Navigational System could lead orbiter astray.	4	Make sure navigational system is troubleshooted prior to assembly and deployment.	Test navigational system with low to midrange tests.	5	200	

(4) Electrical Power System

Functions	Failure Mode	Effect(s)	Sev	Cause(s)	Occ	Design Controls (Prevention)	Design Controls (Detection)	Det	RPN	Recommended Actions(s)
To utilize and distribute electrical power to orbiter.	Electrical power system shorts and does not supply electric power.	Prevents the rest of orbiter to operate with no electric power.	10	Component is shorted from possible internal or external damages.	7	Make component rugged and durable for possible space hazards.	Run tests in various components and in final assembly.	8	560	1. Have multiple checkpoints with assembly. 2. Setup test with various components. 3.Run simulation with space environment before deployment.

(5) S-Band Transmitter/VHF/UHF/GPS Board										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To provide inflight configuration of data rate, modulation scheme, frequency, and RF output	Failure in these components operations could prevent transmissions of any kind including data, images, etc.	Important data and other transmissions are not transmitted to ground operations.	9	Components improperly assembled or not programmed correctly.	6	Make sure components are assembled correctly and comm checked.	Run comm checks in low to mid range before assembling with rest of orbiter.	6	324	1. Have multiple checkpoints with assembly. 2. Setup comm checks from low to mid range. 3.Setup comm checks in high ranges.
To provide transmissions between orbiter and ground operations.			9		5			5	225	
To provide navigational services from launch to Lunar orbit.	Orbiter could be prevented from reaching final destination.	Orbiter never reaches Moon.	10	Navigational system damaged, not assembled correctly, or not programmed correctly.	6	Make sure the navigational system is assembled properly with other components anc checked for proper operation.	Run navigation test from low to mid ranges before assembling with rest of orbiter.	5	300	

(6) Spectroscopy & Infrared Sensors										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To determine the various chemical groups in a compound.	Failure in instruments result in false data collection.	False data prevents Orbiter from deploying impactors to appropriate target.	9	Improper assembly of components and possible damage from space hazards.	5	Make sure component is properly assemble with other components.	Run tests on detecting certain chemicals (H_2O) before assembly.	4	180	1.Have multiple checkpoints with assembly. 2. Setup IR beam and Spectroscopy tests to identify H_2O compounds in a sample. 3.Make sure operations flow in rest of assembly.
To determine the different IR frequencies in a sample.		Could possibly prevent Orbiter from identifying any compound.	8		4	Make sure IR beam from instrument is operating properly.	Run tests on proper operation of IR beam before assembly.	4	128	

(9) Thermal Radiator Back										
Functions	**Failure Mode**	**Effect(s)**	**Sev**	**Cause(s)**	**Occ**	**Design Controls (Prevention)**	**Design Controls (Detection)**	**Det**	**RPN**	**Recommended Actions(s)**
To transfer thermal energy from one component to another.	Thermal energy not being distributed to the rest of the orbiter.	Orbiter unable to operate.	9	Components not properly assembled.	7	Componentes must be properly assembled.	Run tests and simulations on components to make sure thermal energy is properly distributed and not overloading any systems.	6	378	1.Have multiple checkpoints with assembly. 2. Run tests on thermal radiator and analyze performance. 3.Make sure operations flow in rest of assembly.
To prevent heat exhaustion from solar radiation.	Heat exhaustion overloads the orbiter's systems.	Systems fail and cause the orbiter to be overwhelmingly damaged.	8	Thermal energy not being properly distributed.	6	Assess components for any damages.		5	240	

4.1.6. Performance Characteristics

The conditions of space will undoubtedly weather the spacecraft over time. However, for the duration of the mission, each component will have been tested repeatedly under conditions of extreme temperatures as well as extreme pressures. Despite the “shake and bake” test’s reassurance of the survivability of each component, several measures are in place to ensure that Arist43us will be able to withstand the harsh conditions of space. Among these, the thermal radiator will be instrumental as it will ensure that each component neither freezes nor overheats from solar radiation.

4.2. Science Value

4.2.1. Science Payload Objectives

ARIST43US satellite will accomplish the science goal of determining the location and the abundance of water ice in the top 1 meter of the regolith with a ~ +1% accuracy at a spatial resolution of 75m within the Permanently shadowed Regions (PSRs) which is found at the lunar south pole. This will be accomplished through the utilization of a monostatic radar and infrared spectroscopy. Specifically, the spectrometer aboard the spacecraft will scan the surface with wavelengths of 1,000nm and 1,400nm. The first wavelength will be able to determine differences between water and land due to the fact that water absorbs near infrared light (NIR) which will make locating the areas with water more feasible. The second wavelength will conduct the science objective of the mission; handling the photography and analysis of the abundance of water on the surface of the moon. The wavelength of 1,400nm or shortwave infrared light (SWIR) is particularly useful for this purpose and will therefore make the photos appear darker where there is a greater abundance of water in the PSRs. The integration of an impactor on the craft will provide information about the quality and quantity of the water ice within the PSR.

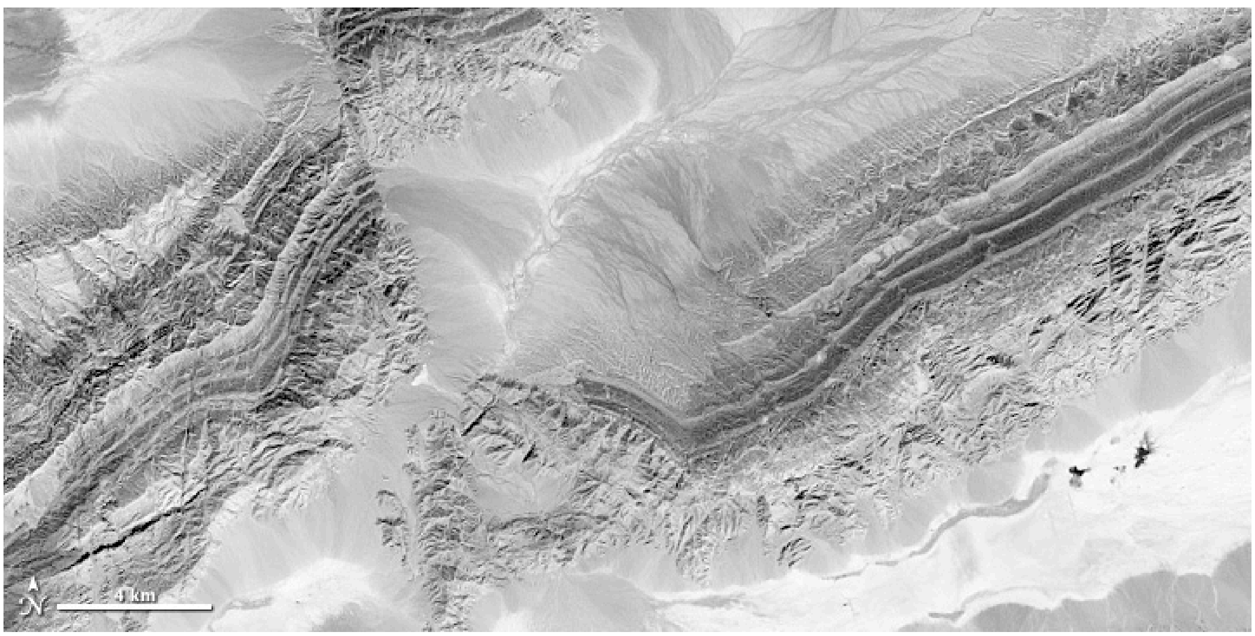


Figure 11. As can be seen in the photo of the Piqiang Fault in China taken from the NASA Earth Observatory, NIR reveals the cross-section of land and water as a dark line

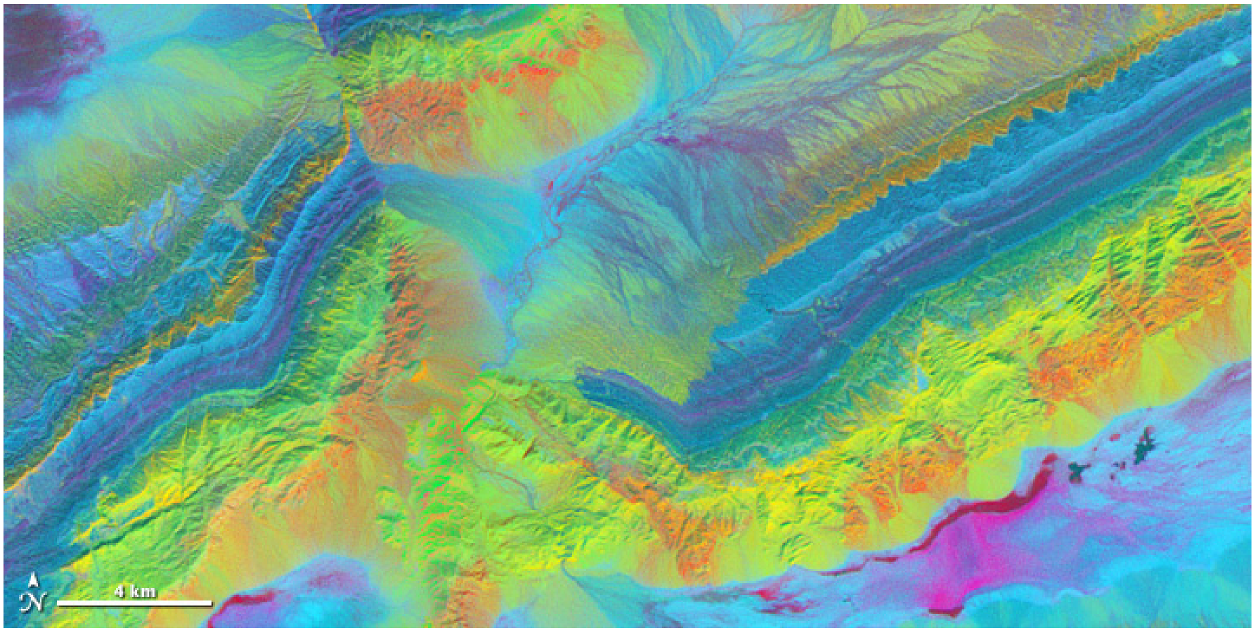


Figure 12. This same Piqiang Fault analyzed under 3 different infrared lights shows darker blue light where water is the most abundant

Aside from the spectrometer, Arist43us also harbors a monostatic radar in order to aid in analyzing and performing the science objective of this mission.

The craft must contain functional thrusters to change the longitudinal line that it is orbiting above; this will enable it to survey the entirety of the PSRs. To promote the longevity of this craft in space, the craft must have a renewable energy source, such as solar power, to ensure it will always have the power to run and to gather and transmit data to the primary mission orbital continually. Additionally, it must also have protective shielding that will protect the telemetry and instruments from radiation as it will be exposed to the Sun for part of its orbit. This also protects the pressure vessel, coolant loop and inner shield from the intense heat generated by the absorption of radiations. It must also guard against dramatic temperature changes when the craft transitions to the far side from the near side and vice versa. The craft must also contain a heating system to regulate its temperature within a tolerable range to ensure its component is protected against damage that may render the instruments nonfunctional. We can use the information gleaned from this craft to prepare for further manned and unmanned missions to extract water from the moon.

4.2.2. Creativity/Originality and Significance

Taking data from the Lunar Orbiter Laser Altimeter (LOLA) and the Lunar Reconnaissance Orbiter Camera (LROC) provided by JMARS, we can see that the south pole presents a multitude of observable PSRs such as Shackleton, Shoemaker, or Haworth.

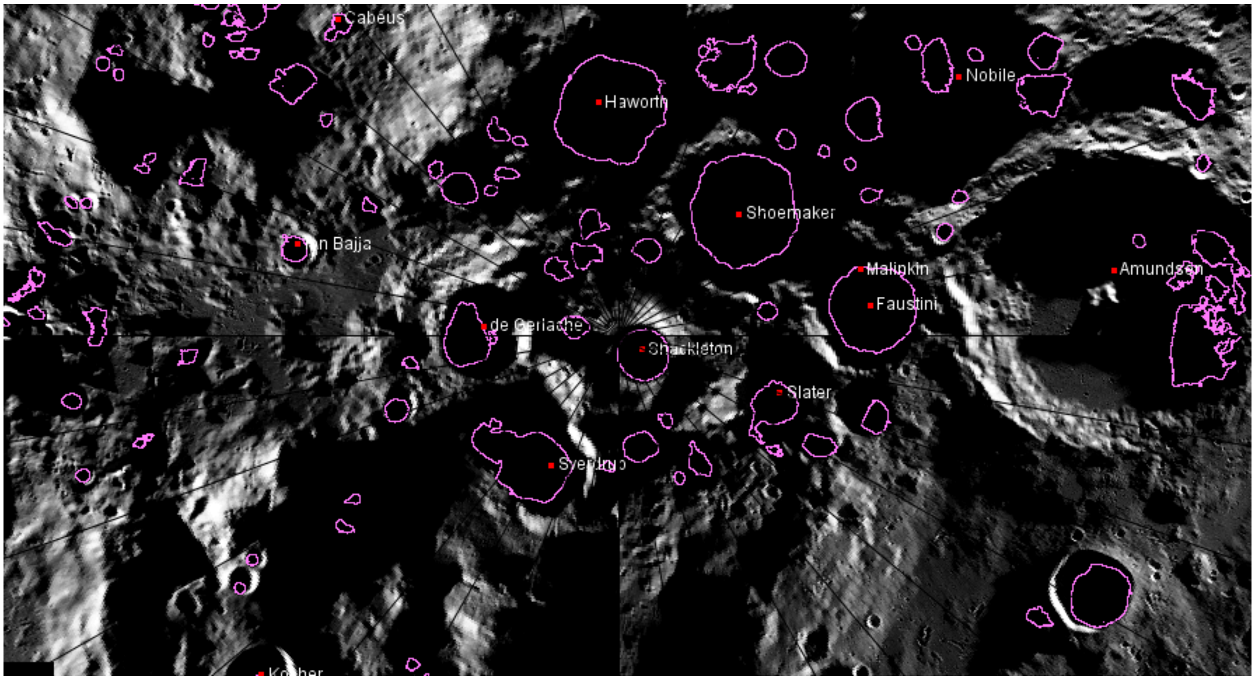


Figure 13. The South Pole of the moon showing all PSRs detected by LOLA

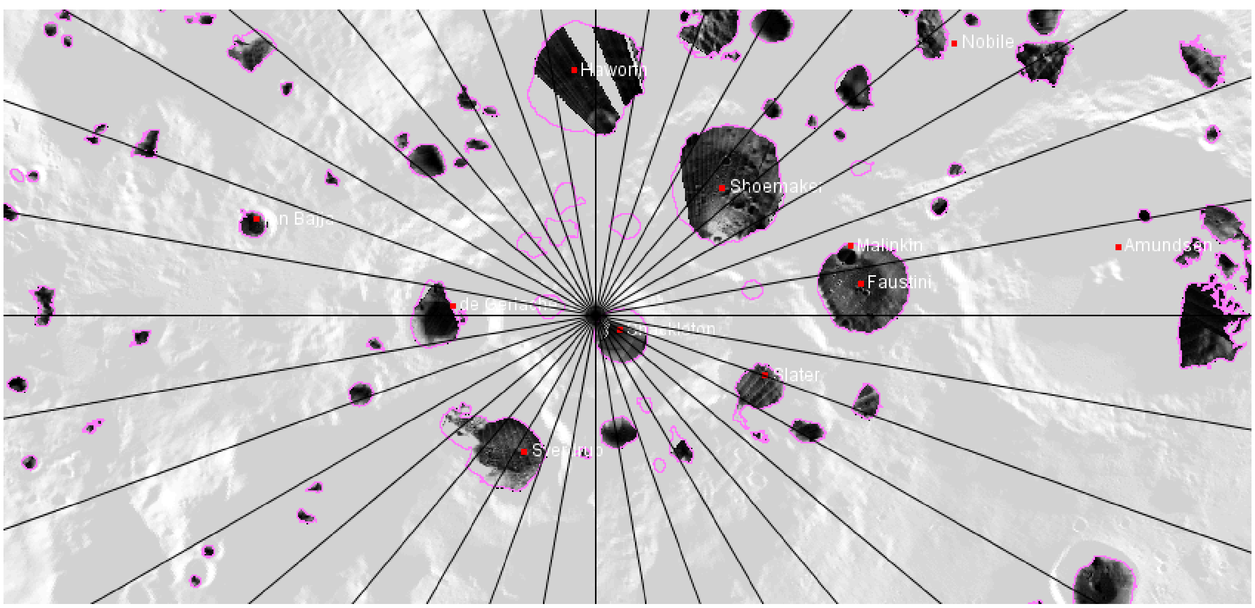


Figure 14. The South Pole of the moon showing all PSRs detected by both LOLA and LROC

As can be observed from these images, the LROC and LOLA data comparing PSRs confirms several viable craters to be used in the mission of Arist43us. Therefore, the orbiter will utilize its thrusters to slowly complete a full circle around the poles; slowly adjusting its orbit to the right until it essentially runs out of fuel. Arist43us will begin its orbit headed towards the north pole at a longitude of 330º, then once it passes its targets on the south pole, it will use its thrusters to slightly adjust its orbit to the right. The orbiter will continue to rotate until its at longitude 340º, longitude 350º, longitude 360º, longitude 10º, and so on until it comes full circle. This will ensure that Arist43us will be able to observe all of the PSRs on the surface. While studying every crater is amazing, this mission will focus specifically on Haworth Crater, Shoemaker Crater, Faustini Crater, Shackleton Crater, De Gerlache Crater, and Sverdrup Crater with emphasis on the Shoemaker, Shackleton, and Sverdrup craters. Along with these craters, another area will be studied just under Cabeus crater due to the data suggesting that the area used to have water but no longer does. The reasoning behind studying all of these craters is based in scientific exploration as well as historical discovery.

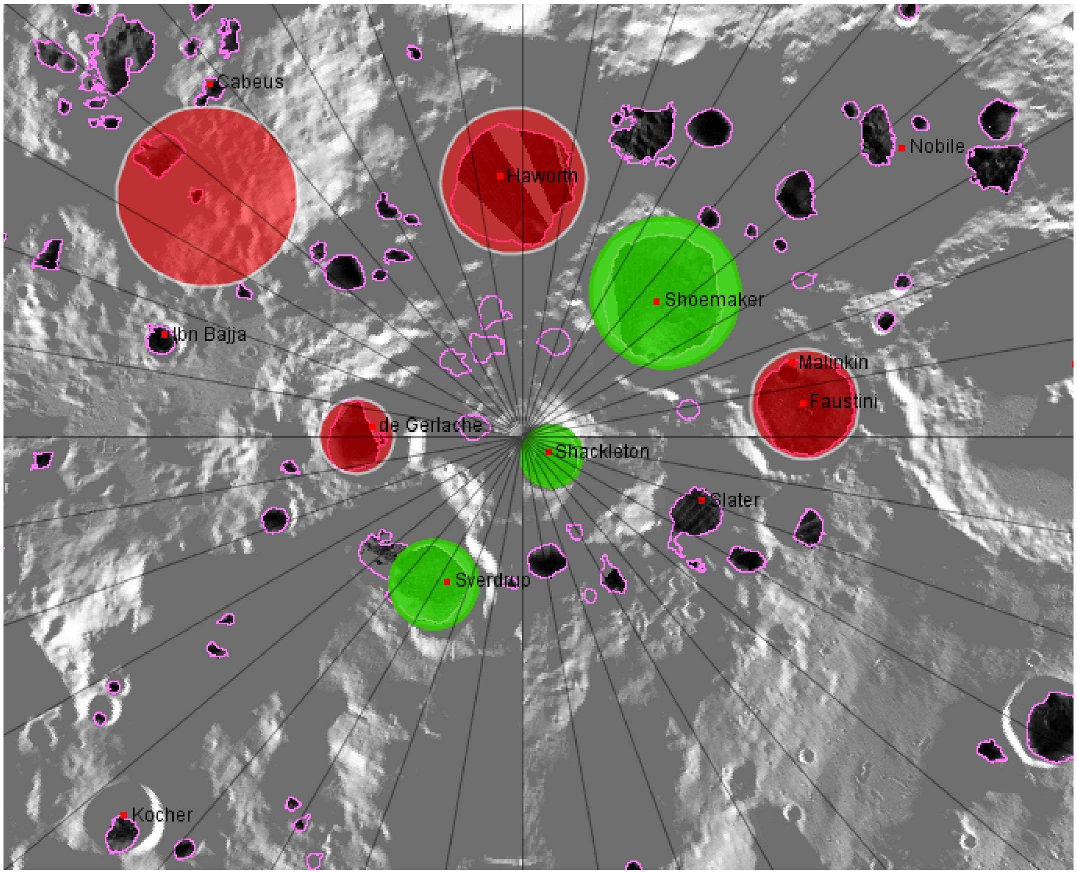


Figure 15. Arist43us mission objectives highlighted with the green circles being the main objectives and the red circles being side objectives

The reason these craters are specifically important is because they all potentially have water and have changed over the course of the moon's life. To further understand the importance of these craters, we must first see the evolution of these craters over the course of the moon's lifespan. Utilizing data gathered from the Diviner, we can observe the ice depth stability of these craters during the current period as well as the paleo period of the moon. Below it can be seen that the paleo data of the south pole hosts a surprising lack of regions with ice depth stability that could actually foster a substantial amount of ice. However, the current data shows that PSR regions have, for the most part, greatly expanded and show a lot of promise for water.

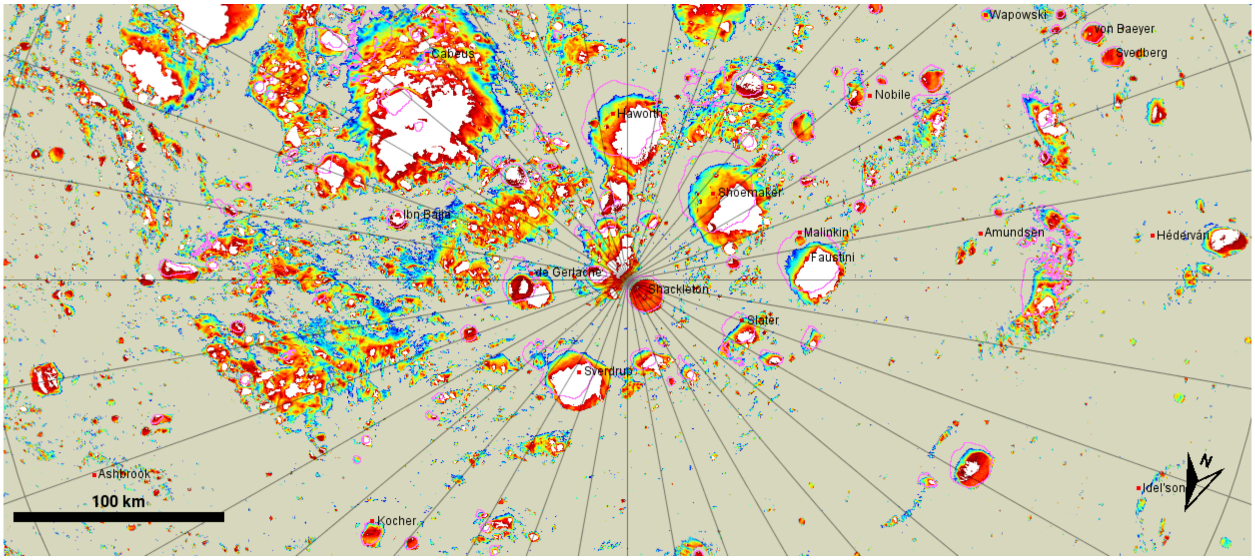


Figure 16. Ice depth stability map of the south pole during using paleo-era data

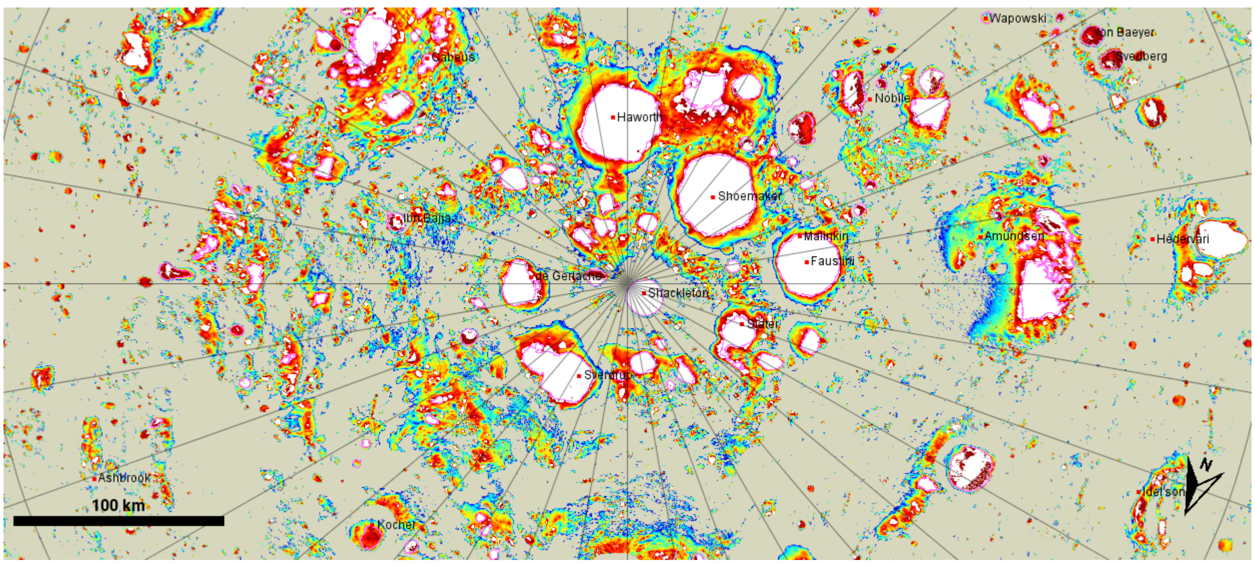


Figure 17. Ice depth stability map of the south pole using current data

These two datasets show vastly different data, with new PSRs growing while others move or die out. This is the very reason for almost all of the areas we will investigate; historical and geological information! Once these maps are overlapped as can be seen in figure 18, it is very clear that many of the craters being investigated have specific locations that have hosted ice even since the paleo era. Therefore, the areas highlighted in blue circles on the map below will be special areas of interest as they most likely contain the most abundant amounts of water ice.

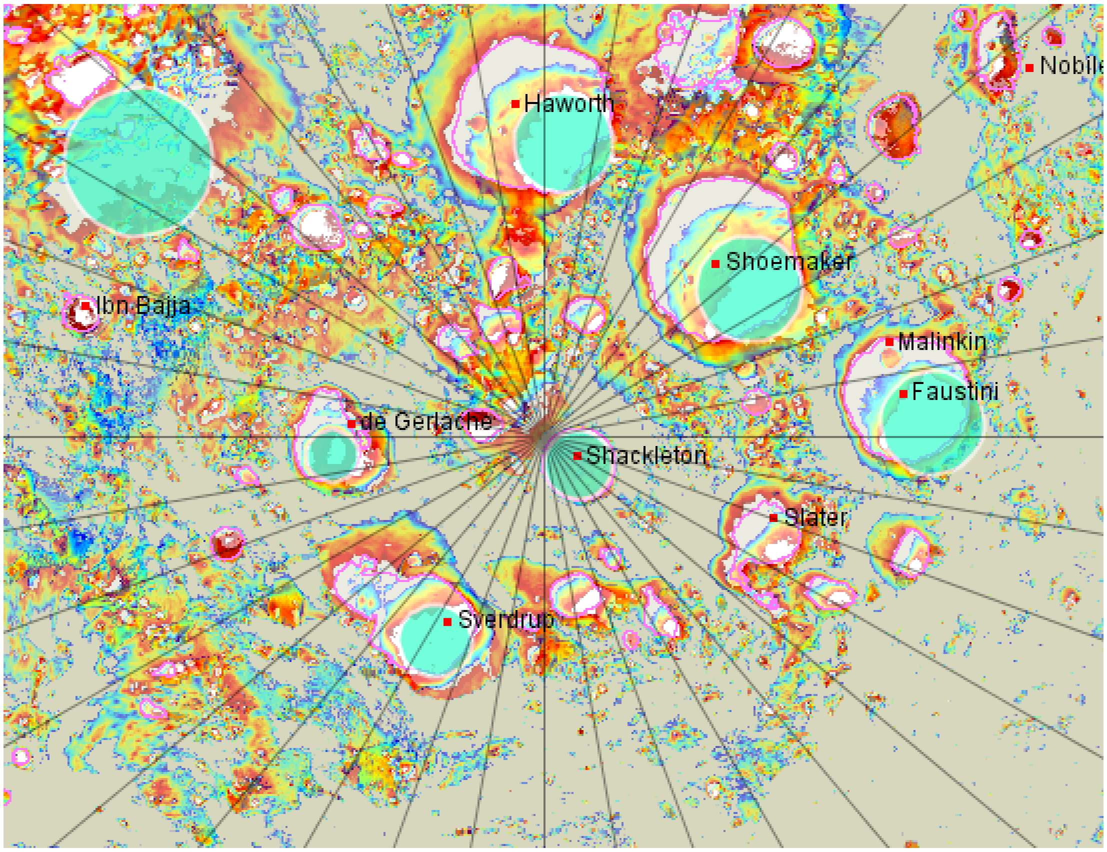


Figure 18. The current and paleo ice depth stability maps have been stacked on top of each other. The blue circles represent areas that have been stable even since the paleo era

The last justification for choosing these locations as mission objectives comes in the form of seasonal temperatures on the south pole. Our mission is set to launch on January 15, 2026 so will therefore arrive at the moon around January 18,2026. This means that the moon will be experiencing winter as well as the moon orbits the Earth so will therefore experience an orbit around the sun similar to ours. With this in mind, compared to summer temperatures as can be seen in figure 19, the moon's PSRs will be extremely cold during the winter which can be seen in figure 20. This is important because the extreme cold will prevent even more water from sublimating on the outer regions of the PSRs which will provide us with better information on the abundance of water in these regions.

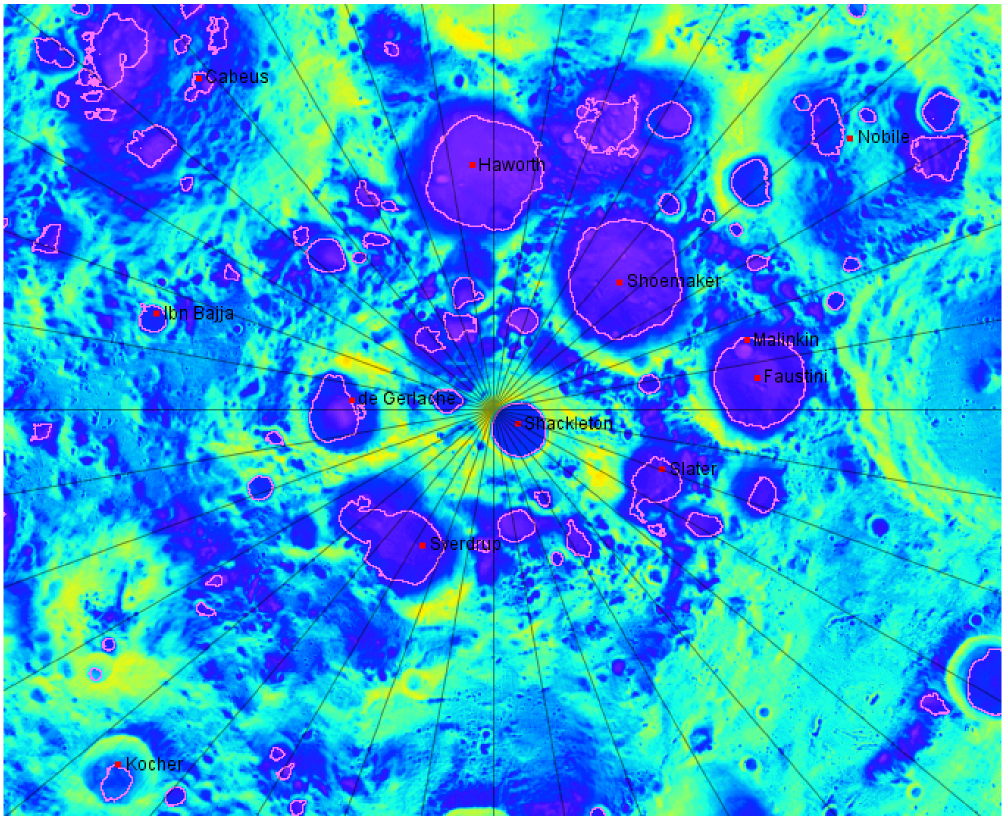


Figure 19. South pole during the summer (temperature gets colder from green to blue to purple)

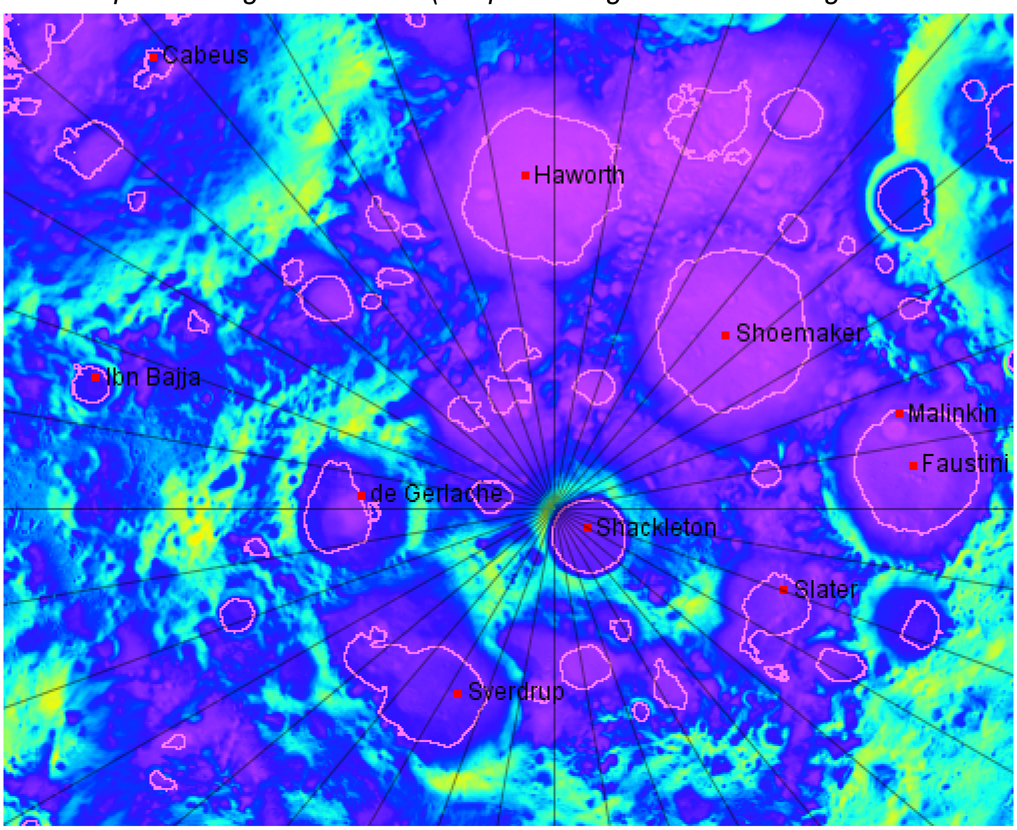


Figure 20. South pole during the winter (temperature gets colder from green to blue to purple)

Lastly, due to there being more than one main objective, the impactor will be saved from use until the orbiter has gone full circle as our team will then have more data to go off of and more information as to which crater we would like to observe more in-depth. However, as of now, we believe that the impactor will most likely be deployed into Shoemaker crater as it is the biggest crater with the largest PSR and will therefore most likely be the best indicator for the average abundance of water ice in the regolith around the south pole. As well as being a good estimate of the average abundance of water in each crater at the south pole, Shoemaker also holds the most promise as a future source of water for lunar settlements if there is a substantial amount of water because the crater itself is so large.

4.2.3. Payload Success Criteria

The success of Arist43us's instrumentation is entirely dependent on whether or not they can provide accurate measurements and data from such a long range. To begin, the infrared spectrometer is designed with a wavelength range between 900 and 1,700nm. This range will be used in two ways: the lower wavelengths for NIR spectroscopy and determining the separation of land and water lines if there is any and the higher wavelengths for SWIR spectroscopy or determining the abundance of water in the regolith. Success for the spectrometer would be clear images and an accuracy of at least ±5%. As for the radar,

4.2.4. Experimental Logic, Approach, and Method of Investigation

In order to study the PSRs, Arist43us will utilize two main scientific instruments to acquire the data needed to find the abundance of water ice in the top 1 meter of the regolith at ~±1% accuracy. To accomplish this goal, the orbiter will employ a monostatic radar dish and an infrared spectrometer. In addition, a lunar surface impactor will be used to penetrate the surface regolith.

In regards to the cooperation between the radar and the infrared spectrometer, the spectrometer will capture mostly surface data and images while the radar will collect information 1 meter below the surface. The spectrometer will mainly be utilized in two wavelengths: 1,000nm and 1,400nm. These two wavelengths, as noted in section 4.2.1, will serve to observe NIR light and SWIR light. The NIR images will primarily be used on the ridges of each crater as this wavelength is useful for determining and showcasing land and water lines. Therefore, NIR imaging will be particularly useful on the edges of craters as the ice depth stability of each PSR is seen to decrease as it approaches the edges of these craters. This analysis will hopefully be able to provide useful information on the abundance of water in the area as a clear separating line between the edge of the crater and the inside will prove that the water abundance in the crater is somehow different than that of the areas touched by the sun. Along with NIR imaging, the SWIR imaging at 1,400nm will serve to highlight more water-rich areas for the radar to scan due to the fact that a more abundant area will appear darker than other less water-abundant areas.

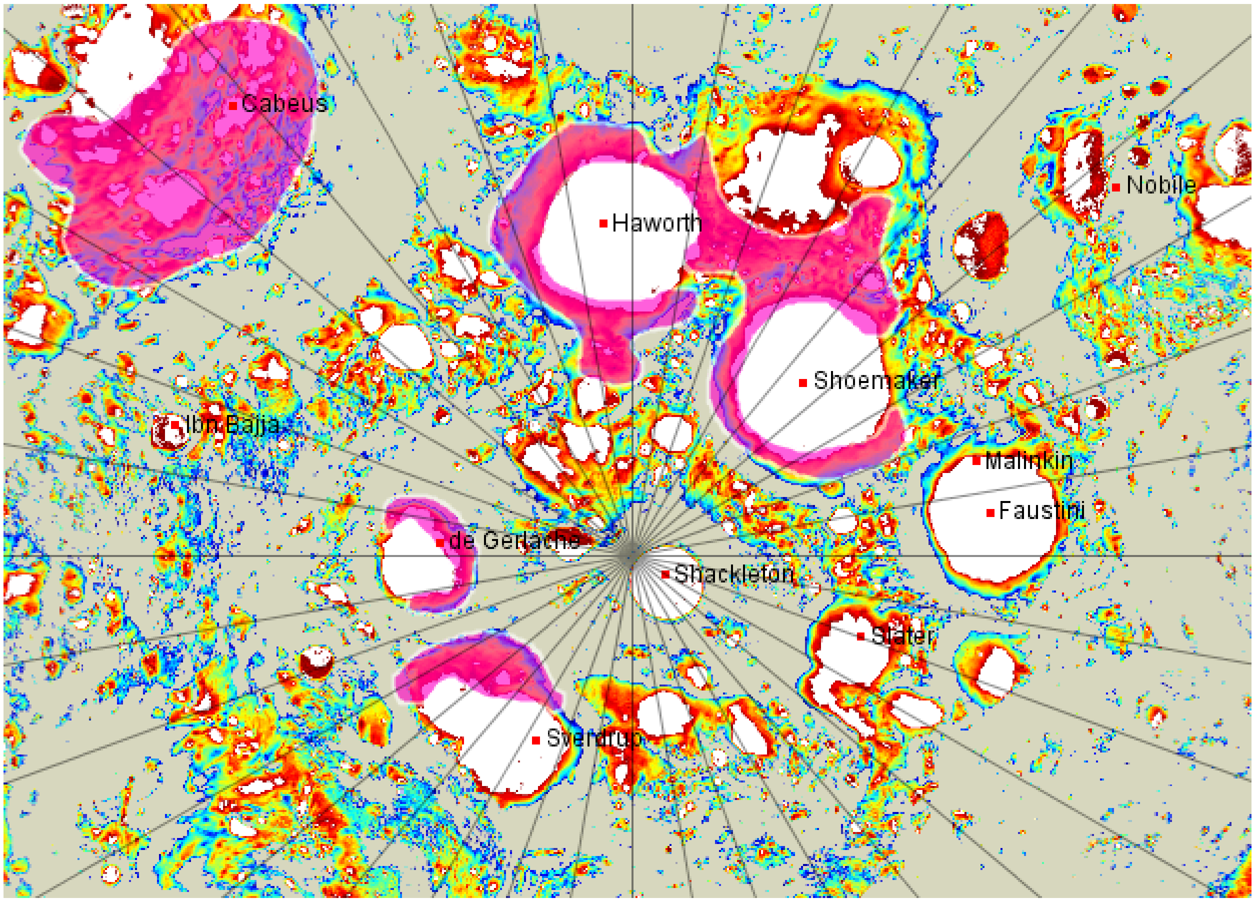


Figure 21. The pink areas highlight areas where ice depth stability wavers, specifically around the edges of several of the craters Arist43us will focus on. These areas will be analyzed by NIR light and will therefore expose where land and "water" meet

As can be seen in the figure, NIR imaging will aid the Arist43us team in determining the best locations to use SWIR imaging as well as the best locations to begin using the radar. Specifically, the area between and on the edges of the Shoemaker and Haworth craters will be beneficial for determining the water saturation relationship between sunlit areas of the moon and the PSRs. Once these areas are analyzed, the SWIR wavelength will then be activated to determine the abundance of water inside these craters; especially just inside the PSRs and inside the areas of interest highlighted in figure 22 below.

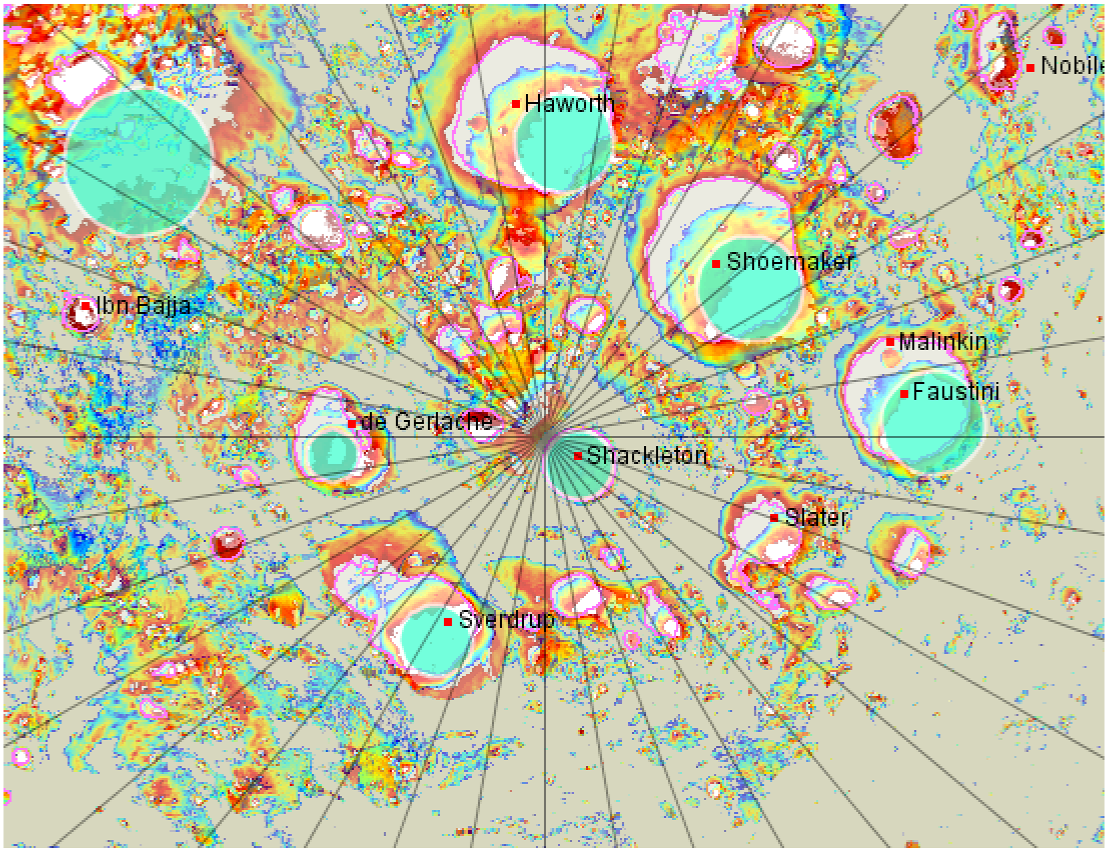


Figure 22. The areas of interest map from 4.2.2 represent areas where SWIR imaging will be utilized. Aside from the blue circles, each crater will be studied in full allowing the NIR and SWIR data to concatenate into a more accurate depiction of where the water is on the surface

In regards to the radar, Arist43us will utilize a monostatic radar capable of scanning at least one meter below the surface of the moon. This radar will do occasional scans in areas where water ice is predicted to be the most abundant. In this regard, the radar will cooperate with the spectrometer as the spectrometer will be able to scan and detect the areas in which water ice appears to be the most abundant or dark in the spectrometer's images.

By method of design, the oribter will adjust its orientation to allow the separation of the onboard impactor at the correct timing. After separation, the impactor will follow with a deorbit burn allowing it to hit the surface with tremendous kinetic energy. The impact will result in surface regolith to be set into motion and displaced in all directions. This is what the authors of "New Approaches of Lunar Ice Detection and Mapping" refer to as "kinetic excavation." The ejecta cloud produced by the impactor will then be analyzed by the infrared spectrometer. Although spectroscopy will continue throughout the lifetime of the mission, most data of water abundance in the PSRs will be obtained during this stage of the mission.

Each of the components on the orbiter will need to work together to be able to collect the necessary data. This includes instruments for propulsion, power, orientation, and communication. The overarching experimental plan and procedure for collecting data during the life of the mission is to make adjustments to the orbit of the satellite in order to deploy the impactor and utilize the radar and infrared spectrometer systems to analyze the PSR regions.

4.2.5. Testing and Calibration Measurements

Once in the desired orbit around the moon, ARIST43US will conduct a series of tests to determine if the spacecraft is fully prepared to carry out its mission. Among all of the components of the spacecraft, the solar panels and battery will be the first and most important test because without power the whole mission will be for naught. To test this, Arist43us will first test the flexibility of its motors that rotate the solar panels by conducting a full rotation of the solar panels to ensure that the solar panels will be able to absorb the most amount of sunlight possible. This test is of course after the solar panels have been unfolded. The battery will also send data concerning the energy output of the solar panels to ensure that the solar panels are functioning at full capacity. The next test to be conducted will be on the radar and the spectrometer. The motors will conduct a full rotation of the instruments to make sure that both are rotating to the degree that was intended when building the system. After the rotation, both the radar and the spectrometer will conduct a general test to determine whether or not the lenses and sensors are functioning. This test will essentially just be both instruments doing their normal job of gathering data on the abundance of water in the regolith but before the important part of the orbit above the target zone so that no orbits are wasted. The thrusters will also be tested by aligning the spacecraft in a way that will only speed up or slow down the spacecraft when they are all fired at once, therefore ensuring that both directional motors are functional while at the same time leaving the orbital path of the spacecraft relatively unchanged. The test conducted on the impactor system will be tricky as there is a limited amount of impactors which makes each one valuable. For this test, the system will take the risk and fire when the spacecraft is above the target zone. The worst case scenario for this scenario is simply missing the PSRs, but the impactor could still prove useful and give information about another area not even in the scope of this mission. After all of these tests, ARIST43US will be ready to begin its actual research.

4.2.6. Precision of Instrumentation, Repeatability of Measurement, and Recovery System

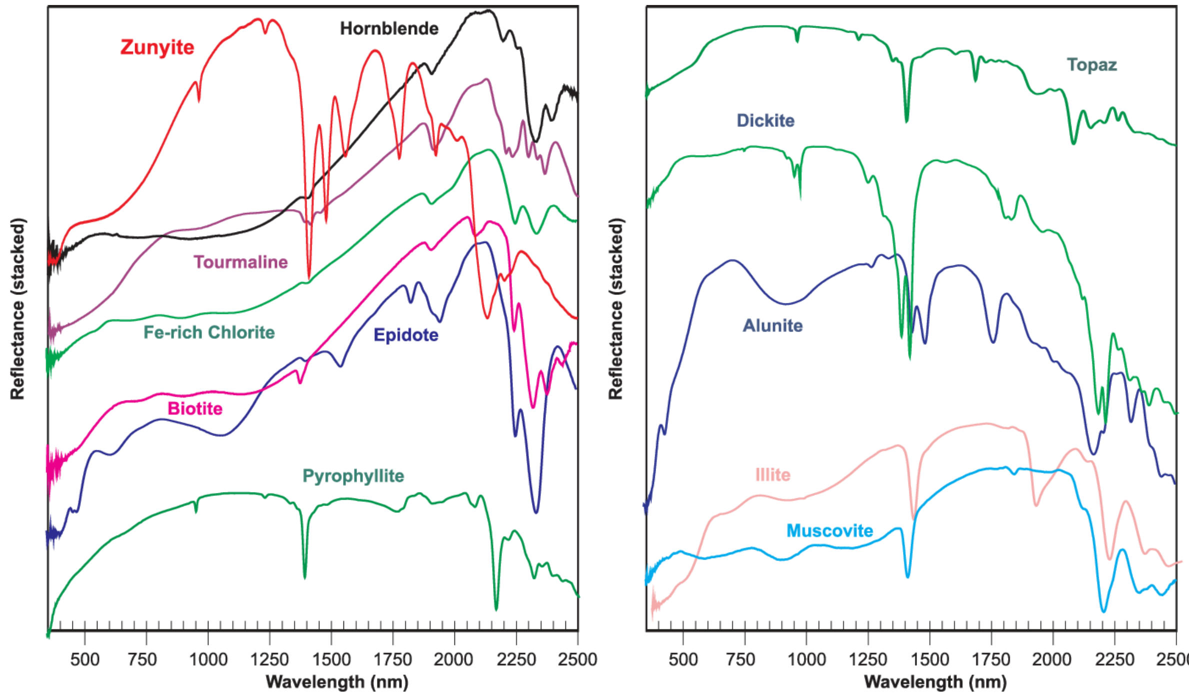
There are two main sensor systems ARIST43US utilizes to collect scientific data: an infrared spectrometer and a monostatic radar. The way these will work together involves the spectrometer locating promising regions where ice is most likely going to be abundant then the radar scanning these areas with increased accuracy and depth. As stated multiple times in section 4.2, the spectrometer will utilize two wavelengths to find these regions: 1,000nm and 1,400nm or NIR light and SWIR light respectively. Using these two types of light will aid in locating the specific lines between land and ice as well as detecting which areas in the PSRs are likely to have the most abundant stores of ice. After the spectrometer finds promising locations, an ice-calibrated radar detects promising concentrations from ground level to one meter under the surface, with an impactor agitating the regolith for a full chemical analysis via infrared spectrometer.

These instruments both will act as the backbone of the mission as they will be the only instruments engaging in the scientific aspect of the mission. Therefore, a high standard of accuracy must be assigned to each of these instruments in order to validate the findings of this mission. In order to be successful, the spectrometer must be able to scan with an accuracy of at least ~±5%. The radar must also be able to detect at least one meter beneath the surface with an accuracy of at least ~±1%.

Of course, these expectations for the spectrometer and radar could easily be affected by several different factors. Some examples could include the rays of the spectrometer not being perfectly parallel, therefore causing reflection and obliquity errors in the data. Other possibilities include the cathode being misaligned and the lenses being too polarized. All of these events are entirely possible under the extreme environments Arist43us must undergo during the mission which is why the shake and bake test on earth is so crucial. Along with all these possibilities for the spectrometer, the radar could also have several issues such as the radar dish not being large enough or not deploying at all.

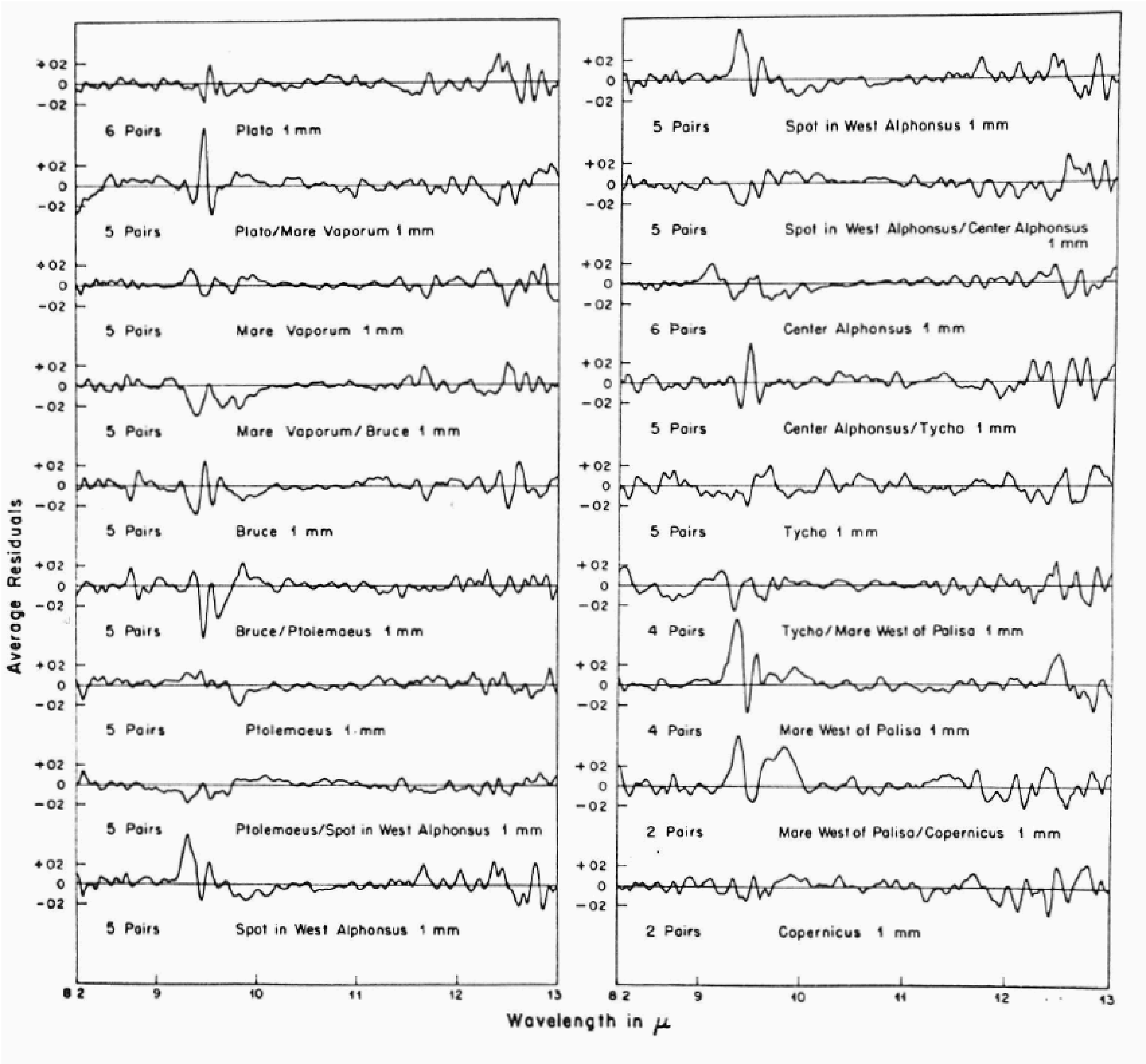
If any of these events were to occur, the spectrometer and the radar are both capable of and designed to conduct different types of science. Therefore, if one were to break, then the other could still provide valuable information regarding the abundance of water on the south pole. Although less accurate and only on the surface, the infrared spectrometer could still bring about crucial data points regarding the abundance of water in certain areas of the PSRs using SWIR imaging as well as provide evidence of ice in the PSRs courtesy of the NIR imaging. In the case of the spectrometer being unsuccessful or simply not working, the radar will be able to conduct in depth research as well due to the fact that it is designed to be able to study up to a meter below the surface. However, this would be less efficient as the team operating the orbiter would have to simply make guesses about where the best spots to scan would be. Lastly, if both instruments broke, Arist43us also comes equipped with an impactor that could kick up dust for other moon orbiting missions to observe despite not having the instruments needed to conduct the research for this mission.

4.2.7. Expected Data & Analysis



A reference table of unique mineral spectra taken from the paper *VISIBLE/INFRARED SPECTROSCOPY (VIRS) AS A RESEARCH TOOL IN ECONOMIC GEOLOGY: BACKGROUND AND PILOT STUDIES FROM NEWFOUNDLAND AND LABRADOR* By A. Kerr, et al.

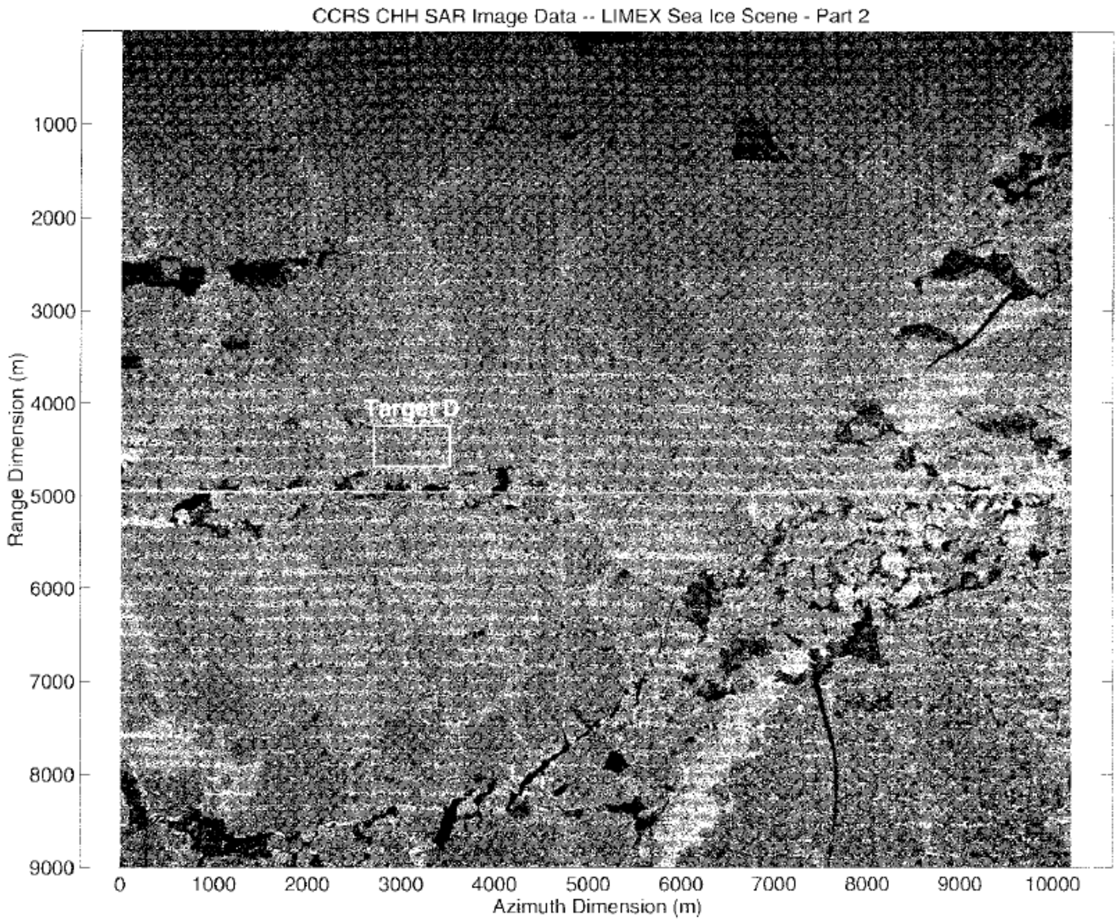
The ARIST43US satellite will come equipped with both an infrared spectrometer and monostatic radar dish, which will receive radiometric data from the lunar surface over the course of the mission, both from the Permanently Shadowed Regions (PSRs) at the lunar poles and the surrounding sunlit surface. Most silicate minerals, which make up the bulk composition of the lunar regolith have unique infrared spectra due to what the thesis paper, *Infrared 8-13μ Spectroscopy of the Moon and Some Cold Silicate Powders* by Alexander Franklin Hermann Goetz refers to as fundamental Si-O stretching vibrational mode. However, in that same paper it is noted that well defined spectral differences occur mainly in relatively homogenous mineral specimens, and since those are unlikely to occur over our resolution, it is likely instead to yield a relatively uniform spectral data which can then be contrasted with any non uniform data which will suggest large scale compositional differences in a given area, either due to water ice or another large irregularity in the surface regolith. A mixture of automated processes and human data analysis will use unique mineral spectra reference tables and existing infrared spectral data from the lunar surface to average data over given areas and determine the bulk composition of those areas. Thus our data will make use of spectral data like in the figure above but will most likely look like the figure below, at least for lunar data from the surface. However, post impactor deployment, it is probable that the infrared spectrometer may receive data of a much higher resolution and be able to identify more exact mineral composition of not only lunar regolith but also bedrock.



A table of average residuals from a spectral analysis of 22 lunar sites in the thesis paper *Infrared 8-13μ Spectroscopy of the Moon and Some Cold Silicate Powders* by Alexander Franklin Hermann

Radar analysis of the lunar surface will also take place during the mission alongside infrared spectroscopy, and will provide supplemental data for comparative analysis with the spectral data from both the PSRs and the sunlit lunar surface. Due to the complex compositional differences between the average lunar regolith and the surface water ice postulated to exist in the PSRs on the lunar poles, reflected electromagnetic waves emitted by the ARIST43US satellite should detect distinct differences between the average lunar surface and any water ice which exists in large quantities on the surface. However, analysis of these differences will require primarily human data analysis as different types of ice and the depth of any water ice formations will create discrete differences in the radar images providing images like those found below.

(a)



An overview of the Synthetic Aperture Radar (SAR) data from a paper on Arctic Sea Ice called “Uncertainties in the Estimation of ACF-Based Texture in Synthetic Aperture Radar Image Data” by Michael J. Collins and and Jin Huang

When aggregating the data from the spectrometer with radar imaging data, a process that will require human analysis and scientific study, a detailed picture of the compositional makeup of the polar lunar regolith, including any potential surface water ice will be created. In addition, in specific areas which will be chosen during the mission based on their data potential, the impactor spectroscopic data will enable a high resolution analysis of the chosen site’s regolith and bedrock composition. This will, hopefully, provide a detailed picture of where any potential water ice may be present in useful quantities on the surface for further exploration and analysis.

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