# NASA RASC LUNAR HABITAT

# Final Proposal

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# DISCLAIMER

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# EXECUTIVE SUMMARY

The NASA RASC Lunar habitat is a concept that evolved from NASA's project description for a habitat that would be able to be set up on the moon that could support 2 astronauts for 30 days. The habitat is not to exceed a dry mass of 6000kg, and is to be ready for first use by 2028. The team has came up with a final concept named "The Babylon Space Capsule", includes 3 different subsystems, Micrometeorite Shielding Protection (MSP), Multi-Layer Insulation(MLI), and the titanium tubing bone structure. The habitat is designed for transport in the Falcon 9 rocket; meeting all of the payload dimensions and requirements. Specifications for the design are based on standard codes and regulations from NASA, ASME, ASNI, and ASTM to ensure that all of the subsystems are up to par for implementation. Two testing procedures for the thermal analysis of the habitat, and the hypervelocity impact test for the micrometeorite shielding. Both of these testing procedures use the program Solidworks to conduct computational studies on the habitat. Potential critical failures are then considered to get a better understanding of where the design could go wrong. Various parts of the design are considered for failure, which are shown in the risk analysis section. A risk tradeoff analysis is then conducted to get a better understanding of which parts of the design the team is willing to compromise to meet budget and size requirements. After the risk tradeoff analysis, the final design is decided and an implementation plan is discussed.

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# 1 BACKGROUND

## *1.1 Introduction*

In response to Revolutionary Aerospace Systems Concepts- Academic Linkage (RASC-AL), this preliminary report discusses the initial discoveries, challenges as well as provide preliminary concepts for building a durable low-mass lunar surface habitat.

As part of a new era of space exploration, NASA's Artemis Missions will prepare humanity for the next giant leap, a manned mission Mars. The Artemis projects main objective is to establish a lunar presence by the end of 2028. Since the Apollo Missions, it has been understood that space is a harsher environment for life than previously understood. A lunar presence would increase the opportunity for further science, establish lunar commerce, extract resources, and use the moon as a waystation to further exploration into space ensuring human survival.

## *1.2 Project Description*

**DURABLE LOW-MASS LUNAR SURFACE HABITAT THEME**

*After the initial Artemis mission lands the first woman and the next man on the Moon in 2024, the Artemis program will continue with longer and bolder missions on the lunar surface throughout the 2020s. A key enabling system for those future missions will be a habitat that can support crew on the lunar surface, as they continue the exploration of the Moon and prepare for future missions to Mars. To leverage developing commercial lander capabilities, NASA is interested in a low -mass habitat that can be used on the lunar surface.*

*For this theme, teams will design a durable, low-mass habitat that can support a crew of 2 for 30 days at the lunar south pole, with a dry mass limit of 6,000 kg. The habitat should be ready for first use in 2028, with an annual budget of no more than $1 billion per year from 2022-2028 (including delivery to the lunar surface). Teams should create a development timeline with a realistic technology portfolio that can credibly achieve that date. The habitat should be capable of re-use, as it will serve as the starting point for expanding to greater crew capabilities on the surface, and for preparation for Mars missions. Thus, teams should identify how their habitat can be used to support both of these goals." - NASA RASC-AL*

# 2 REQUIREMENTS

Every engineering project has a goal, and with every goal comes its associated customer and engineering requirements. Customer requirements were informed by the team's faculty advisor and instructor. Weights were assigned to each customer requirement on a 1-10 scale, with astronaut safety taking main priority, followed by project feasibility. This would include budget and transport related requirements. The engineering requirements were generated to fill our customer requirements, and were all assigned measurable units, target values, and associated tolerances with each target value. Sections 2.1 and 2.2 list and describe the customer requirements and engineering requirements the team generated respectively.

## *2.1 Customer Requirements (CRs)*

The customer requirements that applied to the project, and associated weights are listed and expanded upon below:

1. **Be Able to Support Own Weight (Weight Assigned = 8)** – The structure would need to support its own weight in order to house and protect astronauts. The team weighed this customer requirement highly because it directly effects astronaut safety.

2. **Ease of Assembly (Weight Assigned = 7)** – Astronauts would need to be able to assemble the habitat easily within a reasonable amount of time. Ease of assembly is important because astronaut's suits are difficult to work in and making small bolts or tight places to fit pieces together would make it nearly impossible for assembly on the lunar surface. The team weighted this customer requirement fairly highly, because without considering it, astronauts could potentially fail the assembly process.

3**. Supports 2 Crew Members (Weight Assigned = 6)** – This customer requirement was formed using the project description given by NASA. The team weighted this one somewhat neutrally because it did not directly affect the safety of the astronauts, or the feasibility of the project. Although it was still important, because the habitat could not only support one astronaut as this would severely affect their mental health.

4. **Able to Fit on a Rocket (Weight Assigned = 9)** – The structure would have to be able to fit on existing rocket designs in order to be able to be transported to the moon. The team weighed this customer requirement highly because the design would be unfeasible if it is not transportable.

5. **Can be Disassembled and Reused on Lunar Surface (Weight Assigned= 4)** – This customer requirement was also formed using the project description given by NASA. One of NASA's goals was to create a habitat which could be deconstructed and stored for future missions. The team weighed this customer requirement fairly low because it did not directly affect astronaut safety, or project feasibility. Although it is an excellent goal to shoot for, it does not have a direct effect on the success of the project.
**6. Safe (Weight Assigned = 10)** – This is a more general customer requirement which encompasses all safety related requirements. It was created to skew the importance values of safety related engineering requirements in order for the team to have astronaut safety as the priority. As stated above, this customer requirement was rated a 10 for the sole purpose of ensuring that we have safety related requirements as top priority.

7**. Comfortable (Weight Assigned = 4)** – A comfortability requirement is an excellent way to ensure that the astronauts living in the habitat for one month are not cramped or otherwise uncomfortable. Although it is a nice requirement to have, it is not rated highly because it does not affect astronaut safety, or project feasibility.

8. **Under Budget (Weight Assigned = 9)** – This customer requirement simply states that the project must come in under the specified budged given to the group. This was rated highly because it would make the project unfeasible if over budget.

9. **Payload Limits of Existing Systems (Weight Assigned = 7)** – All existing rockets have payload limits which must be met, or the habitat would be immobile. This customer requirement was generated based on the dry mass limit requirement given by NASA's description. The team rated this requirement relatively highly, as it effected the feasibility of the project; however, solutions could be created to work around it if the structure were over existing payload limits.

10. **Ready for Use in Specified Time (Weight Assigned = 6)** – This customer requirement was also created using the project description. It was rated somewhat neutrally because it had some effect on project feasibility, however it did not affect astronaut safety at all.

11. **Shield Radiation (Weight Assigned = 9)** – This requirement was created with some research being done on space radiation effects on the Apollo astronauts. Shielding from radiation is absolutely necessary to guarantee the safety of the astronauts, and for this reason the team rated it very highly.

12. **Maximize Lunar Resources (Weight Assigned = 6)** – This requirement was created with the team's faculty advisor so that the team would make it a priority to include use of lunar resources. This customer requirement was rated somewhat neutrally because it did have some effect in the astronaut's safety in the form of radiation protection through utilizing the lunar regolith. It did not however, have any effect on the feasibility of the project.

13**. Innovative System or Subsystem (Weight Assigned = 5)** – This requirement was also created with the help of the team's faculty advisor to push the team towards innovative solutions. The reasoning behind this is NASA often considers innovative ideas even if they are not completely feasible because they could be made to work in the future. For this reason, the team rated this requirement neutrally, because it had no effect on 7 astronaut safety, but creating an innovative design could help the feasibility of the project.

## *2.2 Engineering Requirements (ERs)*

The engineering requirements with associated units and target values with associated tolerances are listed in order of relative technical importance (RTI) below:

1. **Budget ($ per Year, 11.4% RTI)** – This requirement was also created with the help of the team's faculty advisor to push the team towards innovative solutions. The reasoning behind this is NASA often considers innovative ideas even if they are not completely feasible because they could be made to work in the future. For this reason, the team rated this requirement neutrally, because it had no effect on astronaut safety, but creating an innovative design could help the feasibility of the project.

2. **Levels of Radiation Exposure (millirads per Day, 11.0% RTI) –** The radiation exposure had a target value of 25 millirads per day, with a tolerance of 2 millirads per day. These values were created based off of the levels of radiation that astronauts aboard the ISS see based on the ISS crew members dosimeter readings. This engineering requirement was created to fill the Shield Radiation customer need, and was rated highly because it had a direct effect on astronaut safety.

3. **Number of Livable Days (Days, 9.2% RTI) –** The number of livable days had a target value of 30 days as provided by the project description, and had a tolerance of 1 day. This value was decided on with the limited number of resources that the astronauts could bring to the moon. More than 1 day without sustenance could cause the astronauts to get weak, and not be able to complete the mission.

4. **Livable Space (m3 , 9.2% RTI)** – The amount of livable space had a target value of 130 m3 and a tolerance of 5 m3 . The team could not benchmark these values on the ISS because it is much larger scale than the lunar habitat, so the target value was based on values approximated by engineering toolbox for what amount of space people can live comfortably in. This value also accounts for supplies, equipment, and samples brought in by astronauts. The tolerance value allows the team some room for change in the

overall design. This engineering requirement was rated high because the mental health and comfortability of the astronauts is important to the success of the mission.

5. **Assembly Time (min, 9.1% RTI)** – The assembly time had a target value of 360 minutes, with a tolerance of 30 minutes. The target value is set so that the astronauts don't go for an extended period of time without rest and re-hydration. The tolerance value was decided on based on an upper limit of time that the team would not want the astronauts to exceed as it could cause them to get weak. This engineering requirement was rated highly because the safety of the astronauts directly depended on it.

6. **Time Limit (years, 8.9% RTI)** – The time limit had a target value of 7 years with a tolerance of 0.5 years. The time limit engineering requirement was created based on the project description timeline, and also filled the Ready for use in specified time customer need. This engineering requirement was rated somewhat neutrally because without meeting a deadline, the design idea would never be implementable, however it had no affect on the safety of astronauts.

7. **Dry Mass Limit (kg, 8.6% RTI)** – The time limit had a target value of 7 years with a tolerance of 0.5 years. The time limit engineering requirement was created based on the project description timeline, and also filled the Ready for use in specified time customer need. This engineering requirement was rated somewhat neutrally because without meeting a deadline, the design idea would never be implementable, however it had no affect on the safety of astronauts.

8. **Inside Air Temperature (Celsius, 8.1% RTI)** – The time limit had a target value of 7 years with a tolerance of 0.5 years. The time limit engineering requirement was created based on the project description timeline, and also filled the Ready for use in specified time customer need. This engineering requirement was rated somewhat neutrally because without meeting a deadline, the design idea would never be implementable, however it had no affect on the safety of astronauts.

9. **Inside Air Pressure (KPa, 5.9% RTI)** – The inside air pressure requirement had a target value of 101 kPa with a tolerance of 0.25 kPa. These values are based on the pressures that are used in the international space station, which is atmospheric pressure at sea level. This engineering requirement is necessary for the safety and comfortability of the astronauts.

10. **Reusable (# of Assemblies, 5.6% RTI)** – The reusability engineering requirement had a target value of 3 and a tolerance of 1. This engineering requirement was based on the project description and its target value was a goal set by the team to have the habitat be usable for 3 different missions. This value, and its tolerance is simply a goal, and is not based off of any benchmark. This engineering requirement was rated somewhat low, as it is something that was provided in the project description, but not detrimental if goals are not met.

11. **Air loss (% per day, 4.7%)** – The target value for the air loss engineering requirement was .03% per day, with a tolerance of .005%. The team wanted to lose no greater than 1% of the air within the habitat, in order to keep an adequate pressure for the astronauts. This engineering requirement was important for the comfortability and safety of the astronauts, but the effects of air loss are usually quite low in the ISS, so the team decided that it was not as crucial as the other habitat living conditions.

12. **Lunar Resources Used %, 4.5% RTI)** – The target value for this engineering requirement was 15% with a tolerance of 5%. Similar to the re-usability requirement, the target values and associated tolerances are based off of a goal for the team, and is not based off of any benchmark. This engineering requirement was created to fulfill the maximize lunar resources requirement, which was created with the help of the faculty advisor.

13. **Number of Novel Subsystems (#, 4.0% RTI)** – The target value for the number of novel subsystems was 2 with a tolerance value of 1. Similar to the lunar resources used requirement, the target values and associated tolerances are based off of a goal that the team set. This engineering requirement was created to fulfill the innovative system or subsystem customer need.

## *2.3 Functional Decomposition*

### 2.3.1 Black Box Model

The black box model is a diagram which analyzes the inputs and outputs of a system. This is a useful tool in the concept generation process as it illuminates the different kinds of flows to design around. The bold, heavyweight line represents the material flows, which include anything physical that takes up space entering the system. The term solids is used to describe any equipment, supplies, samples, and other physical materials that the astronauts will be bringing into the system with them. The black lightweight line is used to represent energy which flows into and out of the system. Energy can take many forms, however in this case only radiant energy from the sun, and electricity from external sources are relevant. The dashed line represents signal flows. Signals are waves which carry information, in this case radio waves are used to communicate with NASA. The black box model gives the team an overall general understanding of the different inputs and outputs of the design. Figure xxx below displays the teams Black Box Model.


**Figure 1: Black Box Model**

### 2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The functional model is a more detailed breakdown of the flows into and out of the system. Notice how the same input and output flows from the Black Box Model are present in this model as well. Each subsystem starts with its own import function, where the material, energy, or signal flow is imported into the system. The overall system is broken down into 5 subsystems: radiation, air and temperature regulation, astronauts and solids, radio signals and finally power. The primary function for this system is to “maintain” or preserve astronauts. Inputs of air, conditioned air, astronauts, solids, and an auditory signal for communication are required to sustain the life of the astronauts. This model was useful for get a deeper understanding of what specific subsystems accomplish. It gave the team a good idea of what subsystems to benchmark, as well as helped the team consider how these subsystems would affect the overall design. This was useful in the concept generation process. The functional model also helps the team get an overall visual understanding of everything entering and leaving the system. The functional model was updated to include urine processing as part of the ECLSS subsystem. The radiation part of the functional model was also updated to be more accurate, showing radiation being absorbed and reflected now. Line breaking was also done to make the functional model read better. Figure xxx below shows the teams finished functional model.

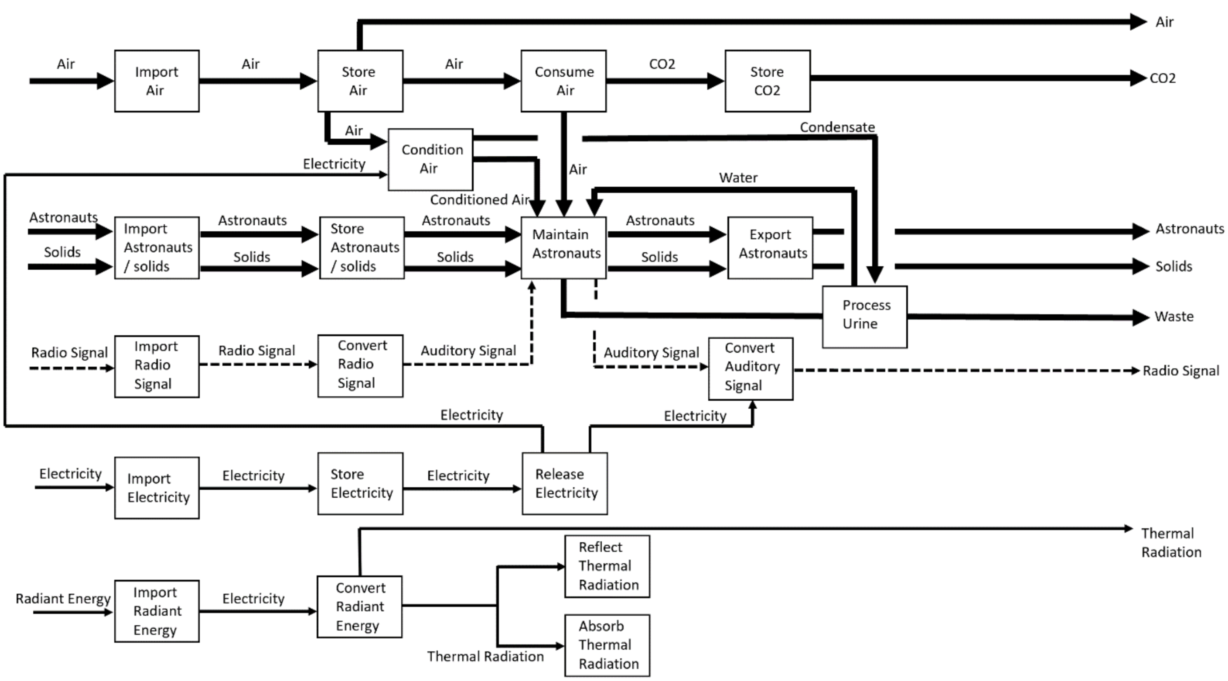


**Figure 2: Functional Model**

## *2.4 House of Quality (HoQ)*

A House of Quality (QFD) was used to rate and evaluate the team’s customer requirements and engineering requirements. The House of Quality helped the team determine that Budget, Levels of Radiation Exposure, and Number of Livable Days were the three most technically relevant engineering requirements. This helped our team select the most important design aspects for the lunar habitat. Testing procedures were added for the engineering requirements 2,7, and 8. Table 1 below shows the teams House of Quality.

**Table 1: House of Quality**

| Customer Requirement | Weight | Number of Livable Days (Days) | Reusable (# of Assemblies) | Liveable Space (m^3) | Dry Mass Limit (kg) | Assembly Time (min) | Levels of Radiation Exposure (milirads per day) | Inside Air Temperature (C) | Budget ($ per year) | Airloss(% per day) | Time Limit (years) | Inside Air Pressure (kPA) | Number of Novel Subsystems (#) | % Lunar Resources Used |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Be able to support own weight | 8 | 9 | 6 | 9 | 9 | 7 | 3 | | 8 | | 3 | | | |
| 2. Ease of Assembly | 7 | 4 | 9 | | 4 | 10 | 4 | | 9 | | 4 | | | |
| 3. Supports 2 Crew Members | 6 | 10 | | 9 | | 4 | 8 | 9 | 7 | 4 | 3 | 8 | | |
| 4. Able to fit on a rocket | 9 | | 4 | 9 | 10 | 8 | 4 | | 8 | 4 | 6 | | | |
| 5. Can be dissassembled and reused on lunar surface | 4 | 4 | 10 | 7 | 4 | 9 | 4 | 4 | 8 | 7 | 5 | 9 | | |
| 6. Safe | 10 | 8 | 4 | | 6 | 5 | 10 | 9 | | 6 | 6 | 9 | | |
| 7. Comfortable | 4 | 7 | | 9 | | | 9 | 10 | 8 | 1 | 3 | 9 | | |
| 8. Under Budget | 9 | 9 | 4 | 9 | 8 | 4 | 8 | 8 | 10 | 3 | 9 | 8 | 8 | 6 |
| 9.Payload Limits of Existing Systems | 7 | | 2 | 8 | 10 | 7 | 6 | 7 | 7 | | 7 | | | 8 |
| 10. Ready for use in specified time | 6 | 6 | 3 | 4 | | 4 | 8 | 7 | 9 | 4 | 10 | 4 | 8 | 7 |
| 11. Shield Radiation | 9 | 9 | | 7 | 6 | 7 | 10 | | 7 | | 5 | | | |
| 12. Maximize Lunar Resources | 6 | 6 | | 4 | 4 | 6 | 6 | 9 | 7 | 5 | 4 | | 9 | 10 |
| 13. Innovative system or subsystem | 5 | | 4 | | | | 9 | 8 | 8 | 6 | 6 | 5 | 10 | 9 |
| **Absolute Technical Importance (ATI)** | | 518 | 315 | 519 | 486 | 516 | 621 | 457 | 643 | 263 | 505 | 331 | 224 | 257 |
| **Relative Technical Importance (RTI)** | | 9.2% | 5.6% | 9.2% | 8.6% | 9.1% | 11.0% | 8.1% | 11.4% | 4.7% | 8.9% | 5.9% | 4.0% | 4.5% |
| **Target ER values** | | 30 | 3 | 130 | 6000 | 360 | 25 | 20 | 1 Billion | 0.03 | 7 | 101 | 2 | 15 |
| **Tolerances of Ers** | (+/-) | 1 | 1 | 5 | 100 | 30 | 2 | 3 | 1,000,000 | 5.00E-03 | 0.5 | 0.25 | 1 | 5 |
| **Testing Procedure (TP#)** | | | | | 2 | | 1 | 1 | | | | | | |

## *2.5 Standards, Codes, and Regulations*

**Table 2: Standards of Practice as Applied to this Project**

| **Standard Number or Code** | **Title of Standard** | **How it applies to Project** |
|---|---|---|
| ASNI/AAMI HE 74:2001 | Human Factors Design Process for Medical Devices | Helps in the design of how the device with interface with the user in a safe manner. |
| NASA-STD-3001 VOL 1 | NASA Space Flight Human-System Standard Volume 1, Revision A: Crew Health | Goes into depth on the importance of maintaining crew health. Useful for design of ECLSS systems. |
| NASA-STD-3001 VOL 2 | NASA Space Flight Human System Standard Volume 2: Human Factors, Habitability, and Environmental Health | Discusses effects of environmental conditions on crew health. Useful for design of ECLSS systems. |
| NASA-STD-5001 | Structural Design and Test Factors of Safety for Spaceflight Hardware | Gives standard factors of safety for structural design for space. Useful for structural analysis of habitat. |
| NASA-STD-6016 | Standard Materials and Processes Requirements for Spacecraft | Discusses materials and process that materials need to undergo to be ready for use in space. Useful for specifying a budget and Bill of Materials |
| NASA-STD-7002 | Payload Test Requirements | Useful for figuring out how to test if the habitat meets payload requirements. |
| ASME Y14.5M-2004 | ASME National Standard Engineering Drawing and Related Documentation Practices | This Standard establishes uniform practices for stating and interpreting dimensioning, tolerancing, and related requirements for use on engineering drawings and in related document. |
| ASTM F593-17 | Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs | Aids in the design of our M-24 steel hex head bolts so we can ensure the structural integrity of our micrometeorite shield. |
| ASTM D8101/D8101M-18 | Standard Test Method for Measuring the Penetration Resistance of Composite Materials to Impact by a Blunt Projectile | This engineering standard gives our team insight into how we can test the impact resistance of our own composite materials (i.e. Kevlar & Nextel) |
| ASTM B646-19 | Standard Practice for Fracture Toughness Testing of Aluminum Alloys | Helps our team the limitations of our aluminum alloy since it will be under a lot of fatigue due to the frequent temperature variation that occurs on the lunar surface |

# 3 Testing Procedures (TPs)

This section discusses the testing procedure developed by the team for each Engineering Requirement. Two testing procedures have been identified to determine how the engineering requirements have been fulfilled as well as how the testing procedure is conducted.

## *3.1 Testing Procedure 1: Solidworks Thermal Study of Lunar Habitat*

The thermal testing procedure is a computational analysis of the geometry of the lunar habitat. The program SOLIDWORKS can be used to perform a thermal study of the geometry. For purposes of simplicity, steady state conditions will be assumed, and a material selection will be made for the outer shell, and inner living area of the habitat. Although the material selection is not yet finalized, polyethylene, Kevlar, and mylar are being considered for materials to insulate the habitat and protect against radiation. These materials are being considered all have low emissivity values, which corresponds to higher reflectivity. This testing procedure fulfills the Inside Air Temperature Engineering Requirement, and the levels of Radiation Requirements.

### 3.1.1 Testing Procedure 1: Objective

For this testing procedure, a SOLIDWORKS thermal study will be conducted. First, it is important to note that a steady state analysis will be considered, so this will not account for Solar Particle Events or Galactic Cosmic Rays, which could cause unexpected spikes in radiation fluxes. These events can and will be accounted for with a specified factor of safety in the future for the radiation analysis individual assignment. Next, a heat flux of 1422.3 W/m^2 will be applied to the exterior of the geometry. This value was calculated using the closest possible distance the moon could be to the sun at any given moment, and the sun's luminosity constant.

More information on this calculation will be provided in the design selection section. After the heat flux is applied, materials will be selected and applied to the various layers of MLI (Multi-Layer Insulation), as well as the exterior and interior of the habitat. Multiple material combinations will be considered, and separate tests will be ran for each combination. Next, contact sets will be applied in-between each layer. This allows the simulation to account for the thermal resistance change from one layer to another. Finally, a conclusion will be drawn for the best combination of materials to mitigate radiation flux getting into the habitat. Because of the nature of radiation, this will also mean that it will keep any heat from getting out of the habitat as well. This testing procedure is crucial to validate that the habitat will be able to keep the astronauts safe and comfortable within the habitat.

### 3.1.2 Testing Procedure 1: Resources Required

[Provide a complete description of necessary items for the test to be completed satisfactorily. This includes (but is not limited to): people, software, hardware, tools, location, etc.

This testing procedure will be simple to perform as far as resources go. It will only require one person and the SOLIDWORKS software to perform. This simulation can be performed anywhere, at home or on campus.

### 3.1.3 Testing Procedure 1: Schedule

[Provide a breakdown of how long the test will take, when it will likely be run, and how it fits into your second semester schedule. Also describe anything that must be completed before this test can be run.]

There is always expected to be a learning curve when working with a part of a software the team has never used before. Because of this the estimated time for this simulation is around 2-3 weeks. A lot of work is expected to get done on this by the end of this semester because it is being used in the heat transfer application project. This is beneficial for the team because it will put the team ahead of schedule for the testing procedure. If nothing else, it will give members experience with the SOLIDWORKS thermal study program. For the simulation to be complete, a more detailed CAD with a radiation subsystem must be completed. This has already been done and was presented in the final presentation, so this testing procedure is ready to be completed.

## *3.2 Testing Procedure 2: Hypervelocity Impact Test Analysis (HITA)*

### 3.2.1 Testing Procedure 2: Objective

The HITA test will be conducted analytically by using the computer-aided design software Solidworks. This is for the purpose of discovering whether our design can withstand the high levels of kinetic energy that a high-speed micrometeorite can create. We are also attempting to understand how much damage other physical parameters will have upon impact with our shield (i.e., Oblique impact versus Normal impact, Pressure, Impulse, Momentum, etc.). The information that we gather will allow us to make the proper adjustments to ensure with confidence that our astronauts will be safe for the duration of this project (thus satisfying our number of livable days engineering requirement and safety which is a customer requirement).

### 3.2.2 Testing Procedure 2: Resources Required

For our tests to run smoothly we will need the full suite of Solidworks as well as the linear and non-linear dynamics packages. To access this software and the necessary add-ons I will need to use the engineering building's computers. I will also need the assistance of one of our teammates Ryan Navarrete because he possesses a greater knowledge of Solidworks.

### 3.2.3 Testing Procedure 2: Schedule

Testing could take anywhere between one week to over two weeks depending on how long it takes me to understand the software packages. We plan on testing sometime during week 1-6 of next semester so that we can be ready for the testing proof portion of the ME 486C course. Before any of the testing can happen, I will need to ensure my thought process about the physical concepts surrounding the micrometeorite shield is correct by doing some back of the envelope calculations. To assist providing a visual representation of my calculations I will be using MATLAB to create various plots of different physical parameters.

[Include as many Testing Procedures necessary to fully test all CRs and ERs.]

# 4 Risk Analysis and Mitigation

## *4.1 Critical Failures*

### 4.1.1 Potential Critical Failure 1: Urinary Process Assembly

The life support system on board the lunar habitat will be an integrated system that can recycle the water on board through multiple steps. The Urinary Process Assembly (UPA) will be the first step in filtering and cleansing the urine from the astronauts. Within the International Space Station (ISS), the initial storage tank of this model where the urine is first stored has shown multiple symptoms of microbial growth from the urine. This has led the liquid to create a foggy congestion making it difficult for the liquid to effectively flow through the pipes and enter the next stages of filtration. This is caused by the failure of no microbial growth prevention fluids mixed in with the urine in the initial storage tank. Thus, the UPA must initially mix the collected urine with the compounds $H_3PO_4$ and $Cr^{6+}$ in order to prevent microbial growth and chemical stability. [1]

### 4.1.2 Potential Critical Failure 2: Water Process Assembly

Within the life support system, the Water Process Assembly (WPA) collects all the wastewater and the runoff from the UPA and initiates the water refining process. One of the most crucial steps of the WPA is a particulate filtration that degasses the liquid and passed through a high temperature in order to cleanse the liquids. In recent years, on board the ISS, this method has shown ineffective as some of the unfiltered smaller contaminants such as dust, skin cells, and left-over urine precipitation, have formed precipitation over the particulate filter walls. The precipitation clogs the intakes and lowers the efficiency of the model. Instead of the current models of the particulate gas filtration methods, a Rotary Gas Separator (RGS) has shown much more promising efficiency ratings and has proven to be a much more effective tactic. The RGS design allows the flowing water and gaseous combination to flow into a rotating centrifuge with inducers and straight vanes. [2]

### 4.1.3 Potential Critical Failure 3: Bumper Initial Impact

The bumper could potentially fail only if the thickness of it is too large because studies have shown that if the shield is too large the projectile will not completely tear apart upon impact. If this failure occurs there could be catastrophic damage to the following shields. This failure can be prevented if we model our shield closely to the stuffed whipple shields on the ISS because they have already been extensively tested. We will also validify our reasoning by doing back of the envelop calculations.

### 4.1.4 Potential Critical Failure 4: Intermediate Bumper Failure

Our intermediate bumper could fail due to the debris cloud from the impact of the projectile and the bumper. If the debris cloud has too many large projectiles as a result of the failure of the bumper the intermediate bumper could sustain a great amount of damage or even fail. If it fails the rear wall could sustain more damage than it was designed to withstand and this could lead to a fatal eventuality for our astronauts. This will be prevented by first ensuring that the first shield is thick enough to completely dismantle the object. Secondly, we will ensure that each layer between the bumper and the rear wall have both 4 layers of Nextel and Kevlar (2 layers of each). Each layer will have a thickness of two millimeters and each material will have six layers each totaling 12 layers and 24 millimeters of protection.

### 4.1.5 Potential Critical Failure 5: Rear Wall Impact Failure

Our rear wall is our last line of defense if the first two shields fail. One way that the wall could fail is if the first two shields fail. If the first two fail this means that the projectile is still for the most part intact. If this occurs a greater amount of force will be generated onto the wall which has the possibility of creating a lot of damage. To prevent this from happening the rear wall will have a larger thickness of about five millimeters. This is a little bit bigger than the shields used on the ISS but since we will be on the lunar surface it is better to provide a little more insurance of safety.

### 4.1.6 Potential Critical Failure 6: M-24 Hex Bolts Fatigue Failure

Our entire micrometeorite shield will be held together with M-24 hex head bolts to ensure that our shield is secure and can accomplish the task we designed it to do. However, it can fail due to the variation in temperature on the lunar surface which can make the steel hex bolts reach plastic deformation faster. To mitigate this we will using space grade bolts. These bolts will be very similar to the ones that are used on the ISS which should be able to withstand the atmosphere on the moon.

### 4.1.7 Potential Critical Failure 7: Composite Material Woven Failure

For the composite materials we have chosen Kevlar and Nextal because of their tensile strength as well as their thermal coefficient expansion values. However, despite the materials having strong attributes in terms of aerospace applications they can still fail due to weak weaving of the material. To mitigate failure due to weak weaving we are going to ensure that our Kevlar and Nextel is weaved in fully extended chains to create a rigid like structure.

### 4.1.8 Potential Critical Failure 8: Fracture Propagation due to Plastic Deformation

One way our aluminum portions of the shield could fail is due to the temperature variation that occurs on the moon. This can cause cracks due the constant compression and tensile forces. Fracture will occur if our material continues to plastically deform. To prepare for this we will be using aluminum like the alloy used on the ISS. We will also refer to the engineering code ASTM B646-19 so we can know the limitations of our aluminum alloy.

### 4.1.9 Potential Critical Failure 9: Shield Thickness Failure

A general rule of thumb NASA used while designing the ISS shields was that the total shield thickness cannot be greater than the projectile diameter. The reason for this is because when they tested a shield with a thickness greater than the diameter of the projectile it prevented less damage than if the thickness was less. To ensure this does not happen we will make sure that the total thickness of the shield will be less than the projectile diameter.

### 4.1.10 Potential Critical Failure 10: Standoff Distance

The distance between each part of the shield is critical to the success of this design. The reason for this is because once a projectile encounters the shield it is broken up into cloud of debris. To be rendered harmless by the next portion of the shield there needs to be ample room so that the impact will have a larger surface area to disperse the kinetic energy. If not the kinetic energy and pressure will be concentrated more on one area. To mitigate this possibility, we have made our standoff distance 12cm. The ISS made it 11.6cm but we want as much room as possible to decrease the chance of this occurring.

#### 4.1.11 Potential Critical Failure 11: Bearing Stress Failure

Since the temperature on the part of the lunar surface that we plan on inhabiting varies so much it can cause our shield to expand and contract. This expansion and contraction can cause the bearing stress that occurs on the M-24 hex head bolts to increase exponentially. To mitigate this from happening we have chosen materials that have a high tensile and compressive strength. We also chose materials with a low thermal expansion coefficient which will help in mitigating this.

#### 4.1.12 Potential Critical Failure 12: Material Strain Failure

Strain is an important mechanical characteristic that if not accounted for could cause our design to fail. If we did not choose materials that could not survive aerospace applications our shield would succumb to the tensile and compressive stresses and forces. For example, if we chose a different type of aluminum than aluminum 7050 the temperature variation could cause our material to strain beyond repair (i.e., plastic deformation or fracture). To mitigate against this, we have chosen specific dimensions that allows our material to expand without damaging itself or other components. We have also chosen materials with a low thermal expansion coefficient as well as materials with a high tensile and compressive strength.

## 4.2 *Risks and Trade-offs Analysis*

The FMEA for the ECLSS proves that the existing design for the life systems are a prominent solution to one of the most essential aspects of the design. The ECLSS has been on board the ISS for over 15 years and has served as a forefront of the space travel revolution. Although, the system is not perfect by any means, multiple groups have researched failures of the life support system and have provided multiple approaches to the solutions. The approach to these solutions consists of dissolving the liquid with a base that would destress the consistency and prevent the precipitation. Throughout all the analysis, only one part of the subsystem proved to be more efficient if changed out altogether.

| Subsystem Name | Part Name/Function | Potential Failure Mode | Potential Failure Effect | Severance (SEV) | Potential Causes | Occurrence (OCC) | Action Recommended | Detection (DET) | Risk Priority Number (RPN) |
|---|---|---|---|---|---|---|---|---|---|
| Atmosphere Control | Valve | Scale Buildup of unknown microorgansisms causing thermal expansions | Not effectively removing CO2 from breathable air | 8 | Scale buildup of unknown microorganisms | 4 | Self-Awareness systems- self cleansing | 2 | 64 |
| | Heater | Heater Shortage on the controller fault | Not being able to provide protocol temperature conditoins | 5 | Not having a control box large enough to sustain the pressure of system | 4 | Multi-control system for different ranges | 2 | 40 |
| | Pump/Blower | Human error on control box not being able to filter microorganisms | Temperature Control failure | 6 | Overexhausting the engine effecting the filter for microorganisms | 3 | Larger engine to sustain the work, self awareness sensors for warning protocols | 1 | 18 |
| | Duct Failure | Absorbent dust blocking the air vents/ducts | effeciently filtering air and proving staff with clean air | 10 | Not cleaning the air vents often enough, larger air vents | 2 | Self-Awareness systems- self cleansing | 3 | 60 |
| | | | | | | | | | |
| Urinary Process Assembly (UPA) | Initial storage tank | Microbial Growth from the urine | This could potentially create a congested liquid for water to flow through | 9 | Not filtering the urine enough before kept in initial storage tank | 2 | Compound Cr6+ and H3PO4 added to maintain the microbial growth | 1 | 18 |
| | vapor compression distillation (VCD) | low-pressure rotating vapor compression evaporation system | System not clearly cleansing urine to the vapor state | 10 | Unfiltered particles would impact the filteratin statuses of later stages | 1 | High temperatures and filteration processes | 2 | 20 |
| | | | | | | | | | |
| Water Process Assembly (WPA) | Particulate Filter | Baceteria forms a percipitation over walls | the percipitation clogs the intakes and lowers the effeciency | 5 | Unfiltered smaller contaminents like dust, skin cells, left over urine percipitation | 6 | Replace with a Rotary gas seperator- 98% effeciency | 3 | 90 |
| | Multifiltration Bed | dimethylsilanediol formed by methyl siloxane | Clog the filtration system and reduce the effeciency | 7 | organic compounds are absorbed, and ionic compounds are removed | 2 | Aquoporins transmembrane protein | 3 | 42 |
| | | | | | | | | | |
| Fire Detection and Suppression | Sensor Failure | System not being able to detect fire | Uncontrolled Fire would cause death | 10 | degradation, sensor contamination | 1 | Maintanence on the sensors | 1 | 10 |

Figure 3. ECLSS FMEA

# 5 DESIGN SELECTED – First Semester

The preliminary design selected is the Babylon Space Capsule and is generated from multiple concept variants. Since the preliminary design was generated, numerous structural and safety considerations have been made such as choosing circular tubing, volume requirements, radiation reduction and protection, and mitigation of psychological and physiological impacts. In this section, a detailed description is provided, and an implementation plan is discussed in the next stage of the design development.

## *5.1 Design Description*

The design shown below is named the Modular Space Capsule. As shown below, on the outside is a big cylinder with a window section at the end. The design is designed for versatility with assembly as it is designed to be a small pod. The structure is manufactured on earth and initially assembled on earth for testing. After the final testing process, the structure could be taken apart and shipped to space in rockets in modular sections for assembly in space, or on the lunar surface. The figure below shows the initial design and the improved Babylon Space Capsule design.

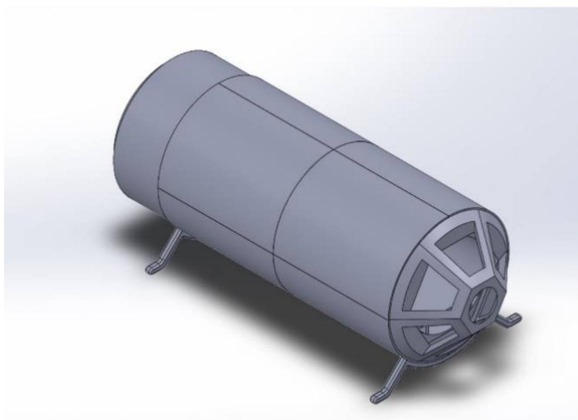

**Figure 3: Preliminary Babylon Space Capsule**

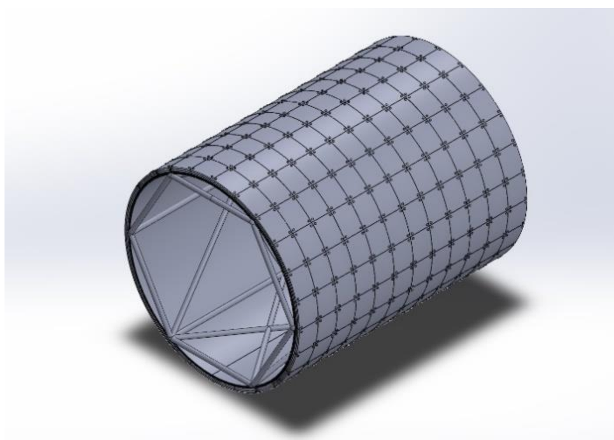

**Figure 4: Internal Structure with the space shield.**

Radiation protection was also examined to determine the appropriate materials to use. The two common radiations that astronauts will be exposed to are electromagnetic radiation and neutron radiation. Electromagnetic Radiation (Most notably Infrared, Ultraviolet, Visible wavelengths). Neutron Radiation -

Free flying neutrons (large fermions with no charge). The worst-case scenario radiation influx is expected to be 1422.3 W/m^2. Three materials were examined for radiation protection: Y9360-3M Aluminized Mylar, 7452-Mystic Aluminized Kapton (Polyimide Film) and Borated Polyethylene. Mylar has been chosen as the insulator of choice as its emissivity is 0.03 with a flux transmission of 42.67 W/m^2. This would reduce the radiation flux to 97% of the exposed rate. The specified thickness of the MLI layer is to be anywhere in the range from 12-14mm depending on which thicknesses the sheets of materials can be manufactured in. This thickness was determined based off of the radiation shielding used on the ISS.

**Micrometeorite Shielding Protection (MSP)**
Physiological shielding was also examined to reduce micrometeorite impacts.
The chosen micrometeorite shield design is based on the famous Whipple shield which is currently being used on the ISS. It is comprised of four components which are the front bumper, three layers of the intermediate bumper, and the rear wall. The bumper and the rear wall are both made from Aluminum 7050 which is a strong and durable material with a high tensile strength (400 MPa) and high modulus of elasticity (80 GPa). The front bumper has a thickness of two millimeters and the rear wall has a thickness of seven millimeters. For the intermediate bumper we chose Nextel and Kevlar to comprise this portion of the shield of. The bumper has three layers total and within each layer is two layers of Nextel and two layers of Kevlar. Each layer of Nextel and Kevlar have a thickness of two millimeters totaling a thickness of 24 millimeters. Overall, we have a total thickness of 31 millimeters for the entire design. The general rule of the thumb that NASA used when they were designing the Whipple shield for the ISS was to keep the total thickness of the shield below the estimated projectile diameter. This allows our team to protect our astronauts against various sizes of projectiles that our lunar module may encounter during the 30 day mission.

1. Bumper (First Layer)
    - Material: Aluminum 2219
    - Thickness (mm): 2
2. Intermediate Bumper (Secondary Layer)
    - Material: Kevlar-29 & Nextel-610
    - Thickness (mm): 2 each layer (Total of 24 for the Intermediate bumper)
    - Thermal Expansion of Nextel-610 (ppm/C): 8
    - Thermal Expansion of Kevlar-29 (cm/cm/C): -4x10
    - Tensile Strength of Kevlar-29 (MPa): 3,600
    - Tensile Strength of Nextel-610 (MPa): 2,800
3. Rear Wall (Last Layer)
    - Material: Aluminum 2219
    - Thickness (mm): 5

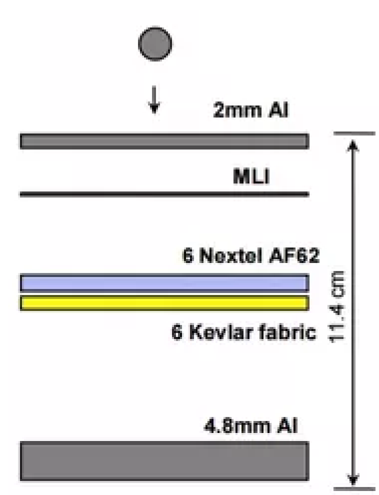

Figure : NASA Configuration []

The mylar and whipple shield have been incorporated into the preliminary design. The improved design and its section view of the placement of the materials is provided below in figure 5.

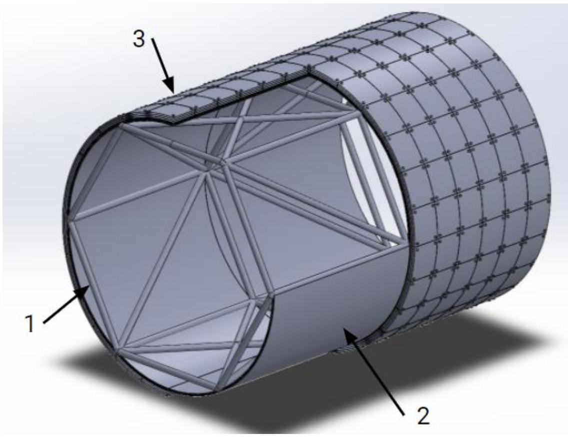


Figure 5: Parts of current CAD model.

The figure describes the three layers that go into the structure.

1. Bone Structure: Circular Tubing made out of Titanium.

2. MLI: Multi-Layer Insulation that consists of a Layer of Kapton on top, followed by a layer of Plasti-Shield Borated Polyethylene, and finally a layer of Aluminized Mylar. It has a thickness of 12 to 14mm similar to the International Space Station.

3. Whipple Shield Array: Three-layer shield made out of multiple materials to block out harmful radiation.

The generated concept structure must adhere to the minimum habitable volume (NHV) to accommodate for a safe livable area. According to human factors research, our net habitable volume for 2 individuals for 30 days is 55 +/- 5 cubic meters. This net volume not including the air lock chamber is 3m x 7.5m x 2.5m (width x length x height). This results in a volume of 56.25 cubic meters.

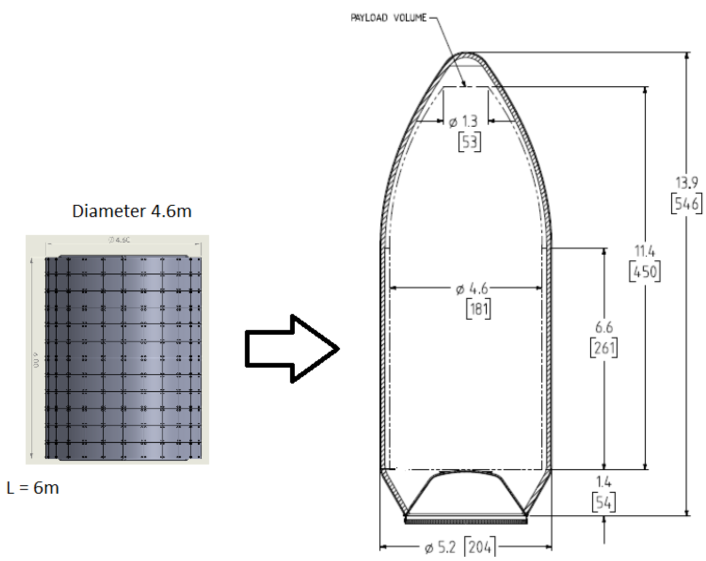


Figure 6: Payload to current design comparison. [4]

An alternative option to transport the structure is to place it in the Falcon 9 as a fully assembled rocket and deployed to the lunar site of interest.

The figure describes the dimensions of the structure during the design phase. The diameter of the structure is 4.6m and the length is 6m. The Babylon Space Module fits into the Falcon 9 payload requirements and there is room for expansion of up to 0.6m in length.

Based on the cad model, the current mass of the habitat is 6300Kg. The structure is just above the requirements. This additional weight should be reduced after structural tests.

The lunar habitats' three main sections are: the front module which houses the air lock chamber, the non-pressurized storage of materials and samples followed by the systems management of the habitat. The system management area contains the air management system, water purification system, power storage, temperature control system and pressure management system. The second module houses the workspace includes laboratory equipment and storage of materials collected on the lunar surface. The third module houses the living quarters, rear bed space, sanitation, and kitchen area. The waste management system is planned to be placed in the hygiene area. The figure below describes the preliminary layout for the capsule.

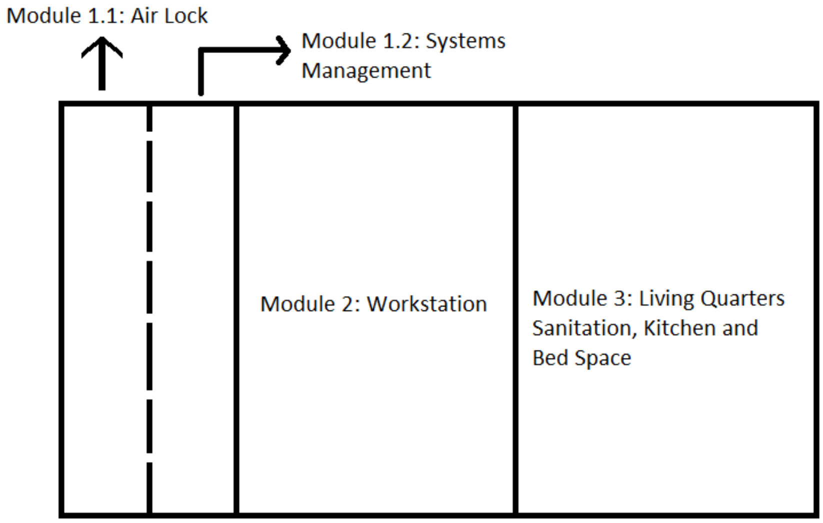


**Figure 7: Module internal Layout**

In addition, the capsule is designed to be expandable via the airlock chamber where it could use a coupling chamber to connect to extra modules if necessary. The figure below describes the preliminary layout for the design.

Currently, all the subsystems necessary to support two individuals exist inside the structure in the first module. The chosen subsystem management is the Environmental control and life support system. The system is designed to detect fire and suppress it, controls temperature and humidity, recovers water from waste management and processes air to maintain healthy oxygen, nitrogen, and carbon dioxide levels. The ECLSS schematic is provided below.

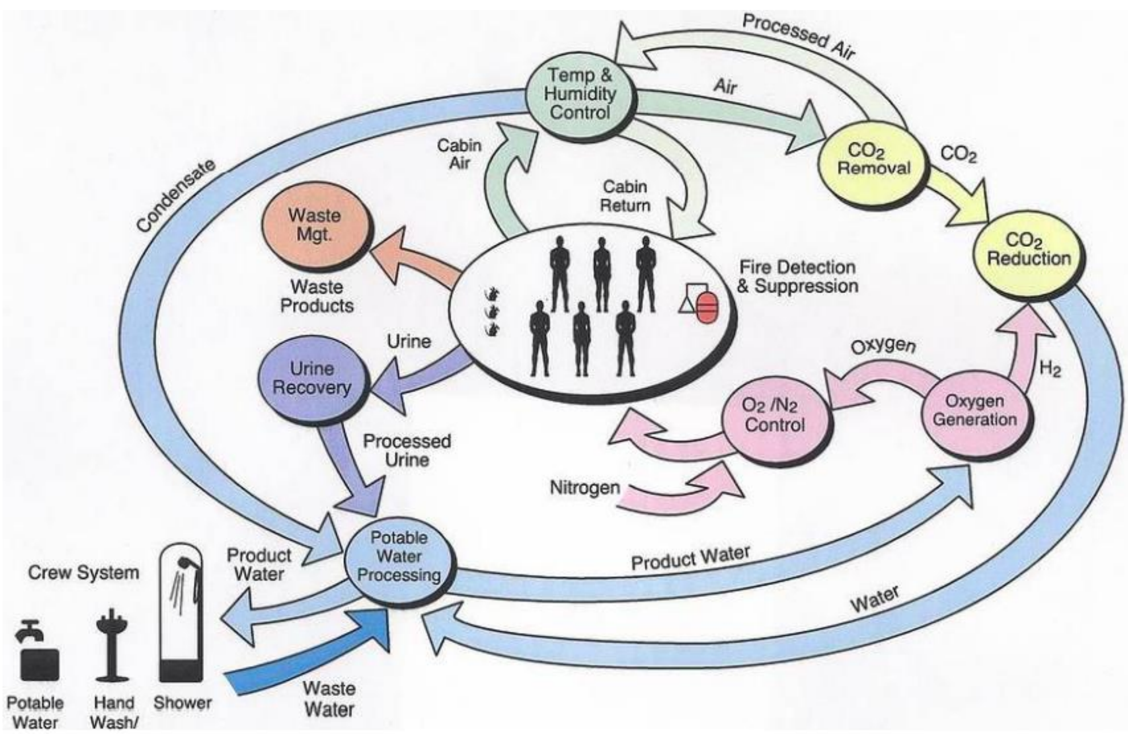


**Figure 8: ECLSS Integrated System [SG3]**

The Water recovery system (WRS) on the ISS is a procedure to reclaim wastewater, cabin humidity condensate and extra vehicular activity (EVA) wastes. The system initiates with a water processor that separates free gas and solid materials such as lint, hairs, etc. then proceeds to a series of multi-fractional beds that extend the purification procedure of the water [1].

A high temperature catalytic reactor assembly removes any remaining microorganisms and organic contaminants. Typical contaminants increase the increases the conductivity of water; thus, conductivity sensors test the purity of the water. If the water does not pass the standard for health and safety of the crew members, the process is conducted again, then stored in a storage tank ready for use by the crew members. The ECLSS system limits hazard from a single system failure.

The system maintains an air pressure at 93.3 to 101.3kPa with 79% Nitrogen and 21% oxygen levels. The Water Process Assembly (WPA) maintains 27L of water in circulation and Urine Process Assembly (UPA) takes up 11.2 m^3. The combined upgrade efficiency of the system is 98%.

A low fidelity prototype was generated to represent the Babylon space capsule and for proof of concept. Throughout the daily operations on board the Lunar Habitat, breathable oxygen is lost due to the habilitation, experimental use, airlock depressurization, module leakage, and carbon dioxide ventilation. The oxygen generation system reinstalls the lost oxygen mainly through its cell stack which electrolyzes the water provided by the WRS, yielding hydrogen and oxygen as its byproducts.

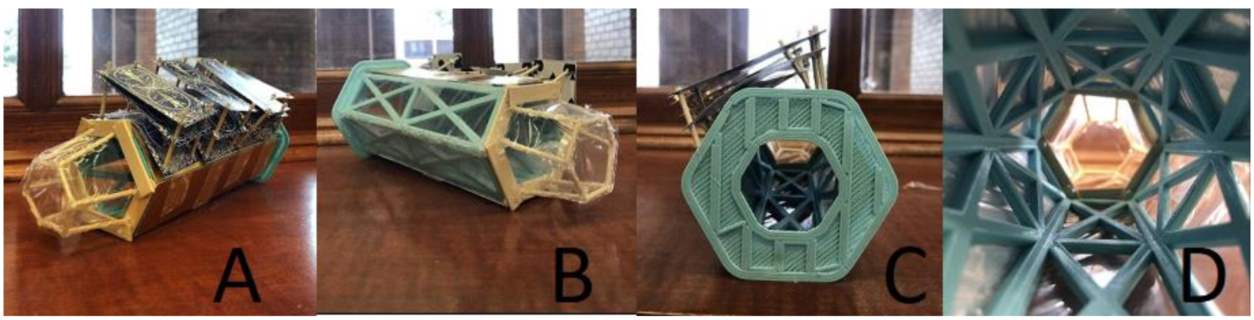


**Figure 9: A. View 1 Isometric B. View 2 Isometric C. Front View D. Interior View**

As described in the figure above, the prototype bare bones were manufactured using 3D printing. The structure was then enclosed with plastic to the scaled down version of the MLI and wrapped in gold paper to represent the Mylar. Next, the whipple shield was modeled using deck cards layered in threes from the base and stacked proportionally next to each other. Some of the construction differences to the cad model is the whipple shield. The difference between each whipple shield is much larger than the cad model and does not provide the best iteration of the model.

## 5.2 *Implementation Plan*

The plan for the concept development process is better understood when looking at the product life cycle chart which is provided below. The Artemis mission is planned to take place in 2028 which gives us 7 years to take the Babylon Space Capsule to mission ready. As shown below, the major processes are listed along with the predicted timeline for each phase of the process. Since it is likely that the final design will go through many stages of iterations, the final design extends into 2022. However, the aim of this project is to complete a fully functional concept.

**Table 3: Artemis Lunar Misssion Life Cycle**

| PHASE | MAJOR PROCESSES | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Concept Development | * | | | | | | | |
| | Concept Development | * | | | | | | | |
| 2 | Final Design | | * | | | | | | |
| | Manufacturing Plan | | * | | | | | | |
| | Fabrication and Assembly | | | * | | | | | |
| | Testing Module | | | | * | | | | |
| 3 | Fabrication and Assembly | | | | | * | | | |
| | Integration and launch | | | | | * | | | |
| | Lunar Transfer | | | | | * | | | |
| 4 | Module Assembly | | | | | | | * | |
| | Module Testing on Lunar Surface | | | | | | | * | |
| | Systems Testing | | | | | | | | * |
| 5 | Lunar Mission | | | | | | | | * |
| | Systems Operations and Motoring | | | | | | | | * |

A fully functional concept requires a detailed design. As such, before the final prototype can be generated, the radiation analysis, structural analysis. These analyses will be conducted as part of the individual analysis in the final weeks of the first part of the concept development. Once confidence is established in the analyses, the prototype will be manufactured to represent the cad model as closely as possible with the appropriate material selection. The next phase is testing and planning a preliminary manufacturing plan.

The testing for the prototype will be conducted for vibration. The testing plan is provided above in the testing procedures 2. Based on the tests, the necessary revisions will be made to each component of the concept design starting with the bone structure, the whipple shield, and ECLSS system place holders established. The final redesigns happen for the weight and optimal budget while maintaining the existing operation level.

The Gantt chart for next semester is provided below and illustrates the schedule starting in august till December.

| | | |
|---|---|---|
| **5** | **Final Planning for Fall** | |
| 5.1 | Technical Risk Management | |
| 5.2.1 | Radiation Testing Plan | All Team |
| 5.2.2 | Vibration Testing Plan | Keerthi |
| 5.3.1 | Design Optimization | |
| 5.3.2 | Manufacturing Plan and Vendor research | |
| 5.4 | Project Performance | |
| 5.6 | Project Performance and Final Evaluation | |
| **6** | **Fall Schedule** | |
| 6.1.1 | Update CAD Model | |
| 6.1.2 | Posst Mortom | |
| 6.1.3 | Website Check | |
| 6.2.1 | Testing for Design and Failure | |
| 6.2.2 | Fabrication Plan for the final Prototype | |
| 6.2.3 | Individual Research Topics II | |
| 6.2.4 | Midpoint Presentation | |
| 6.3.1 | Technical Risk Management | |
| 6.4.1 | Prototype Build | |
| 6.4.2 | Prototype Test | |
| 6.5.1 | Redesign for Weight | |
| 6.5.2 | Redesign for Optimal Budget | |
| 6.6.1 | Final CAD Model for Concept | |
| 6.6.2 | Manufacturing Plan and Vendor research | |
| 6.6.3 | Project Performance | |
| 6.6.4 | Project Performance and Final Evaluation | |
| 6.7 | Final Presentation | |
| 6.7.1 | Final Product Operation/Assembly Manuel | |
| 6.7.2 | Final Report and Poster | |
| 6.7.3 | Final CAD Package Delivery to Vendor | |

**Figure 10: Gantt Chart for Fall Semester**

Below is a tentative budget that our team is using to understand how much money we are spending over the course of the one year on various parts for our lunar module. This also gives us an indication of how much money we could be spending yearly in anticipation of NASA's Artemis mission.

| NASA RASC-AL Budget/BOM 2021 | Part Number | Part Name | Material Name | Quantity | Units | Category |
|---|---|---|---|---|---|---|
| Materials & Manufacturing | 1 | Multi-Layer Insulation (MLI) | Kapton | 90 | $ft^2$ | Materials & Manufacturing |
| Quality Assurance & Testing | 2 | MLI | Polyethylene | 90 | $ft^2$ | Materials & Manufacturing |
| Labor Expense | 3 | Micrometeorite Shielding Protection (MSP) | Kevlar-29 | 59 | kg | Materials & Manufacturing |
| Insurance | 4 | MSP | Nextal-610 | 206.1 | kg | Materials & Manufacturing |
| | 5 | M-24 Hex Head Bolts | Steel | 144 | Bolts | Materials & Manufacturing |
| | 6 | Window | Tempered Alumino-Silicate Glass Pane | 20 | kg | Materials & Manufacturing |
| | 7 | ~ | ~ | ~ | ~ | Labor Expense |
| | 8 | ~ | ~ | ~ | ~ | Quality Assurance & Testing |
| | 9 | ~ | ~ | ~ | ~ | Insurance |
| | 10 | MSP | Aluminum 7050 | 72 | kg | Materials & Manufacturing |
| | 11 | Life Support Systems | ~ | ~ | ~ | Materials & Manufacturing |
| | 12 | Bare-bone Structure | Titanium | 6374.8 | kg | Materials & Manufacturing |

| Description | Cost | Balance | | Category Total Cost |
|---|---|---|---|---|
| Radiation protective material | $ 113,259.00 | $ 999,886,741.00 | Materials & Manufacturing | $ 225,836,075.96 |
| Radiation protective material | $ 27,811.80 | $ 999,858,929.20 | Quality Assurance & Testing | $ 575,000,000.00 |
| Heat resistive material with high tensile strength | $ 300,000.00 | $ 999,558,929.20 | Labor Force | $ 90,000,000.00 |
| Lightweight and fire retardent material | $ 257,625.00 | $ 999,301,304.20 | Insurance | $ 100,000,000.00 |
| Hex head bolts to clamp the micrometeorite shield | $ 4,318.56 | $ 999,296,985.64 | | |
| Incredibly strong glass that has a low thermal expansion | $ 10,000.00 | $ 999,286,985.64 | **Total Cost** | $ 990,836,075.96 |
| Entire work force for Lunar Habitat Project | $ 90,000,000.00 | $ 909,286,985.64 | | |
| Materials & Stress Testing | $ 575,000,000.00 | $ 334,286,985.64 | | |
| Insurance | $ 100,000,000.00 | $ 234,286,985.64 | **Total Part Count:** | 11 |
| Material used for the rear wall and the bumper portions of the MSP | $ 14,690.00 | $ 234,272,295.64 | | |
| Comprises all the life support systems (i.e. Recycling air) | $ 225,000,000.00 | $ 9,272,295.64 | | |
| Internal structure that supports the entire lunar habitat | $ 108,371.60 | $ 9,163,924.04 | | |

**Figure 11. Budget/BOM**

# 6 CONCLUSIONS

The NASA RASC Lunar habitat is a project for a habitat on the Moon's Lunar surface could support 2 astronauts for 30 days. The habitat is not to exceed a dry mass of 6000 kg and is to be ready for the first use of astronauts by 2028. The team has come up with a final concept named "The Babylon Space Capsule" which includes 3 different subsystems, Micrometeorite Shielding Protection (MSP), Multi-Layer Insulation (MLI), and the titanium tubing bone structure. Initially, the team ranked the customer requirements and the engineering requirements in order to construct the most promising design. Each team member was then instructed to create multiple designs that would best fit within the parameters, and from the range of requirements, the best designed was handpicked. Throughout the semester multiple CAD models were created and the most prominent design was 3D printed and modeled in the most aspiring design that represented the insulation and shielding's from the micrometeorites. The design also respected a list of codes and regulations set in stone by NASA and the federal government that promoted the safety and health of astronauts, the general public, as well as the environment. With research contributions from the whole team, the final design for the shields were concluded to consist of whipple shielding that will most efficiently protect the habitat from the micrometeorites. The layer of protection beneath will be MLI, a Multi-Layer Insulation that consists of a Layer of Kapton on top, followed by a layer of Plasti-Shield Borated Polyethylene, and finally a layer of Aluminized Mylar. It has a thickness of 12 to 14mm. Testing for the design and the subsystems are in constant work and will be kept updated throughout the summer and the following semester. This design consists of all the essential parameters for two astronauts to survive on the lunar surface for thirty days and ensures their safety and health. The habitat's engineering design is on a great role currently and will be concluded by next semester with help of the team's schedule that lists all the due dates for each assignment.

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# 8 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report. These can contain engineering calculations, engineering drawings, bills of materials, current system analyses, and surveys or questionnaires. Letter the Appendices and provide descriptive titles. For example: Appendix A-House of Quality, Appendix B- Budget Analysis, etc.]

## *8.1 Appendix A: Descriptive Title*

## *8.2 Appendix B: Engineering Calculations*

**Important Physical Parameters for Micrometeorite Shield**

(These parameters will be evaluated during the Individual Analysis)

Force

$F = m*a$

Kinetic Energy

$KE = 0.5*m*V^2$

Momentum

$P = m*V$

Stress (Shear & Normal)

$\sigma = F/A$ (F is the normal force)

$\tau = V/A$ (V is the shear force)

Pressure

$P = F/A$

Impulse

$I = \int F*dt$

Strain

$\varepsilon = \Delta L/L_o$ ($L_o$ is the original length & $\Delta L$ is the change in length between the final distance and the original distance)

Bearing Stress

$\sigma_b = P_b/A_b$ ($P_b$ is the compressive load & $A_b$ is the characteristic area normal to $P_b$)