Viterbi Space Agency

ASTE 524 Human Spaceflight, Fall 2021

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Diana Program **14 December 2021**

Jamestown Base Program (JBP) Proposal

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1.1. JBP Needs Statement

1.1.1. [NGO-N01] Expand the Habitable Domain of the Human Species

1.1.2. [NGO-N02] Maintain U.S. and allied commercial and scientific dominance into emerging areas of competition in the 21st Century

1.2. JBP Goals

1.2.1. [NGO-G01] Maintain persistent human U.S. presence on the Moon

1.3. JBP Objectives

1.3.1. Mission Objectives

1.3.1.1. [NGO-O01] Develop a lunar habitat located at landing zone (LZ) Malapert

1.3.1.2. [NGO-O02] Provide extra-vehicular activity (EVA) and lunar surface transportation capability to the crew

1.3.1.3. [NGO-O03] Provide sufficient instruments for the lunar crew to perform scientific research both inside and outside the lunar base

1.3.1.4. [NGO-O04] Initialize and Maintain Lunar Agricultural Production

1.3.1.5. [NGO-O05] Utilize thorium nuclear fission as the habitat's primary power source

1.3.1.6. [NGO-O06] Utilize solar power as the habitat's secondary power source

1.3.1.7. [NGO-O07] Extract thorium from the lunar surface for In-Situ Resource Utilization (ISRU) to use as fuel for nuclear power

1.3.1.8. [NGO-O08] Extract hydrogen volatiles from the Lunar surface for ISRU

1.3.1.9. [NGO-O09] Maximize exploration of scientific regions of interest (ROI)

1.3.1.10. [NGO-O10] Minimize EVA preparation time to enable high excursion frequency

1.3.2. Design Objectives

1.3.2.1. [NGO-O11] Establish capability to support 4 astronauts for a minimum of 12 months prior to establishing agricultural production

1.3.2.2. [NGO-O12] Maintain capability to support 4 astronauts for a minimum of 8 months after establishing agricultural production

1.3.2.3. [NGO-O13] Provide intuitive display and controls for EVA Suit and Airlock to facilitate safe, high-frequency lunar EVA operations

1.3.2.4. [NGO-O14] Provide crewed rover capabilities for long and short distance surface exploration, transportation, and other surface operations of interest

1.3.2.5. [NGO-O15] Design the JBP to accommodate additional modules in the future

1.3.3. Safety Objectives

1.3.3.1. [NGO-O16] Establish capability to accommodate the physiological needs of 4 astronauts for contiguous periods of 6 months at a time between cargo resupply missions

1.3.3.2. [NGO-O17] Establish capability to accommodate the physiological needs of 8 astronauts for 1 week during crew responsibility handoff periods

1.3.3.3. [NGO-O18] Provide adequate countermeasures to protect a lunar crew and sensitive equipment from hazardous doses of radiation

1.3.3.4. [NGO-O19] Provide adequate countermeasures to protect a lunar crew and sensitive equipment from hazardous depressurization events

1.3.3.5. [NGO-O20] Provide adequate countermeasures to protect a lunar crew and sensitive equipment from hazardous exposure to lunar regolith
1.3.3.6. [NGO-O21] Utilize the crew's capabilities to enact procedures and apply adaptability in response to emergencies
1.3.3.7. [NGO-O22] Select a landing location with a slope of < 5° to accommodate the transportation system

1.3.4. Programmatic Objectives

1.3.4.1. [NGO-O23] Develop the lunar habitat by the year 2030
1.3.4.2. [NGO-O24] Be the first to establish a high-throughput communications tower near the summit of Malapert Massif
1.3.4.3. [NGO-O25] Establish a legal precedent and build international consensus for the peaceful use of space beyond Earth orbit
1.3.4.4. [NGO-O26] Encourage cooperation and prosperity with commercial and international partners

2. Mission Architecture & Site Selection

A trade was conducted to select the optimal site for establishing JBP. The prospective sites were chosen because their associated permanently-shadowed region (PSR) area is at least partially within a 100 kilometer radius of Malapert Massif, a ROI identified by NGO-O24.

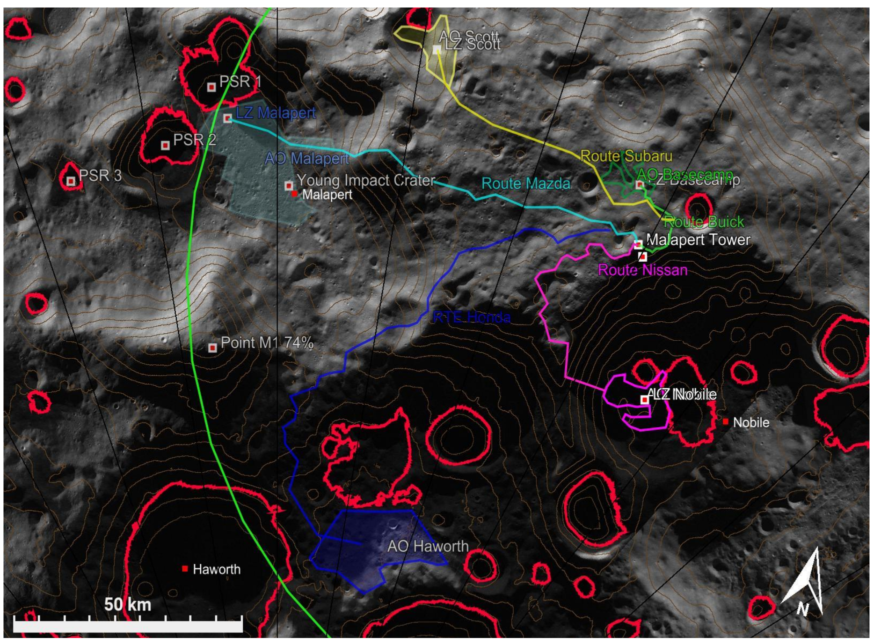

Figure 1: Potential Landing Locations and Respective Routes to the Tower Site

Figure 1 shows a map of the potential landing sites with their associated rover routes to Malapert Massif. Scores for each site within an evaluation criterion are determined by linearly interpolating between the optimal value for that criterion as a "10" and the least desirable value for that criterion as a "1". Evaluation criteria are also weighted based on their importance. The total score for each site is the sum of scores for criteria multiplied by their respective criteria weights. Based on the evaluation criteria outlined in **Table 1**, LZ Malapert scored the highest and was thus chosen as the desired landing location for JBP.

2.1. Evaluation Criteria

2.1.1. Strategic Purpose

Rover Route Length to Comms Tower Site: NGO-O24 calls to be the first to establish a comms tower near the summit of Malapert Massif. This comms tower location was chosen because it is perpetually visible from Earth [10] and therefore offers a political advantage for leading the communications architecture on the lunar south pole. For construction and maintenance purposes it is desirable to select a base location that minimizes rover route distance to Malapert Massif.

2.1.2. Operations

Suitable Slope Area: NGO-O22 requires a landing location with a slope less than 5° to accommodate the transportation system. Sites with greater local area where the slopes are less than 5° are viewed more favorably.

2.1.3. Resources

Presence of Thorium: NGO-O05 calls to employ thorium nuclear fission as JBP's primary power source and NGO-O07 calls to extract thorium from the lunar surface to power these reactors. Sites with higher thorium content are viewed more favorably. Avg. Landing Site Illum: NGO-O06 calls to use solar power as the habitat's secondary power source. Sites with higher illumination are more desirable; however, this criterion is not weighted as heavily as thorium presence because solar is only a secondary power source. Presence of Hydrogen: NGO-O08 calls to extract volatiles for ISRU; thus, sites with higher quantities of hydrogen are viewed more favorably. Distance to PSR: This criterion is also driven by NGO-O08, as volatiles are generally found in PSR's and it is important those PSR's are easily accessible to the lunar crew. Sites with shorter safe paths from the rim to the PSR are more favorable.

2.1.4. Science

Local PSR Area: NGO-O09 calls to maximize exploration of scientific ROI's. It is assumed that sites with access to greater PSR area have more regions to explore.

Specifications	Wt.	LZ Haworth (Lat: -87.53°, Lon: 0.16°)	Nobile Crater (Lat: -85.53°, Lon: 46.51°)	LZ Malapert (Lat: -84.48°, Lon: 6.25°)	LZ Basecamp (Malapert Massif Top) (Lat: -84.31°, Lon: 37.54°)	LZ Scott (-83.91°, 20.93°)
Rover Route Length to Comms Tower Site (km)	10	198 {1}	61 {7.93}	93 {6.31}	20 {10}	82 {6.87}
Suitable slope area, ≤ 5° (km²)	10	351 {9.83}	66 {1.61}	357 {10}	45 {1}	84 {2.13}
Presence of Thorium (ppm) [6, 2]	5	1.004 {10}	0.941 {6.98}	0.878 {3.97}	0.878 {3.97}	0.816 {1}
Avg. Landing Site Illum. (%) [6, 8]	3	0 {1}	16.5 {4.95}	1.6 {1.38}	37.6 {10}	24.3 {6.82}
Presence of Hydrogen (ppm) [6, 2]	5	181.3 {9.44}	186.4 {10}	107.4 {1.27}	129.1 {3.66}	105.0 {1}
Distance to PSR (km)	10	10 {1}	5 {7.43}	3 {10}	10 {1}	6 {6.14}
Local PSR Area (km²) [6]	10	1,002 {10}	170 {2.41}	297 {3.56}	26 {1.09}	16 {1}
Total Score (Greater is Better)	-	318.5	293.6	**329.0**	199.1	191.9

* Scores for evaluation criterion are presented in {curly brackets}

Table 1: Potential Sites and Selection Criteria Weighting

3. Environmental Control & Life Support System (ECLSS) Architecture

3.1. Atmospheric Pressure and Composition

Design Solution

Air Composition of the Jamestown Base, outlined in **Table 2**, is designed to nominally reflect an air mixture of 27.89% Oxygen, 64.84% Nitrogen, 6.88% Argon, and 0.38% Carbon Dioxide. Ambient air pressure is specified as $10.97 \pm 0.45\, psi$ with a partial pressure of oxygen range of $3.06 \pm 0.24\, psi$ [11]. The allowable range for partial pressure of Carbon Dioxide is specified at $0.042 \pm 0.036\, psi$.

	Oxygen	Nitrogen	Argon	Carbon Dioxide	Air
Nominal Pressure (psi)	3.060	7.113	0.755	0.042	10.970
Uncertainty (psi)	0.240	0.087	0.87	0.036	0.450

Table 2: Atmospheric Composition of JBP

Exceeding said upper or lower limit of ppCO2 will trigger alarms to alert the crew and mission control. Redundancy for pressure regulation is provided by multiple mechanical pressure regulators from the storage tanks, digital sensors, and crew alarms, as well as a servo operated ball valve able to bypass malfunctioning regulators [1]. The crew is able to access a manual shut off valve in the event of a leak.

Rationale for Design Solution

The nominal specifications listed provide an atmosphere with similar ambient pressure to 8,000 ft. above sea level on Earth. JBP is designed to maintain nominal partial pressure of oxygen to avoid the risk of Hypoxia. The design also considers an allowable range for partial pressure of Carbon Dioxide, which has an upper limit to eliminate any risk of Hypercapnia and a lower, non-zero limit to maintain a sustainable atmosphere for plant photosynthesis. The lower limit is approximately the same as the partial pressure at sea-level on Earth. The upper limit is approximately 13.5 times as great. Nitrogen and Argon are utilized as inert, non-toxic filler gases with Nitrogen having the partial pressure equivalent to an EVA campout on the ISS. Argon is used to make up the remaining absolute partial pressure. These design considerations were chosen to address NGO-O10, regarding minimizing EVA preparation time. This solution effectively eliminates the need to perform a campout prior to EVA and thus allows EVA preparation to be conducted same day with only approximately 2 hours of mask pre-breathe.

These design considerations allow for a safe and comfortable atmosphere for long-term inhabitation. **Figure 2** below depicts atmospheric composition by percent for nominal conditions and for maximum percent oxygen. To address flammability concerns, the maximum percent oxygen is limited to 30.0% and water sprinklers will be incorporated in the design. As a consequence of maintaining lower air pressure, any crew entering the base should pre-breathe 100% O2 for approximately 1 hour. This is only a concern for alternate space suit designs that don't incorporate 100% O2 nominally, or if new crew are transitioning from transport vehicle to base.

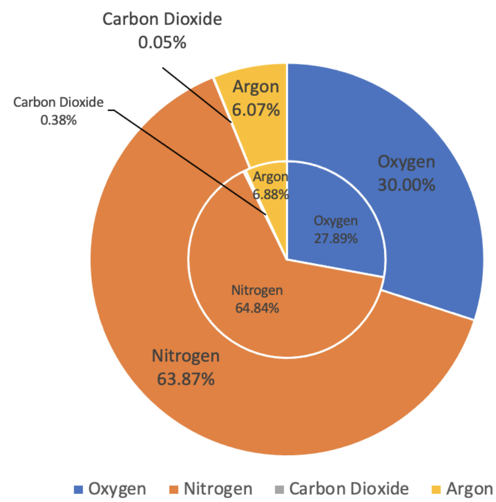

Figure 2: Atmospheric Percent Composition of JBP at Nominal (inner) and Maximum Percent Oxygen (outer) Conditions

3.2. Provisioning of Make-Up Gases

Design Solution

Jamestown Base ECLSS is designed to initially provide required consumables until later mission phases where ISRU can supplement oxygen supplies from water ice. Primary make-up gasses include nitrogen and argon (as physiologically inert diluent gasses), and oxygen stored in two banks of liquid state Monel alloy storage tanks. Tank #1 stores pure LOX. Tank #2 stores gasses in a nitrox + argon solution. Automatic pumps, heater-expanders, and gas regulators work to maintain pressure within the designed limits and are monitored in real time by sensors [11]. The tanks must be scaled to store approximately 1200 kilograms pure O2 and 400 kilograms nitrox + argon mixture. This accounts for an initial 12 months consumables requirement, a volume at 9.3 m^3, a nominal O2 consumption rate of 0.8 kg/CM/day for 4 crew members, a leakage rate of 0.14%/day and other EVA/purge losses. Liquid storage reduces pressure vessel mass and thermal control requirements. It will occupy approximately 5 m^3 of vehicle volume and use approximately 2500 kilograms of vehicle mass budget. Emergency oxygen is provided in the form of 16 kilograms of oxygen candle supplies [7]. ISRU focusing on exaction of polar water ice is planned to be established within 6 months of initial operating capability (IOC). Once established, the make-up gas subsystem will require approximately 600 kilograms of Oxygen, 80 kilograms of Nitrogen, and 20 kilograms of argon every 6 months.

Rationale for Design Solution

Six of the eight COPVs store gasses in a nitrox + argon solution to simplify delivery and reduce probability of a regulator malfunction, which can lead to an oxygen toxicity hazard. The two oxygen tanks conform to industry standards for oxygen compatibility, including Monel alloys, non-reactive softgoods, and suitable plumbing geometry [11]. Although regolith extraction is promising and ubiquitous on the Lunar surface, make-up gas extraction from regolith is orders of magnitude more expensive in terms of time, machinery, and energy inputs to equal the same amount as water ice extraction. A later

ISRU goal could be processing argon from heating lunar regolith, demonstrating technology that could be useful for future Martian exploration.

3.3. Temperature Control

Design Solution

Rejection of waste heat will be handled by radiators placed around the base on the ground in a horizontal orientation, insulated from the lunar surface as shown in **Figure 3**. Heat will be transported to the radiators from the base with a heat pump with ammonia as the working fluid. The base will also be buried partially or completely in lunar regolith, which will reflect and insulate the base from solar radiation.

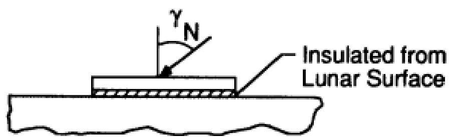

Figure 3: Waste heat radiator configuration

Rationale for Design Solution

The nuclear reactor powering the base will produce large amounts of waste heat that can be used to heat the base during the long nights at the Malapert Crater site. A system of heat pumps will collect waste heat from the reactor and pump some of it to the base for heating and the rest for rejection. The moon has no atmosphere for convection and the lunar regolith is a strong insulator, which rules out conduction. Radiators are a proven method of heat rejection on the ISS and other orbital vehicles [13]. At the south pole the sun is always low to the horizon and the lunar surface is highly reflective, so the optimal orientation of the radiators will be horizontal and insulated from the lunar surface [12]. Ammonia will be used for the working fluid of the heat pumps because it exhibits desirable thermal characteristics while meeting NASA’s standards for toxicity and flammability, and it has a proven track record on the ISS [13].

3.4. Humidity Control

Design Solution

The Temperature and Humidity Control (THC) subassembly controls the temperature of the cabin air, maintains humidity within certain limits, and generates ventilation air flow through the cabin. The THC is able to provide these functions through the Cabin Air Bacteria Filter Assemblies (CABFAs) and the Common Cabin Air Assemblies (CCAAs) [9]. The CCAA includes a cabin fan, condensing heat exchanger, air temperature control valve, and zero-g moisture removal equipment. The CCAA is able to remove heat and moisture from the Lunar Base. It is divided into seven On-Orbit Replaceable Units (ORUs) [9]. The key ORU for the humidity control is the Water Separator and Electrical Interface Box (EIB). The Water Separator ORU is primarily composed of a pitot rotary separator which draws a small amount of air and condensate from the condensing heat exchanger in the CCAA (6.5 cfm to 8 cfm) [9]. The condensate and air are then separated through a centrifugal system that is used to pump the water pressure up to the maximum condensate pressure being 8 psig [9]. The separated air is then sent back to the heat exchanger. Typically, the humidity should not exceed 70% RH or there could be problems for the astronauts health or equipment . High humidity can lead to the growth of microorganisms that could cause illness [9].

Rationale for Design Solution

We chose to not repurpose the Nafion banks for the lunar base because they are only suited for the mission scope of the Crew Dragon. For the Nafion Banks, a filter medium is required to scrub ammonia from the system's membranes to avoid chemical contamination. As a result, Nafion banks would need to be replaced after each mission. Since Nafion banks are susceptible to and will experience this chemical degradation, the long term use for the ECLSS would not be applicable for the lunar base [11]. The CCAA and Water Separator ORU is being used on the International Space Station today. This system is designed for long term use and has a lifespan much longer than that of the Nafion system. Each ORU that comprises the CCAA is also completely replaceable along with all of their subsystems. Therefore, if there are any issues with the ORUs they can be fixed to be fully operational without replacing the entire system. There are also benefits from this system's centrifugal water removal system. The water is not wasted and about 93% of the water is recycled [9]. This will allow the Lunar base to help maintain its water supply from using the collection of the water from the air. This is another benefit of using the CCAA over the Nafion banks because the Nafion dehumidifier system expels the water into space and has no means of recycling, collection, or storage [11]. While the Nafion banks were found to be less effective than originally predicted, the CCAA has met all its requirements with a high margin during its performance tests. The case-radiated noise of the assembly stays within an NC-45 at 500 cfm and within an NC-40 at the nominal flow (430 cfm) [9]. This can be heard in practice when the assembly is operating in a ducted test and it is difficult to hear any difference when the system is on or off. When investigating power consumption it was found that it draws 23% less power than what was specified [9]. This is primarily due to the high aerodynamic and motor efficiencies of the fan. The thermal requirements were initially found when the coolant water was defined as 40°F, but are able to still meet with a 10% margin when using 42°F coolant water [9]. Lastly, this design is very flexible and robust which in turn allows it to meet a variety of application requirements.

3.5. CO2 Removal

Design Solution

A regenerable strontium exchanged silico-alumino-phosphate (Sr-SAPO-34) sorbent system was chosen as the CO2 removal system for JBP. This system is closed loop and will use a schmitt-trigger + proportional-integral-derivative (PID) controller to maintain satisfactory ppCO2 levels called for in the atmospheric design.

Rationale for Design Solution

There are two types of CO2 removal systems: regenerable and non-regenerable. Non-regenerable systems are simpler, but create more waste products and are not reusable. For JBP, regenerable systems were considered because they are reusable and more mass efficient for long-term missions [7]. The regenerable systems considered in the trade space include the ISS Carbon Dioxide Removal Assembly (CDRA), Metal Oxide (METOX), Na-SAPO-34 sorbents, and Sr-SAPO-34 sorbents. To compare these options, we evaluated whether the system was closed loop, if it had flown, and the CO2 adsorption at ~2mmHg ppCO2 ,which is close to the ppCO2 called for in the design. Closed loop options are desirable since they do not create opportunities for habitat leak paths and flown systems are desirable because they have been validated. It is also desirable to adsorb as much CO2 as possible per gram of sorbent in the interest of mass savings. To compare the options, a trade table was created and each evaluation criterion was given weights. **Table 3** shows that Sr-SAPO-34 received the highest weighted result; therefore, the regenerable CO2 removal system was chosen to be Sr-SAPO-34.

Regenerable System	Closed Loop (yes=1, no=0)	Flown (yes=1, no=0)	Adsorption at ~2mmHg ppCO2 (mmol CO2/ g sorbent) (weight=value)	Weighted Result	Source
CDRA	No	Yes	0.57	1.57	[4]
METOX	No	Yes	Not Confirmed	1.0	[5]
Na-SAPO-34	Yes	No	0.15	1.15	[3]
Sr-SAPO-34	Yes	No	0.7	**1.7**	[3]

Table 3: Trade Criteria for Regenerable CO2 Removal Systems

As NGO-OO4 calls to cultivate agriculture, a control system will be incorporated into the closed-loop Sr-SAPO-34 sorbent system to dynamically account for the CO2 that may be adsorbed by a growing number of plants. A Schmitt trigger may be employed to throttle the system to full adsorption when the max ppCO2 is reached and turn the system off when the lower ppCO2 bound is reached. A PID controller may be used to throttle the system when ppCO2 resides between min and max bounds.

4. EVA & Surface Exploration Concept of Operations

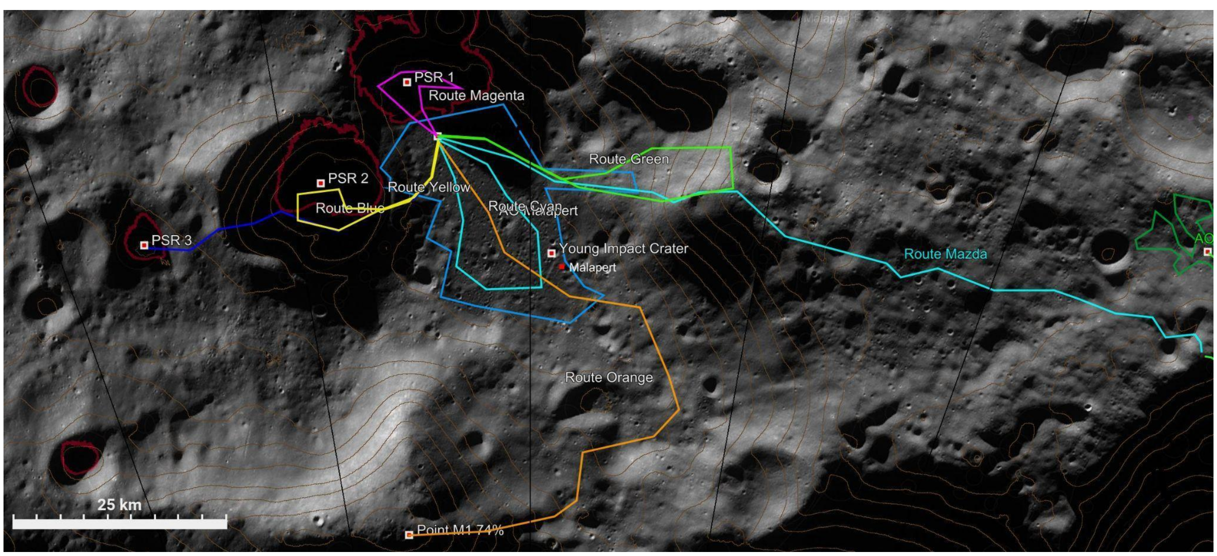

Figure 4: EVA ConOps Diagram

The selected area of operations (AO), LZ Malapert, is located near two large PSR's and is depicted in **Figure 4** as a blue, closed polygon. The area within the enclosed region has slopes < 5° that can accomodate a 10 kilometer landing ellipse and is suitable for module construction. NGO-O02 calls for surface transportation capabilities. Thus, the EVA CONOPS includes one small unpressurized rover in the 50-kilometer range class for routine operations near JBP and three pressurized 300 kilometer-class rovers for expeditionary EVAs to long range ROI's. The rovers are rated for four days of consumables, electrical power for a crew of two, and are capable of hauling up to 4000 kilograms of unpressurized payload. They are capable of conducting contingency buddy recovery in the event of an immobilized vehicle. The labeled routes show rover-trafficable paths to local ROIs that do not exceed 10° slope. Route Mazda goes to the peak of Malapert Massif, the location of the planned communications tower. Routes Magenta, Yellow, and Blue are routine routes for PSR volatile extraction and exploration. Route Green and Route Orange lead to high illumination points. Of particular interest, Point M1 on Route Orange acts as an alternate location for the communications tower project. Route Cyan shows a routine ring route with minimal slope that could be used to traverse easily throughout the AO and has easy access to a young impact crater with scientific value. Routine construction and maintenance EVAs are able to be conducted daily, with water ice extraction EVAs scheduled once per week. Expeditionary EVAs to distant ROIs are capable of being conducted 2-3 times per month, requiring one operational vehicle at the base on recovery standby. The green polygon to the East shows the Malapert Massif AO, which may be used as a secondary base camp and LZ for construction materials in future tower project EVAs.

5. Prototype Airlock Interface Design

There are two primary display/control interfaces used during EVA airlock operations. The first is the EVA Suit Interface (EVASI), which provides a display and control interface for pertinent suit systems. The second is the Intra-Vehicular Umbilical Interface (IVUI), which is used for EVA depress and repress procedures inside the crew-lock (C/L). Many of the functions of the EVASI and IVUI are derived from those that are used for EVA operations on the ISS [7]. The design emphasizes ergonomics and intuition to address NGO-O13.

The EVASI consists of both a wrist-mounted interface and chest-mounted interface. **Figure 5** shows the wrist mounted interface, which has a touch screen as well as mechanical actuators. To minimize inadvertent action of the touch screen, an icon must be touched and then the "SELECT/TOGGLE" button must be pressed to confirm the action. For redundancy, a directional pad is available to control the touch screen in the event the touch screen becomes unresponsive. All mechanical actuators are recessed to avoid inadvertent actuation, but the recession size is such that a gloved finger may actuate it. Nominal comms are voice activated, but a "PTT" button is added for redundancy. Text in the "WARNING MESSAGES" and "ECLSS READOUT" on the display are color coded; green = nominal, yellow = warning, and red = emergency.

Figure 6 shows the EVASI chest-mounted interface, which contains the less frequently actuated systems including a mechanical pressure gauge and O2 actuator, power mode switch, and umbilical connector. The chest-mounted interface is designed to be mirrored such that it is viewed legibly from a wrist-mirror reflection. The O2 actuator has 4 modes: 0.9 PSID IV, OFF, 4.3 PSID PRESS, and 4.3 PSID EVA. The recessed mechanical O2 actuator track is accessible via gloved finger and has detents (shown as black dots) the knob can click into when selecting a new state. The knob must actuate through the OFF position when cycling from the IV position to the 4.3 PSID as a suit leak check is needed before transitioning to the 4.3 PSID positions.

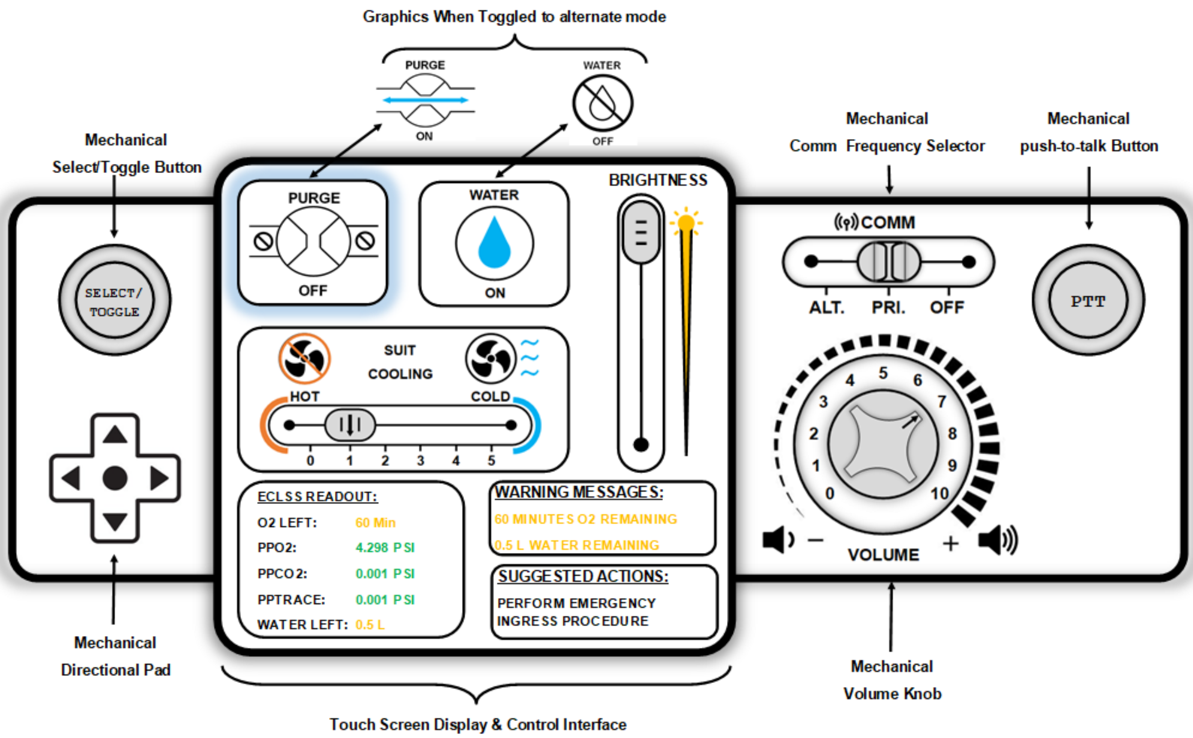

Figure 5: Wrist-Mounted EVASI Interface

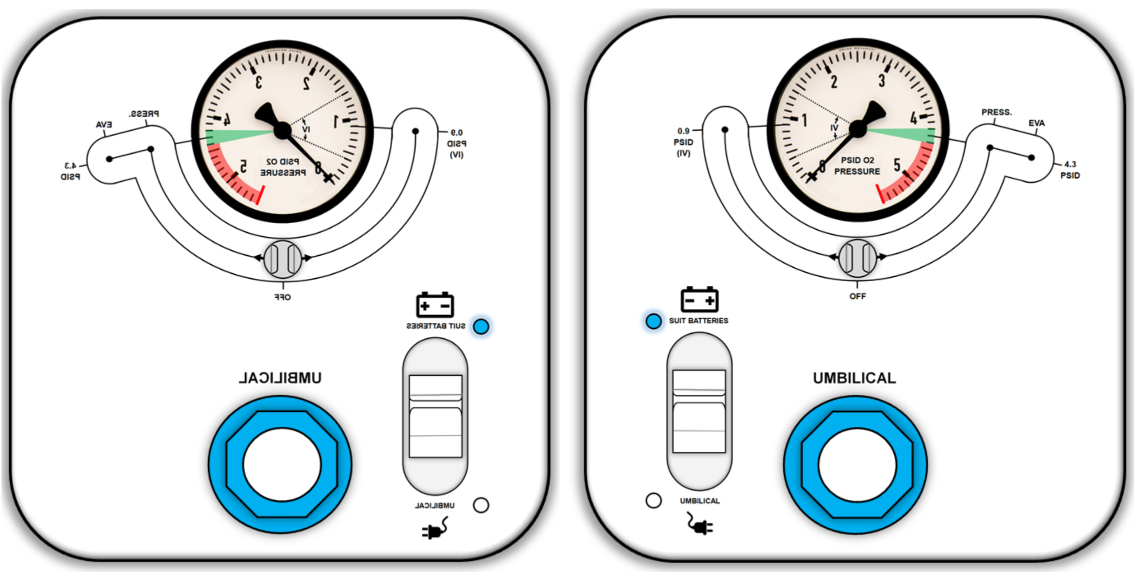

Figure 6: Chest-Mounted EVASI. (Left) Actual Interface. (Right) View of Interface Through Wrist Mirror

The IVUI, shown in **Figure 7**, is mounted on the wall of the crew-lock (C/L) before the extra-vehicular (EV) hatch. It consists of a touch screen and mechanical buttons. The touch screen can only be interacted with while the mechanical "ACTIVATE TOUCH SCREEN" button is being pressed. While pressed, the user may control all IVUI systems through the touch screen. In the event the touch screen is unresponsive, a mechanical directional pad, "SELECT/TOGGLE" button, and keypad are available to fully control the IVUI systems without touching the screen. To minimize information access cost, all controls relating to EVA depress/repress procedures are displayed at once in a legible font with icons that symbolize respective systems. Arrows are placed on these icons to indicate if their quantities are increasing or decreasing. Depress/repress valves are handled by the IVUI to automatically reach the desired input pressure at the appropriate rate. The IVUI controls may be accessed outside the C/L on computers in the main lunar base cabin or on Earth in case the C/L IVUI malfunctions.

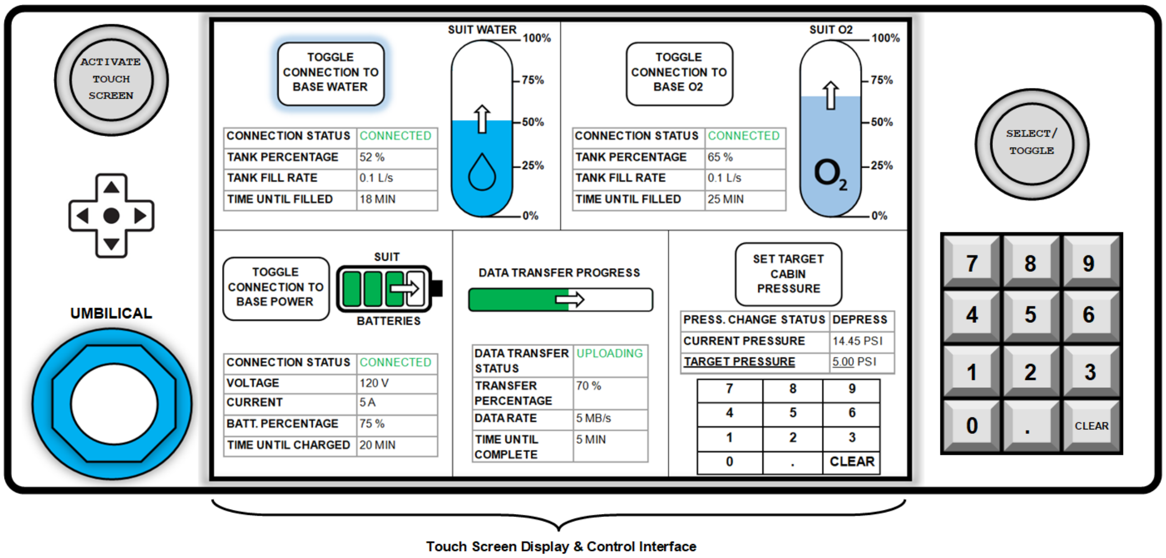

Figure 7: Wall-Mounted IVUI Panel

6. EVA Operations: Flight Rules

6.1. Flight Rule 1: Early Termination of EVA

EVA will be terminated in the event of any of the following anomalies or hazards:

A. Irreparable loss of communication
B. Consumables depleted below the required amount for safe return to base
C. Loss of suit power
D. Hazardous weather conditions
E. Injury or health concern

The EVA will be terminated if the crew's safety is compromised. To ensure the well being of the crew, communication to the lunar base and other crew mates is imperative for correctly executing EVAs in case an emergency occurs. If there is a loss at any time, it will result in a stoppage of the EVA. Furthermore, the loss of consumables such as oxygen, or loss of power of any vital equipment during EVA will force an immediate shutdown. Any weather concerns from the crew members performing the EVA, unexpected injury, or health concern will also effectively terminate the EVA.

6.2. Flight Rule 2: Vicinity of EVA Operations

EVA crew will remain within 30 minutes of the closest pressurized environment.

In the event of life support failure, injury, or another contingency that results in early end of the EVA, planners should ensure the crew has a safe pressurized environment that can be reached in 30 minutes or less. Apollo astronauts managed approximately 2 km/hr on *foot, which would give an effective range of 1 km, but the vicinity is given in units of time rather than distance to allow for the use of quicker modes of transportation that may be included in later missions. The flight rule also does not specify that the pressurized environment in question must be the base; it could, for instance, be a pressurized rover.*

6.3. Flight Rule 3: EVA Communication

During an EVA, communication shall be maintained between all members of the EVA crew, Jamestown Base, and Mission Control. All EVA crewmembers must remain within line of sight of each other at all times.

Timely communication between the members of the EVA crew, Jamestown Base, and Mission Control is critical to the success of the EVA. Crew members must be within line of sight of each other so that hand signals can be used in case telecommunications are lost. EVA planners should make sure that the mission plan does not require crew members to separate or lose line of sight; this way, in the event of loss of line of sight or loss of communication, the crew will immediately know that something is wrong and can initiate a search for the missing crew member.

7. EVA Operations: Airlock Nominal & Contingency Procedures

The Jamestown base will have a dual airlock system, consisting of an Equipment Lock (E/L) and C/L, to establish ingress/egress redundancy for the initial base design. Unlike the ISS, Jamestown's atmosphere is designed to have lower air pressure, eliminating the need for overnight acclimatization prior to EVA Operations. This reduces EVA preparation time to approximately 2 hours and 10 minutes. This procedural reduction makes it feasible to execute EVA operations at much higher frequency, thus enabling one EVA per day assuming consistent EMU Checkout.

Scheduled/Unplanned Depress Procedure

Procedures for Scheduled or Unplanned Depressurization are as follows:

Note: All steps are performed by the EVA crewmember

Base	10.01 Mask Pre-Breathe → Complete (110 minutes nominal) 10.02 Non-required equipment → Remove from C/L and stow in E/L 10.03 Lavatory - use (if required)
E/L	11.01 E/L → Enter 11.02 Suit → Complete Donning 11.03 Suit Umbilicals → Connect to Suit 11.04 O2 ACTUATOR → IV position (+0.9 PSID)
C/L	12.01 C/L - Ingress 12.02 Suit Umbilicals → Connect to C/L Interface/Controls 12.03 Airlock controls (in C/L) → Configure to supply power, water, and oxygen to suits 12.04 IV Hatch → Close 12.05 √ Hardline Comms → Check and Set 12.06 IVUI → Set C/L TARGET PRESSURE to 5 psia **WARNING** Verify suit pressure does not exceed EMU maximum specified gauge pressure of 5.5 PSID. If suit gauge pressure > 5.5 PSID, STOP depress.

	12.07 √ SUIT PRESS = 5.9 +/- 0.5 psi **CAUTION** If Suit Pressure < 5.4 psi, go to Contingency Repress Procedure, Service Suit. If Suit Pressure does not decrease below 6.4 psi, proceed to STEP 30.01 C/L Leak Contingency Procedure and Service Suit. 12.08 O2 ACTUATOR → PRESS position (+4.3 PSID, Reserve O2 Tanks OFF) 12.09 √ Suit Leak Check 12.09A If GO, continue with STEP 3.10. If NO-GO, proceed to STEP 90.01 C/L Leak Contingency Procedure 12.10 SUIT O2 ACTUATOR → EVA (+4.3 PSID) 12.11 RESERVE O2 TANKS → ON 12.12 DEPRESS PUMP → Reduce C/L PRESS to 2.0 PSIA 12.13 √SUIT PRESS < 5.5 PSID (EMU maximum) 12.14 EV EQUALIZATION VALVE → OPEN and vent C/L to < 0.5 PSIA 12.15 EV HATCH → OPEN 12.16 EV EQUALIZATION VALVE → CLOSE 12.17 SUIT POWER SRC SWITCH → SUIT BATTERY 12.18 C/L SUIT UMBILICALS → OFF, disconnect, and stow. 12.19 Time - Record (NOTE: This marks the start of the EVA) 12.20 SUIT WATER SWITCH → ON 12.21 √ TEMP CONTROL 12.22 √ SUIT STATUS PARAMETERS Page 12.23 C/L - Egress

Table 4: Scheduled/Unplanned Depress Procedures [7]

Scheduled/Unplanned Repress Procedure

Procedures for Scheduled or Unplanned Repressurization are as follows:

Moon	20.01 Regolith Contamination - Use Swiffer Moon Brush ® to remove > 75% of particles 20.02 C/L - Enter
C/L	21.01 Suit Umbilicals - Connect to C/L Interface/Controls 21.02 IVUI → Configure to supply power, water, and oxygen to suits 21.03 UTILITIES SW→ UMBILICALS, Turn off Suit Utilities 21.04 √ SUIT UTILITIES - OFF 21.05 EV HATCH → CLOSE 21.06 Verify EV Equalization Valve is Closed 21.07 Configure Suits for Hardline Comms 21.08 Time – Record (This marks the end of the EVA) 21.09 Use Electrostatic Brush to remove remaining Regolith Contamination 21.10 IVUI → Set C/L target pressure to 5 PSIA 21.11 O2 ACTUATOR → PRESS position (+4.3 PSID) 21.12 √ RESERVE O2 Tanks - OFF 21.13 √ EV HATCH - Leak Check 21.13A If leak present, proceed to STEP 90.01 C/L Leak Contingency Procedure 21.14 O2 ACTUATOR → IV (+0.9 PSID) 21.15 IVUI → Set C/L TARGET PRESSURE to 10.97 PSIA 21.16 √ SUIT PRESS = 11.87 +/- 0.5 PSIA 21.17 O2 ACTUATOR → OFF 21.18 EVASI PURGE VALVE → ON (to equalize to ambient pressure)

	21.19 Helmet(s) → Remove 21.20 EVASI PURGE VALVE → OFF 21.21 √ Suit Resources - Nominal after regeneration 21.22 C/L Suit Umbilicals → OFF, disconnect, and stow 21.23 C/L HATCH→ OPEN 21.24 E/L HATCH - Enter
E/L	22.01 C/L HATCH → CLOSE 22.02 Suit - Doff, Clean, and Stow 22.03 E/L HATCH → OPEN 22.04 Habitation side of hatch - Enter
Base	23.01 E/L HATCH → CLOSE 23.02 Debrief

Table 5: Scheduled/Unplanned Repress Procedures [7]

Contingency Repress Procedure

Procedures for Contingency Repressurization are as follows:

Moon	30.01 <u>C/L - Enter</u>
C/L	31.01 <u>EV HATCH → CLOSE</u> 31.02 <u>IV EQUALIZATION VALVE → EMERGENCY OPEN</u> 31.03 <u>√ EV EQUALIZATION VALVE - CLOSED</u> 31.04 <u>SUIT WATER SW → OFF</u> 31.05 <u>C/L HATCH → OPEN (AS SOON AS POSSIBLE)</u> **WARNING** Once immediate action steps are complete, further steps should be taken to mitigate the emergency and communicate the nature of the emergency to crew and operations. The EV EQ VALVE should be visually inspected for damage after each EMERGENCY OPEN.

Table 6: Contingency Repress Procedures [7]

8. Crew & Mission Control Training Plan

Table 7 shows the mission-specific JBP training plan. This training plan pertains to both astronauts and flight controllers since every JBP operation requires skills, knowledge, and synergistic cooperation between both parties. The program includes 4 weeks of training focused on individual skills and knowledge pertaining specifically to JBP, followed by an individual evaluation. Following the 4-week training is a 6-week portion focused on group simulation activities pertaining to nominal and contingency JBP operations. While astronauts and flight controllers will be training for the same operations, their contributing roles to those operations will be different. In each stage of training, astronauts will focus on in-person operations while flight controllers will focus on the ground operations required to facilitate those in-person operations.

The astronauts are trained to operate each system, to recognize malfunctions, and to perform corrective actions if needed. The Sonny Carter Training Facility and the Neutral Buoyancy Laboratory (NBL) provide controlled neutral buoyancy operations in facility water tanks to simulate the zero-g or weightless condition that is experienced by the crew during space flight. These facilities will prepare astronauts for any spacewalks that may be needed outside the transportation vehicle if a contingency arises during cislunar travel. For lunar surface operations, NASA's Active Response Gravity Offload System (ARGOS) will be used to simulate the Moon's lower gravity to prepare the crew for maneuvering and operating in the expected environment [7]. Several full-scale mock-ups and trainers are also used to train astronauts within these facilities. These mock-ups and trainers are used for onboard systems orientation and habitability training. Astronauts practice meal preparation, equipment stowage, trash management, use of cameras, and experiment operations. Lunar South Pole specific training teaches basic field geology and practical skills in analogue terrains. Analogue training should involve the integrated expertise of a broad group: the astronaut office, astronaut trainers, field geologists, site selection teams, geologists involved in surface operations planning, lunar sample analysts, in-situ resource specialists when appropriate, equipment designers, flight controllers, and management. Integration of human and robotic exploration components should be tested in analogue terrains with realistic simulations of lunar surface operations. Likewise, all tools to be used by crew in lunar surface operations should be tested in realistic simulations. Training for extended duration missions will need to develop greater crew independence in order to be prepared for the Lunar South Pole environment and to capitalize on the crew's ability to adapt to the situation as needed. Pilot astronauts maintain flying proficiency by flying 15 hours per month in NASA's fleet of two-seat T38 jets. Non-pilot astronauts fly a minimum of 4 hours per month. The T38 is used for flight readiness training to help the astronauts become adjusted to the flight environment, including the g-forces experienced on launch. All operations discussed above include communication and coordination with flight controllers, who will be involved in monitoring and guiding the crew throughout these operations.

<table>
<tr><td rowspan="2">JBP Specific Training</td><td>Week 1</td><td>1. JBP Introduction
2. Lunar South Pole Environment
3. History</td></tr>
<tr><td>Week 2</td><td>1. Systems Training</td></tr>
<tr><td rowspan="2">JBP Nominal Operations</td><td>Week 3</td><td>1. JBP EVA Training
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2. Team Certification</td></tr>
<tr><td>Week 8</td><td>1. JBP Simulation Review and Analysis</td></tr>
<tr><td>Week 9</td><td>1. JBP Simulation
2. Team Certification</td></tr>
<tr><td>Week 10</td><td>1. JBP Simulation Review and Analysis
2. Credentialing
3. Graduation Ceremony</td></tr>
</table>

Table 7: Crew & Mission Control Training Plan

9. References

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