AERO 451/651: Human Spaceflight Operations

Artemis II Mission Operations: Final Report

Spring 2022

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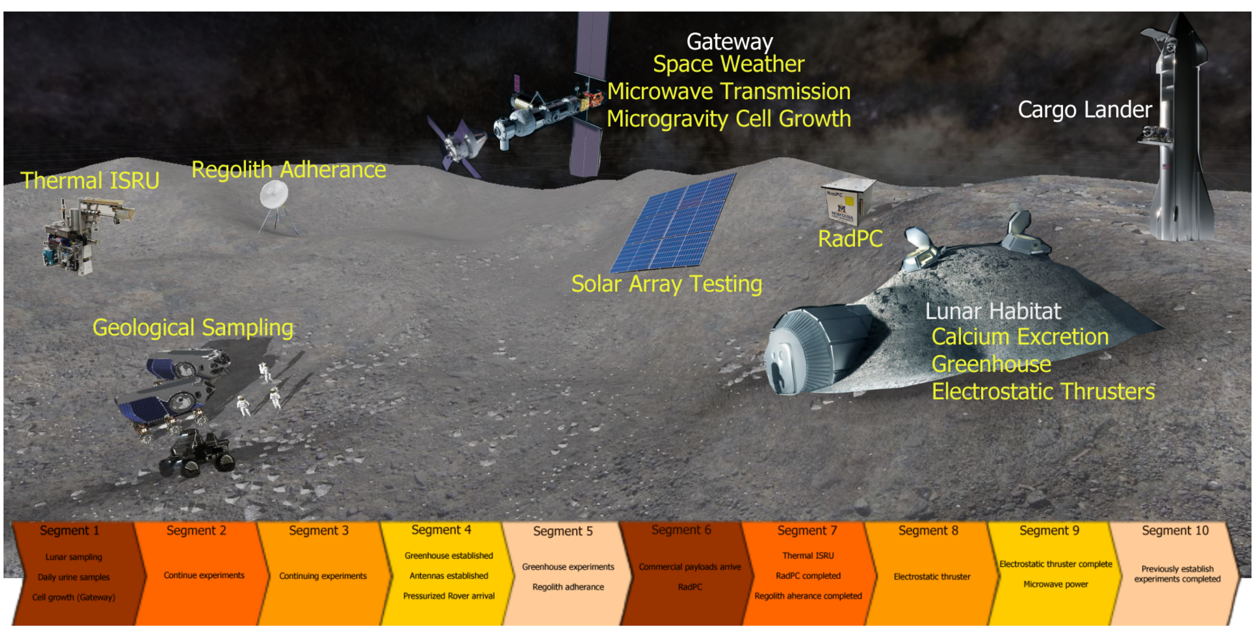
1. CONOPS Graphic



2. Assumptions And Constraints:

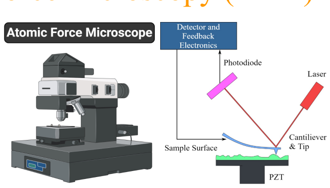
Any assumptions or constraints specific to your working group, The general overarching constraints imposed by mission managers don’t need to be mentioned unless they are relevant to what you are doing

- a. Assumptions
  - i. Initial Lunar Habitat Module established
    - 1. Hardware supporting power, thermal, and ECLSS established
  - ii. Gateway established
  - iii. Science & Utilization architecture readily available as needed on lunar surface
  - iv. Necessary communication infrastructure established
    - 1. Relay acquired data
    - 2. Support EVA mission
    - 3. Astronaut to Earth comms
- b. Constraints
  - i. Required construction will determine onset of experimentation or ISRU
  - ii. Astronaut’s work/rest schedule
    - 1. Earth support for daily/weekly/monthly tasks
  - iii. Lunar/Space environmental effects
    - 1. Events preventing EVA’s
    - 2. Micrometeoroid damage
    - 3. Astronaut safety
  - iv. Nominal operations
    - 1. Off-nominal plans may take longer
    - 2. Repairs delay results

3. Architecture:

Any buildings, rovers, satellites or other technology that is needed for your working group to achieve its goals over the time of the mission. Mention in this section what would need to be built on the moon and what would already be present on the moon before the mission starts.

- a. Regolith Adherence Characterization (RAC)
  - i. Single particle adhesion force measurements will be made using atomic force microscopy (AFM)



ii. Multiple particle adhesion will be evaluated using a custom-built particle adhesion testing device

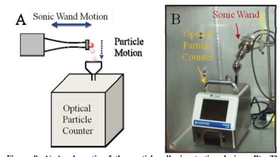
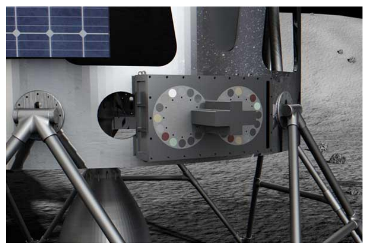


Figure 8. A) A schematic of the particle adhesion testing device. B) The components of the particle adhesion testing device included a 0.23 m^3 aluminum environmental chamber, a sonic wand (red), and an optical particle counter (orange). The device was constructed to enable several environmental conditions to be altered (i.e., electric fields, humidity and pressure levels, atmospheric composition, UV exposure).

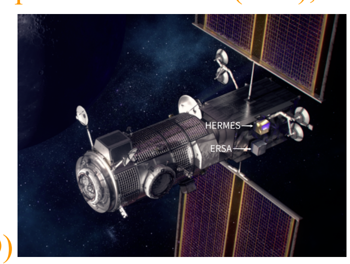
iii. Trays containing various materials will be loaded onto lunar payload lander (Reminiscent of MISSE Trays)



b. Space Weather Forecast Enhancement

i. 2 space weather instrument suites: NASA's HERMES & ESA's ERSA

ii. Pre-loaded on the Gateway Power and Propulsion Element (PPE), and Habitation and Logistics Outpost (HALO)



c. Calcium excretion experiment

i. DEXA Scanner

ii. Urine Sample Storage (cold storage)

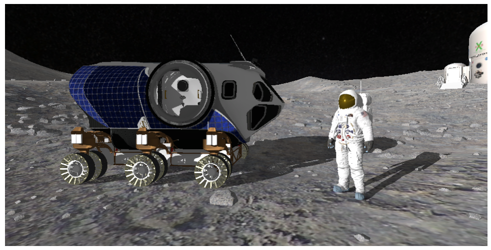
iii. Urine Analysis Equipment (urine strips & device)

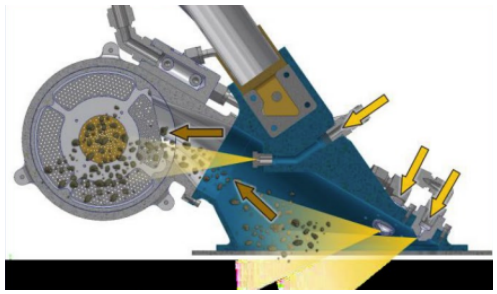
d. Lunar Greenhouse (LGH)
    i. Cylindrical, deployable plant growth unit 18 feet long and more than 8 feet in diameter
    ii. Regolith Advanced Surface Systems Operations Robot (RASSOR) Excavator

e. Geological sampling with EVA
    i. Short Range
        1. EVA suit
        2. Unpressurized rover
        3. Collection tools

    ii. Long range
        1. EVA suit

        2. Pressurized rover
        3. Collection tools





f. Thermal Energy for Lunar In Situ Resource Utilization
    i. Hydrogen Reduction Reactor
    ii. Advanced Carbothermal Electric Reactor

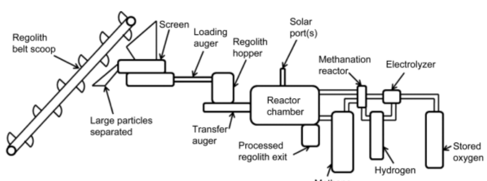


Figure 17.—Diagram of current ORBITEC carbothermal reduction reactor with features identified.

    iii. Solar Concentrator Array
    iv. Carbothermal Regolith Reduction Module
    v. Inflatable parabolic concentrator
    vi. Rigid mirror concentrator

g. Cell Growth Kinetics studies
    i. Microscope
    ii. UV sterilization
    iii. Shielded Environment
    iv. Storage

h. Electrostatic Thrusters for Microgravity Propulsion in a Pressurized Environment
    i. Safety area for small to medium sized models
        1. Equipped with a safety net in all walls and cushioned floors to prevent too much damage on vehicle in case of crashes.
    ii. Test bench for static test for small to large engines

1. Motion tracking and recording capability for ease of logging experimental findings

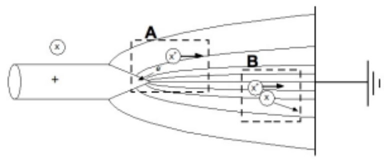
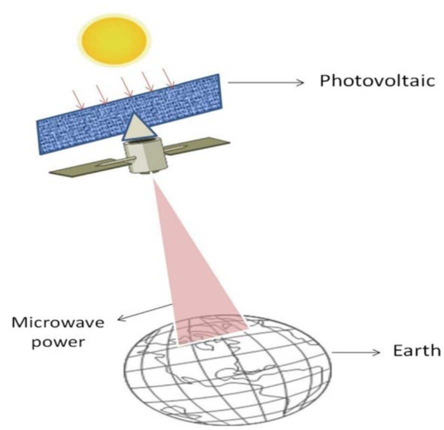


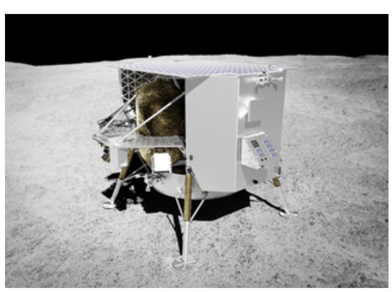
Figure 1 - Ion-Drag Pump thruster concept.

i. Microwave Power Transmission
    i. Commercial Lunar Orbiter
        1. Solar cells for power generation (for spacecraft operation and the experiment)
        2. Microwave transmission equipment
    ii. Ground Equipment for receiving transmitted microwaves
        1. Microwave rectenna
        2. Data collection systems
    iii.



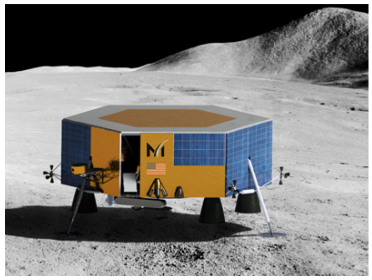
    iv.

j. Solar Cell Testing
    i. Commercial Payload Lander
    ii. Lunar Solar Panels

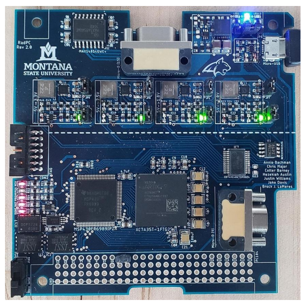


k. Effect of Lunar Regolith on Antenna Systems

    i. Commercial Payload Lander
    ii. Lunar Antenna System



l. Reconfigurable, Radiation Tolerant Computer System (RadPC)
    i. RadPC single board computer
    ii. Montana State University payload



Timeline:

- Gateway is already in orbit and operational
    - Space Weather Experiment conducted by astronauts during their stay on Gateway
- Phase 1
    - Segments 1-4
        - Focused mainly on construction of infrastructure for habitat
        - Short range EVA can be conducted segment 1
        - Fuel Cell Experiments and Greenhouse construction starts in Segment 3
        - Greenhouse construction concludes Segment 4
            - Plant and cell growth experiments begin slowly
        - Calcium Excretion experiment will be conducted for each new crew (every segment)
        - Pressurized rover arrives segment 4
- Phase 2
    - Segments 5-6
        - Conclusion of the habitat construction
        - Crew size increases from 3 to 6
        - EVA missions begin to expand farther distances using pressurized rover segment 5

            - Begin studying the effects of regolith on antenna systems segment 5
            - Commercial Lunar Payloads for experiments begin to arrive in segment 6
                - RadPC
            - Greenhouse completely covered in regolith end of segment 5 into segment 6 and full scale greenhouse experiments begin
- Phase 3
    - Segments 7-10
        - Primary science missions begin segment 7
        - Geological sampling with EVA segment 7, 8, 9
            - This covers shackleton crater experiments, finding ice, etc.
        - Expansion into shackleton segment 8
        - Thermal Energy for Lunar In Situ Resource Utilization segment 7
        - Many experiments at habitat segment 9 (lower priority)
            - Greenhouse experiments continue and expand
            - Electrostatic Thrusters for Microgravity Propulsion in a Pressurized Environment
            - Microwave Power Transmission

4. **Nominal Plan:**

How your working groups goals and work progress and develop over the mission. The plan is split up into 10 6-month segments (5 years) and 3 overarching phases (Construction, Transition, and Experimentation. If in a particular segment there isn't a lot of going on for your group you can explain that nominally things should be progressing about the same as the segment before.

a. Experiment: Regolith Adherence Characterization (RAC)
    i. Purpose: Determine how lunar regolith sticks to a range of materials exposed to the Moon's environment at different phases of flight
    ii. Process of Experimentation:
        1. The payload will be brought down to the surface with the lander attached to the outside of the module.
        2. The payload will have a large range of materials that NASA or commercial partners want to test for lunar regolith adherence.
        3. These materials will be exposed to the lunar regolith where its reaction/adherence will be studied and information can be relayed back to interested parties.
    iii. Results of Experimentation

1. The regolith tends to stick tenaciously to most surfaces because of its small and rough material behavior. This causes performance issues to anything exposed to it and may ultimately result in failure.
    a. It would be very beneficial to utilize materials that passively reject the adherence of regolith
2. The materials will be studied to see what its tendency is to attract regolith or for regolith to adhere to it.
3. The results of this payload will greatly help with future missions to the moon and beyond as it may bring insight to what materials should be used when making space suits, tools, anything that may be exposed to the lunar regolith.
4. Using the data gathered from the materials on board this payload, designing future space suits and equipment that passively reduce the amount of regolith will greatly decrease the amount of thought and effort put into a filtration system and regolith mitigation systems

b. Experiment: Space Weather Forecast Enhancement
    i. Purpose: Monitor the lunar radiation environment and return data back to Earth before crews begin to arrive.
    ii. Process of Experimentation:
        1. NASA's HERMES and ESA's ERSA instrumentation suites will be pre-loaded on the first gateway components
        2. The Power and Propulsion Element and the Habitation and Logistics Outpost components that contain the instrumentation suites will be launched into a highly elliptical seven-day near-rectilinear halo orbit
        3. Once in orbit, HERMES will measure lower energy radiation that will be considered for astronaut safety and ERSA will measures energetic particles from the Sun, galactic cosmic rays, neutrons, ions, and magnetic fields around the Gateway
    iii. Results of Experimentation
        1. Gateway will spend a quarter of its orbit inside Earth's magnetic field. During its orbit it will intersection with the magnetotail,a magnetic field being blown back by the solar wind, and HERMES will enable observations of magnetic fields, protons, electrons, and ions deep in the magnetotail
        2. When Gateway is not inside the magnetotail it will capture solar wind and radiation directly from the Sun without Earth's magnetic field interfering.

3. The data from both section combined alongside two of the five THEMIS spacecraft will allow simultaneous data collection in different locations thus characterizing solar wind behavior as it changes in space and time
4. ERSA will measure ionizing radiation that can create brief spikes in voltage that can make electronics short-circuit. This data will help prevent electronics from failing in space in the future
5. ERSA will measure the energy that would be deposited by radiation in living tissue to better understand human radiation exposure
6. Takeaway: This will help NASA and ESA improve their models of space weather to better predict when such radiation could be on its way from the Sun, enabling better advanced warnings in the future

c. Experiment: Calcium excretion experiment
   i. Purpose: Measure calcium excretion by urination and correlate to bone mass density loss
   ii. Process of Experimentation
      1. DEXA scan of all crewmates to measure bone mass density (BMD) before takeoff
      2. Collect daily urine samples from each crewmate
      3. Measure for 6 naturally occurring calcium isotopes related to bone loss: 40Ca, 42Ca, 43Ca, 44Ca, 46Ca, and 48Ca.
         a. When the body undergoes bone resorption, lighter Ca isotopes will be more prevalent
         b. By measuring the ratios of the 6 naturally occurring isotopes, one can get a picture of the bone resorption rate
      4. Calcium isotope ratio will be determined by thermal ionization mass spectrometry (TIMS) and measured daily during spaceflight
      5. After the mission, a DEXA scan will be conducted to measure bone mass density lost throughout the mission
   iii. Results of Experimentation and Benefit to Future Missions
      1. The hope of this study is to determine a baseline of bone mass density loss rate solely through the use of urine samples and TIMS
      2. Will increase availability of bone loss data, and allow for future studies regarding the effectiveness of various countermeasures
      3. The end goal of this study is to more easily regulate and monitor bone loss in crewmates, so that in long-duration studies, the crewmates are not rendered unable to perform necessary functions when they arrive at their destination

d. Experiment: Lunar Greenhouse (LGH)

i. Purpose: With the long term nature of the mission, establishing a regenerative food source is crucial. This experiment will utilize hydroponics to supplement or support the lunar food supply. Additionally, this bioregenerative life support system (BLSS) will utilize plants and crop production for air revitalization and waste recycling.

ii. Process of Experimentation:

1. Prior to being deployed, the plants, seeds and material for the system will be determined.
    a. In-site resource utilization (ISRU) will be used as possible to conserve fuel, space, and possibly cost.
    b. As of now, the targeted NASA crops are lettuce greens, cucumber, sweet potato, and strawberry.
2. The cylindrical, inflatable, deployable greenhouse will be buried beneath the surface to protect it from radiation.
3. Within the greenhouse, grow lighting can be utilized instead of the sun.
    a. Experimentation using hybrids of natural and artificial lighting will also be done.
    b. The maximum light intensity to be maintained would be 300 - 400 μ mol m^{-2} s^{-2}.
4. The water used in the system will be from reserves brought or water found on the lunar surface.
5. The water is oxygenated, given nutrient salts, and continuously flows across the roots of the plants.
    a. An irrigation and nutrient delivery system (NDS) will be utilized.
6. The food production capability, water balance, carbon balance, and radiation balance will be determined.
    a. Additional data should be collected to find the energy demand, time evolution, and battery capacities needed.
7. Additionally, the system operational requirements, capabilities and weaknesses will be documented.

iii. Results of Experiment and Benefit to Future Missions:

1. Plant growth is essential to closing the loop and creating a self-sufficient system. Soilless plant production allows for controlled nutrition, higher quality produce, more efficient use of water, and more efficient utilization of space. This experiment allows for technological challenges of hydroponic cultivation to be addressed before potential long-term, large-scale production. This system can also be utilized to scrub carbon dioxide and produce

oxygen in addition to its food capabilities. This specialized testing will ensure the system can adequately support a crew. This experiment would allow native processes to sustain life in exploration beyond Earth and has the potential to decrease base reliance on regular supply shipments. In the event that a shipment is delayed, it could supplement the food supply.

e. Experiment: Geological sampling with EVA
    i. Purpose: Collect geological samples for further analysis/testing either on the lunar habit or for further analysis on earth.
    ii. Process of experimentation:
        1. Astronauts collect tools and EVA equipment from designated locations.
        2. Proper tool attachments are prepared for specific sample collection types. (Soil/Regolith core, float, chip, or soil)
        3. The astronauts utilize the LTV to travel to the designated sample collection location
        4. Samples are collected using a variety of different tools and are stored in sample bags
        5. Samples are returned to the lunar habitat and stored for return to earth or analysis in the habitat
        6. Shackleton Crater will be the primary area of target when searching for both subsurface water frost and subsurface water ice
    iii. Results of experiment and benefit to future missions
        1. Sample collection techniques and tools may be tested and improved upon given good feedback from the astronauts. Examples of this could include different size shovels and rakes or larger/narrower sample bags, etc.
        2. Results from the geological samples may provide good insight into potential lunar resources that can help make the lunar habitat sustainable long term. This includes elements such as Hydrogen and Oxygen which may be used to create fuel or oxygen supplies.

f. Experiment: Electrostatic Thrusters for Microgravity Propulsion in a Pressurized Environment
    i. Purpose: Motivated by long-term human exploration missions which could benefit from robotic assistants, a prototype thruster based on an Ion-Drag Pump was developed.
    ii. Process of Experimentation:
        1. Recharging the electrical power unit to operate/test propulsion unit
        2. Run propulsion readiness tests to ensure safety or crew and equipment

a. If a bigger area is needed to perform an experiment, the usage of the entire experimentation capsule/section could be suitable for request if allowed.

3. Ensuring that the experiment will not interfere with any equipment or protocol that is taking place or has a higher priority.
4. Perform static tests to confirm levels of ionized air are being produced
    a. If the device does not pass the static test, then record the data and document accordingly
5. If static tests is successful, a dynamic test might be performed to measure performance characteristics
    a. Some other metrics to be measured are, stability, consistency, endurance, range, and control
6. Measure current, voltage, and thrust periodically to determine outcome of experiment
7. Document data and perform cleanup procedures
    a. Cleanup procedures will be based on a checklist that guides step by step how to re-organize, clean, and sterilize back all the appropriate equipment, as well as logging the appropriate data and locking any relevant equipment.

iii. Results of Experimentation and Benefit to Future Missions:

1. Previous results demonstrated that an engine with an inlet area of 5 cm^2 and a needle density of 1.0 needles/cm^2 can provide a thrust of at least 3mN with electrical inputs of 10kV and less than 100uA.
2. The successful demonstration is a proof of concept and opens the possibility for future engines that could provide the desired thrust to support astronauts in a wide range of activities during their stay at the surface habitat.

g. Experiment: Thermal Energy for Lunar In Situ Resource Utilization

i. Purpose: Obtaining oxygen from lunar raw materials is critical for sustaining a lunar habitat, however this is very power intensive. Solar concentrators are used to harness the Sun’s energy to heat regolith to high temperatures. Over the course of the experiment different solar concentrator designs will be compared.

ii. Process of Experimentation:

1. Different types of concentrators to be tested: Cassegrains, offset parabolas, compound parabolic concentrators, and secondary concentrators. Also tested differences from lenses to mirrors and rigid and flexible concentrators.

2. To obtain oxygen the regolith must be heated to temperatures ranging from 1375K to 1875K based on the various processing methods
3. Either hydrogen reduction or carbothermal reduction processes will be used for all the different concentrators, to extract oxygen.
4. The best method will be determined for heating the regolith

iii. Results of Experimentation and Benefit to Future Missions:

1. A Cassegrain concentrator with an optical cable assembly, could be placed anywhere on the Moon
2. An offset parabolic concentrator using direct sunlight or illumination could operate on the South Pole
3. Highly modular concentrator design lowers the efficiency of the system and oxygen production rates
4. This test has established that the production of oxygen for the lunar habitat is a viable option on the lunar surface.
5. Successfully obtaining oxygen from regolith would help extend human habitation on the Moon, for fuel cells and rocket propellant.
6. In order to produce 1000 kg/year of oxygen from hydrogen reduction, 15,241 W of thermal power will be required

h. Experiment: Cell Growth Kinetics studies

i. Purpose: With the commercialization of spaceflight, the Artemis mission's extended human lunar presence, and planned mars missions on the horizon, long term low and microgravity environments are likely going to induce a drastic shift in cellular growth behavior. To understand the long-term effects of these foreign environments on biological processes, cellular growth in both satellite (microgravity) and lunar (low gravity) habitats will be conducted and observed.

ii. Process of Experimentation:

1. Cultures will be initiated in a clean and cosmic ray shielded environment.
2. At regular intervals throughout the cell growth process, the cultures will be examined and microscopic images will be taken. Many cell growth parameters will be observed such as proliferation, differentiation, gene expression.
3. Cell type, experiment duration, and external stimulus will all be adjusted to test different cell behaviors as a result of microgravity

iii. Results of Experimentation and Benefit to Future Mission: Understanding how long term microgravity environments will affect the growth of biological material is vital to safe human voyages in the future. Human beings have evolved to live in a 1g environment, and altering that parameter has profound effects on the biology of the body. To ensure proper medical preparation for long term microgravity missions, it is vital to reach an understanding of how these micro-processes are altered.

i. Experiment: Microwave Power Transmission
    i. Purpose: In-flight testing of long range microwave power transmission to improve technology for upscaled use in support of future operations and the Moon and Mars.
    ii. Process of Experimentation:
        1. Satellite collects solar energy from the Sun using its on board photovoltaic array.
        2. The solar energy is converted to DC power aboard the spacecraft.
        3. This DC power is then converted into microwaves.
        4. These microwaves are then transmitted across radio frequencies using a microwave transmitter.
        5. Microwaves are received on the Lunar Surface via the use of a microwave rectenna.
        6. The received microwaves are converted into DC Power.
            a. At this point, it is possible to measure the efficiency of the energy conversion process from the point of collection in lunar orbit to the DC output on the lunar surface.
    iii. Results of Experimentation and Benefit to Future Missions:
        1. The results of this experiment aim to demonstrate the ability to transmit power across long distances with a targeted beam collection frequency of 90%.
        2. This would help increase the base-load power available to the crew on the lunar surface without landing any additional hardware besides the rectenna.
        3. Power could be transmitted to any location serviceable from the satellite's orbit.
        4. The success of this experiment would also help to prove the economic feasibility of the concept for future missions in LEO, Lunar orbit, and beyond.
        5. Microwave power transmission could also be useful on mars where microwaves could be transmitted through dust storms and provide steady power to any location.

j. Experiment: Solar Cell Testing
    i. Purpose: Perform small scale testing on state-of-the-art solar cells in the lunar environment.

ii. Process of Experimentation:
    1. Arrange solar cells into the appropriate configuration for testing.
        a. CIGS (Cu(In,Ga)Se_2) Solar Cells
        b. Perovskite Solar Cells
        c. Compound III-V Solar Cells
    2. Collect data for the voltage and amperage output of each solar array.
    3. Repeat data collection for 6 months.
    4. At the end of the experimentation period, analyze data to compare with theoretical output expectations and degradation rates.

iii. Results of Experimentation and Benefit to Future Missions:
    1. The results of the experiment should display the performance of new high-efficiency solar cell technology.
    2. Scientists will be able to examine how the solar cells performed in the harsh space environment after being subjected to radiation and temperature extremes.
    3. This experiment could help further improve solar cell technology to allow for the creation of solar cells approaching 40 to 50 percent efficiency. This technology could be used for all future space missions.

k. Experiment: Effect of Lunar Regolith on Antenna Systems
    i. Purpose: Determine the effects of lunar regolith on the effectiveness and efficiency of communication systems on the surface of the moon.
    ii. Process of Experimentation:
        1. Identical static antenna stations will be placed on the surface of the moon. Each antenna will be placed in the same configuration and in areas of comparable conditions (geography, etc.).
        2. Each antenna will be tested for functionality and baseline measurements will be taken.
        3. The antennas will be covered with regolith to varying degrees, and measurements will be repeated.
        4. This cycle will be repeated until enough results are collected.
        5. Additionally, the effects of periodic cleaning/maintenance will be explored by allowing for one of the antennas to be cleaned periodically.
    iii. Results of Experimentation and Benefit to Future Missions: The main outcomes of this experiment will be the effects of contamination via lunar regolith on the communications systems. This experiment will determine the interval at which communication systems shall be cleaned and

maintained to remain effective and efficient. Transmission power and losses will be determined based on each antenna's performance.

l. Experiment: Reconfigurable, Radiation Tolerant Computer System (RadPC)
    i. Purpose: Determine and demonstrate the effectiveness of a radiation tolerant computing system.
    ii. Process of Experimentation:
        1. RadPC systems will be implemented across the mission
        2. Systems will be tested for functionality and baseline measurements will be taken
        3. The hardware will inevitably be exposed to varying amounts of solar radiation which will be monitored closely.
        4. Measurements will be taken continuously to determine radiation effects on C2 systems
        5. This cycle will be repeated until enough results are collected
    iii. Results of Experimentation and Benefit to Future Missions: The results of this experiment will be used to characterize the effects of solar radiation on electronic systems. Research on this topic will impact how C2 hardware is developed for future missions. Results can also be applied to the electronic components of other ops teams.

Integration with Other Teams:

- Overall Integration
    - For all of the experiments:
        - we referenced PLAN's mission timeline to ensure that our experiments lined up with important dates such as:
            - Pressurized rover arrival
            - Greenhouse construction completion
            - Commercial payload arrivals
        - We communicated with the Lunar Lander team to ensure that our science instruments and infrastructure were able to be brought to the surface
        - There was a lot of interaction between all of the teams on Trello
        - Flight rules contributed to SAFE
- Geological Sampling
    - Surface Operations and Safety and Flight Rules provided constraints for EVA contributions for sample collection.
    - Surface Operations, Surface Transport, as well as Safety and Flight Rules provided constraints for rover contributions for sample collection.
- Lunar Greenhouse

    - Excavation carried out by RASSOR excavation rover a key component of the Surface Operations planned construction methods
    - Worked with PLAN, HAB, and Surface Operations to determine when completion of the greenhouse would be done and when it will be possible to begin experimentation
- Thermal Energy for Lunar ISRU
    - Conducted to support the ISRU Integration team
- Electrostatic Thrusters
    - Worked with HAB and SAFE to ensure that this was feasible

5. **Off Nominal Plan:**

Any situations the nominal plan doesn't consider but doesn't put the lives of the crew immediately at risk. Rovers breaking down and needing to be fixed, losing tools, Not being able to produce/collect enough oxygen, water, regolith, etc. Any situation that wouldn't be considered an emergency but can hinder the progression of the mission. How do we solve these situations? (Include information about what systems you make redundant as that could help to solve these problems)

a. Calcium Excretion Experiment
    i. If the TIMS stops functioning properly during the mission, the urine samples can be stored at -20℃ until the machine is able to undergo proper maintenance or repair. The isotopes will not denature and will be valid in representing calcium excretion for up to 1 year.
    ii. Although this would cause a delay in the data, it will still allow for ample analysis of the samples to determine calcium loss rates.
b. Electrostatic Thrusters for Microgravity Propulsion in a Pressurized Environment
    i. With regards to contingency, the experiment has to follow strict guidelines and safety procedures to be performed, while constantly checking for the oxygen, thrust, and stability data to ensure that the experiment is conducted in a contained and controlled manner.
    ii. The levels of redundancy will have to come from each one of the different experimental systems. Each one of them should be serviceable and should come with detailed instructions, tools, and spare parts for those that are the most likely to fail. Emergency handling and procedures should also be included in the guide and how to tackle them.
    iii. If an emergency does show up and it has not been considered under the guidelines provided along with the respective experimental system, then standard emergency procedure shall be followed. Depending on the nature of the emergency, the crew shall do what is needed following the safety guidelines provided by the standard procedures for experimentation. Full

shutdown, seal, depressurization, oxygen depletion, etc shall be available to contain or resolve any appropriate situation.

c. Thermal Energy for Lunar In Situ Resource Utilization
    i. Having m When staging the concentration of sunlight, the thermal energy can be redirected to the desired process location, while being further concentrated. Utilizing a secondary and tertiary concentrator within the system will allow the primary concentrator to track the Sun. This allows the concentrated sunlight to be focused on a specific location relative to the surface. However, utilizing multiple concentrators will decrease overall system efficiency.
    ii. There are losses associated with each mirror or lens within the concentrator system. They are due to light absorption, geometry inaccuracies, and scattering. These losses can be improved by using highly reflective mirrors, short ray lengths and highly transmissible lenses.
d. Cell Growth Kinetics Study
    i. The culture environment will have UV sterilization capabilities to minimize risk of contamination and clean contaminations if they do occur.
    ii. Multiple culture samples will be stored for redundancy in case of a test run contamination
e. Microwave Power Transmission
    i. This experiment is more complex and involves interactions between both surface and orbital assets. Because it is not cost effective to have many satellites for initial, experimental testing of this technology, all redundancies will have to be addressed within the satellite for as many systems as possible. Examples of this would be multiple computer systems onboard the satellite or different power management solutions that could help the satellite operate through some failures. For the lunar surface aspect of this experiment, the equipment must still be robust and have redundant systems. However, these systems should also be repairable by astronauts during EVAs to help increase their useful lifespan.
    ii. Like all other experiments, these systems will be monitored to ensure they are operating within their constraints. If any values are out of alignment, the system will have safeguards in place to protect the hardware while keeping critical systems running. If the system is deemed safe for continued operations, the experiment and data collection processes can be continued.
f. Solar Cell Testing
    i. This experiment would take place on the surface near the surface habitat and therefore any emergencies or failures can be solved with operations such as EVAs.

ii. The nature of this experiment involves monitoring solar cell performance. Therefore, the experiment can be monitored with software systems, and, if any anomalies are found, the experiment could be turned off or limited to a certain capacity.
iii. The solar cell experiment can have redundancies in its data collection systems and by having multiple panels for testing. This would ensure that the failure of solar cells or an entire panel would not entirely scrap the experiment.

6. **Resource Management:**
What resources are important to your working group over the entirety of the mission? How much of these resources are required? If you need one resource for multiple places, how will you split up these resources?
   a. Tools and equipment seem to be the most important “resources” required for the science and utilization team.
      i. Greenhouse
      ii. Collection tools
      iii. Other required equipment in habitat
   b. This team is in charge of performing experiments and conducting the experiments that gather resources that will then be used by other groups to aid in mission goals. Important resources that will be gathered are things such as:
      i. Regolith
      ii. Core samples
      iii. Ice
      iv. Hydrogen & Oxygen

7. **Emergency planning/ Risk Matrix:**

Anything situation that is hazardous to the life of the crew. Ammonia leaks, something going wrong to the EVA suits, no power, no cooling things of this nature that would immediately put the crew’s life at risk. A risk matrix should be made detailing these emergency situations. Example of a risk matrix below:

   a. Regolith Adherence Characterization

      i. Astronauts may be exposed to more regolith in order to test these materials

            1. Can stick to space suits, get in habitat, destroy tools/equipment, etc.
   b. Space Weather
      i. Measurements from both HERMES and ERSA are made at time of impact and do not directly provide warnings for solar radiation events
      ii. Potential Failures of either instrumentation suites will require EVA to conduct repairs
   c. Calcium Excretion Experiment
      i. DEXA scan exposes the crewmate to radiation before and after spaceflight (Moderate)
   d. Lunar Greenhouse
      i. The materials involved with this experiment could pose a low risk of toxic spill.
      ii. If it was relied on to provide the majority of the food supply and there was a failure event, it would starve the crew.
         1. The same could be said if the carbon dioxide scrubbing functionality was depended on.
   e. Geological Sampling with EVA
      i. Exposure to radiation during EVA.
      ii. An astronaut may get stuck traversing the lunar terrain.
      iii. The LTV breaks down when the astronauts are away from the lunar habitat.
   f. Electrostatic Thrusters for Microgravity Propulsion in a Pressurized Environment
      i. Since a micro-scale thruster was tested, bigger, more powerful Electrostatic Thrusters will be tested and the testing area will become more and more compromised. Implementing safety scale factors to all the safety procedures, as well as boundaries to the size/thrust to be allowed in the testing area will help prevent many safety risks.
      ii. List of different possible emergencies,
         1. Oxigen source is depleting from the research section. Unlikely to happen as leaks are rare. Significant (4) to Severe (5) risk, depending on the rate of depletion
         2. Thrust is not controlled and/or significantly higher causing an impact on crew or equipment. Very unlikely to happen as systems are restrained, and when not there will be an appropriate area for the experiment to prevent such a

possibility. Mild (3) to Significant (4) risk, depending on the size of the system and magnitude of damage.

3. System destabilizes and damages equipment or crew. Unlikely since the vehicles will be tested with a proper area to prevent accidents. Mild (3) to Significant (4) risk, depending on the size and magnitude of damage.

g. Thermal Energy for Lunar In Situ Resources Utilization
    i. The lunar environment provides several design challenges for the solar concentrator. Lunar regolith dust causes three primary challenges to the structures; dust clinging, abrasiveness and clogging.
    ii. Another safety concern would be vacuum welding of moving parts. Since there are no oxidation reactions in a vacuum, parts of a moving system can bond to each other, causing the mechanism to halt.

h. Cell Growth Kinetics Study
    i. An important aspect of any biological system is its ability to fend off or deal with harmful stimuli. It is very important to understand how microgravity may affect the human body's ability to fight off infection, disease, and other harmful stimuli like radiation and trauma. If cultures are to be tested against these stimuli, it is important to ensure proper safe-keeping of dangerous materials so as not to affect any unintended biological systems.

i. Microwave Power Transmission
    i. Depending on the radiofrequency and methods used for transmission, levels of high-powered RF energy can be present in close proximity of the lunar basecamp and the astronauts working in the vicinity. This RF energy could exceed the recommended safe exposure limits and safety precautions will need to be taken into consideration.

j. Solar Cell Testing
    i. Any dust that collects on the solar panels would affect the reliability of the experimental results. Thus, astronauts would need to perform EVAs to routinely clean these panels. These added EVAs would further increase the safety risk for astronauts.

k. Effect of Lunar Regolith on Antenna Systems
    i. The main concern of this experiment is the high levels of RF radiation that crew may be exposed to. This will be mitigated by the safety and flight rules, as well as the fact that the experiment measures radiation's effect on electronics rather than human life.

I. Risk Matrix

Likelihood		Consequence				
		Negligible (1)	Minor (2)	Moderate (3)	Significant (4)	Severe (5)
	Almost Certain (5)	- Radiation from DEXA scan - Solar Radiation	- Regolith (dust clinging, abrasiveness, and clogging)			
	Likely (4)	- RF Radiation				
	Possible (3)	- Falls During EVA	- LTV getting stuck	- Astronaut getting stuck during EVA	- Vacuum Cementing	
	Unlikely (2)		- Loss of communication	- Medical injury during EVA - LTV Breaking down	- Loss of power	
	Rare (1)	- Moonquakes	- Greenhouse Failure	- Micro-meteoroid impacts	- Thruster malfunction	- Exposure to toxic materials - Regolith Ingestion

- **Flight Rules:**
  - No human surface operations during a solar radiation event
    - Rationale: During a solar radiation event, the radiation is much higher than normal circumstances, this obviously creates a dangerous environment for astronauts that needs to be avoided
  - An EVA must be terminated if inter-suit communication is lost
    - Rationale: EVA must be terminated, because without communication any emergency cannot be conveyed to supporting users meaning further operation is unnecessarily dangerous for the involved crew member(s)
  - Maximum EVA excursion distance = 1 km from the habitat
    - Rationale: Cannot travel more than 1 km from habitat because suit emergency O2 will last for 30 minutes, which is the estimated time to return to the airlock by foot from a distance of 1 km
  - Minimum of 1 astronaut on assistance/comms from the space habitat per EVA astronaut.

        - Rationale: Having at least one astronaut to assist during an EVA from the surface habitat would allow for more EVA's at the same time and for emergency response for each of the EVA astronauts. Minimum of 1 assisting astronaut per EVA astronaut would allow for full personal attention to the EVA astronaut from at least one person.
    - Minimum of two astronauts present for each rover excursion
        - Rational: In the event of an emergency accident, or if the pilot becomes impared, having a secondary pilot/astronaut present provides redundancy. The secondary astronaut endures rapid communication of all events from multiple perspectives.
    - Crewmates must exercise for at least one hour per day under simulated gravity > 1G.
        - Rationale: In order to prevent extreme bone resorption due to the lack of gravity, the crewmates must participate in active countermeasures to protect their bone mass density.
    - Visiting spacecraft must not fire thrusters within 10m of Gateway
        - Rationale: Thruster plumes represent a serious hazard to external elements of gateway, and can cause serious loads upon structural elements, possibly even inducing failure
    - RF levels should not be greater than 1.6 Watts per kg. near any equipment.
        - Rationale: The FCC has determined that RF levels beyond this amount can cause adverse health effects after long-term exposure.
    - ALL experimentation shall be capable of returning itself to a safe and protected state given the case of prolonged communication loss.
        - Rationale: No experiments should be conducted in a manner that is dangerous/damaging to crew or equipment given the event of a communication failure with equipment pertaining to the experimentation.
    - Rover excursions will be halted if C&C systems need to be restarted.
        - Rationale: In the event of a C2 failure, a crewmate will need to perform a manual override to reboot the system.
    - Greenhouses must be buried at least 10ft beneath the surface.
        - Rationale: At this depth, the radiation levels are safe for plants.
    - DEXA scan before spaceflight must occur at least 3 weeks prior to launch
        - Prevent the crew from overexposure of radiation

Resources

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