LIFE ON MARS WHITE PAPER: PIVOTAL MOMENTS SHAPING ITERATIVE OUTCOMES

MISSION 001 – AUDACITY

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Background

Space Commerce Institute, established in 2022 by Space Foundation, is dedicated to opening and expanding opportunities to connect innovators and entrepreneurs with the most dynamic economy in the world through information, experience, training, mentorship, and consultancy. With jobs, services and markets forecasted for considerable growth, Space Commerce Institute allows participants to learn from experts who have perfected what it takes to navigate the evolving mandates from concept to creation and grow businesses in the global space economy.

Capitalizing on four decades of advocacy for the space community and leveraging Space Foundation's unparalleled global network of space leaders, Space Commerce Institute provides accessible, actionable, tangible and targeted programming to bridge the knowledge gap and move participants swiftly toward their goals. To learn more about Space Commerce Institute, visit www.SpaceFoundation.org/sci.

January 26 through 28, 2024, Space Commerce Institute, in partnership with Nova Southeastern University's Alan B. Levan | NSU Broward Center of Innovation, executed a three-day, in-person, experiential Mars habitat simulation called *Life on Mars.* Each day was represented by a Sol. Participants experienced *Life on Mars* and navigated through various exercises and challenges– including catastrophes, isolation, limited mobility, sub-par communications, the use of cargo item cards, and paired-team challenges – that directly impacted their thought processes, iterations of work, collaboration, and final design product. *Life on Mars* is one example of Space Commerce Institute's specialized programming that was conceptualized and created entirely in-house.

The purpose of this white paper is to present a synthesis of *Life on Mars* team thought processes, work iterations, and final collective mission designs to offer a narrative account of what they achieved through their experience. This paper is structured to first provide a succinct synopsis of the much broader *Life on Mars* program. The synopsis is followed by an overview of the real-time challenges and assistive resources presented to participants as they worked toward achieving their team outcomes. Having set the contextual scene, the remainder of this paper is a series of participant-contributed accounts that synthesize team-based outcomes and how those outcomes evolved from initial ideations, through thought process pivots and work iterations, to the culmination of their final product. Finally, the paper offers conclusory remarks to summarize the *Life on Mars* experience and the achievement of its participants.

Synopsis

Life on Mars Mission 001 took place in the future year 2049. A hypothetical global consortium of visionary companies sent a cohort of Earth Ambassadors (participants) to Mars with an aim to create a flagship Mars community. Toward collectively designing their Martian community, six interdisciplinary teams of 5-7 participants were formed, each headed by a Team Lead with an assigned subject matter focus area, including: Health and Safety, Nutrition and Agriculture, Resources Development and Management, Human Services and Recreation, Habitat Operations, and Structure and Suit Design. Each team arrived on a SpaceX Starship with a cargo box that contained a variety of items for their use including cards representing specific items from among tools, equipment, instruments, and reserve resources. As reserve resource cards were used, the availability of that resource was depleted.

Life on Mars participants faced both present and forward-looking team and community challenges. The overall mission objective was to collectively design a self-sustaining permanent first community on Mars. If successful, the consortium would subsequently send an additional cohort of 50 more to join the community in 2054. Toward achieving the mission objective, each team was tasked with resolving its own individual team challenge; one uniquely designed to mobilize the team's subject matter expertise, while also ensuring their design was integrative and complimentary to the overall community's design. In broad terms, each team challenge required designing the ecosystem of infrastructure, facilities, systems, services, and comforts within the team's purview as necessary to operate in functional harmony with a collective community plan.

Along the way, however, all teams faced additional real-time challenges to work through as they unexpectedly arose, including an emergency rescue, a dust storm catastrophe, evacuating to repair a cracked viewport, resolving a resource use dispute, repairing decontamination pods, and treating patients in the sick bay. As teams worked to resolve the scenarios confronting them, participants 'played' the respective cards for the cargo items they made use of. At the conclusion of the three-days, team and mission success was adjudged by an esteemed panel of space-experts comprised of current and former NASA officials, as well as space technology executives who evaluated the presentations of each team's design outcomes and their coordination into the community plan.

Real-Time Challenges and Assistive Resources

While working through their individual team challenge and the overall mission objective, all teams confronted some unexpected real-time thought exercises, including a dust storm catastrophe and a paired-team challenge. These scenarios implicated a need for teams to pivot course to iterate work with revised design ideas, processes, and collaborations. As available resources to assist guiding their efforts, teams had access to electronic sources of academic and technical research, direct recommendations from Earth Experts, and use of cargo items (represented by cards) that accompanied each team to Mars on board their ship.

Dust Storm Catastrophe

Sol one, all teams encountered a dust storm and the implications it brought to bear on their team challenges. The presented dust storm was not as large as a planetary storm, but it was more expansive than a smaller dirt-devil type dust-up. Once all teams were remotely warned to shelter in place, the dust storm scenario was broadcast over two-way radio, including information regarding atmospheric and environmental conditions, the composition and size of Mars "dust," general characteristics of Mars "dust storms," and the insidious effects and havoc that such dust can cause to infrastructure, space suits, health, agriculture, mechanics, and the like. To resolve these effects, teams were required to incorporate remedial and preventative measures into their design. In addition, when a team member returning to his ship was stuck outside as the storm set in, he was rescued and taken to the medical bay for treatment and observation related to his direct exposure.

Paired-Team Challenges

Sol two, all teams worked through a paired-team challenge. Each challenge implicated an authentic scenario for paired teams to collectively work through to successfully sustain life on Mars. One challenge required both the Nutrition and Agriculture team and the Resources Development and Management teams to reconcile how best to use a single site on Mars that optimally met each of the teams' own respective needs and purposes, with a community vote the deciding factor. Another presented a cracked ship viewport, requiring the Human Services and Recreation team and the Structure and Suit Design team to resolve the crack while organizing team members and cargo items for single-file evacuation in priority order. The third scenario presented team members who became seriously injured while climbing a rocky crag just prior to communications going dark. The Health and Safety team and the Habitat Operations team were challenged to create a plan of action to recover each injured team member one-at-a-time.

Earth Experts and Cargo Item Cards

Experienced, cross-disciplinary space experts located on Earh, dubbed "Earth Experts," were virtually available to participants to help guide their efforts in working through team challenges. Teams scheduled time to virtually contact the experts for guidance, technical assistance, and recommended actions in alignment with the team's needs and the mission objective. In addition, teams contemplated how their cargo items could assist in resolving their challenges, then used or 'played' the respective card for each cargo item tool, equipment, instrument, and reserve resource that they used toward the intended outcome. Where a challenge implicated the need for cargo items not in their possession, teams could obtain the required items by bartering, swapping, or some other means of agreed exchange.

Team Pivots, Iterations and Outcomes

Habitat Operations Team[1]

Challenge

Design the community's supporting infrastructure and systems, to source, store, and supply energy, and provide mobility and transportation of cargo and people.

Ideation and Initial Design Direction

The team recognized that a sustainable living environment would require innovative solutions and efficient habitat operations. Laying the foundation for self-sufficiency and long-term survival on the Red Planet is critically important and cannot be overstated.

To expand Mars habitat operations and maintenance to include the aspect of perpetuity requires a deep dive into the sustainability and scalability of systems. Operating indefinitely requires advanced recycling technologies that go beyond water and air to include all types of waste, ensuring every resource is used to its fullest potential. This requires developing a robust, self-repairing or easily maintainable infrastructure that can withstand the harsh environment over long periods. The goal was to create a closed-loop ecosystem to minimize Earth inputs and maximize the habitat's self-sufficiency, ensuring its relevance and sustainability for generations.

Integrating local resource utilization strategies for building materials and essential chemicals would reduce reliance on Earth resupplies. It was deemed paramount to establish bioregenerative life support systems, including agriculture, that support human and plant life. These systems not only provide food and oxygen, but also contribute to the psychological well-being of inhabitants by offering a connection to Earth-like living conditions.

Harvesting water on Mars presents significant challenges due to the need to locate, extract, and convert ice or bound water molecules into liquid water. This energy-intensive process requires substantial heating to melt the ice found beneath the surface or within the regolith. Once melted, the water must be purified to remove impurities, making it safe for human consumption. Energy

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[1] Habitat Operations team participants include: Niccolò Pinzan, Arijit Sengupta, Kristiyan Stefanov, and Terry Trevino (Team Lead).

requirements for heating, extraction, and purification processes are considerable, requiring reliable and efficient power sources, such as solar panels or nuclear reactors, to ensure the habitat has a sustainable supply of potable water.

Energy management was decided to be a large concern over time. Managing energy with 700 solar panels producing approximately 1.2 GW involves regular cleaning to remove Martian dust, monitoring for damage from environmental factors, and system optimization to ensure peak performance. For water production from subterranean ice, significant energy is required for drilling, heating to melt the ice, and then purifying the water. The exact energy depends on the efficiency of the technology used but is a considerable part of the habitat's energy budget. Operating a greenhouse to feed 50 requires energy for lighting, temperature control, and possibly to power hydroponic systems. The energy for consumable water includes purification and possibly heating, which, along with greenhouse operations, must be balanced within the 1.2 GW generated. Lithium-ion batteries are crucial for energy storage, allowing the habitat to maintain power during periods of low sunlight and managing peak demand times efficiently.

Directional Pivots: Evolving Thought Processes and Work Iterations

During the simulation's initial hours, the team realized the importance of being actively involved in the planning and engineering of the entire habitat to ensure effective maintenance and long-term community health. To integrate the team more deeply into the overall design process, we proactively pivoted toward collaboration with other teams, embedding our members across the different ship modules. This collaborative approach was already underway prior to Mission Control announcing the dust storm and paired team challenges. By that point, the team had disregarded the cargo item cards completely. So, when the challenges occurred, they were more of a nuisance because the team had already addressed potential issues, like the initial layout of the facility with what was available on hand (the Starships and their arrangement laying down with the nosecone facing inward), as well as air filtration and dust mitigation upon ship module ingress and egress, which ultimately included enclosing passageways between ship modules. Once the other teams saw the added value, collaborations were more easily forthcoming.

Final Design

Oxygen is vital for creating a livable atmosphere within the habitat. To ensure a continuous supply of fresh oxygen to the community, the team designed an innovative system to produce oxygen using methods that convert CO_2 into breathable oxygen, supplemented by plant-based oxygen generation. Similarly, to enhance plant growth for consumption, the team used human waste as a bacterial additive. This method not only manages waste effectively but also improves the Martian regolith by enriching it with necessary nutrients to make it more suitable for agriculture. Likewise, the team's water mining design emphasized conservation and recycling of this precious resource. Advanced techniques ensure that every drop is used judiciously, with significant reductions in water usage for hygiene through water-saving technologies. These measures, along with efficient recycling, allow for a sustainable approach to managing community water for drinking, cooking, and agricultural needs. In support, the team designed comprehensive shielding strategies to protect inhabitants from radiation. Mars' harsh radiation levels are significantly higher than on Earth due to a thin atmosphere and lack of a global magnetic field. The team designed measures essential to minimize habitat exposure to radiation, including personal protective equipment.

The team additionally identified storage and power generation as being critical for sustaining operations and life on Mars. The design of storage structures for oxygen, water, and supplies is critical to maintain a well-connected and functional habitat. The structures not only store essential resources but also ensure easy accessibility, improving the habitat's overall efficiency and the community's well-being. For power generation, the habitat requires a robust system capable of sustaining life support, agricultural pods, and research facilities. Solar radiation on Mars, however, is about 40% of that on Earth, so surface solar panels on Mars generate a lot less power and cannot serve as the sole power supply. Therefore, alongside solar panels, Radioisotope Thermoelectric Generators (RTGs) played a crucial design role to ensure a reliable power supply for all necessary operations while meeting community energy demands. Similarly, as a novel approach to resource utilization, the team designed an innovative use of Starship exhaust systems for metallurgical processes, allowing for iron ore extraction for construction and tool production, showcasing the ingenuity required for Mars inhabitation. Likewise, as a practical solution for moving materials and people, even in the face of dynamic weather like heavy sandstorms that can damage infrastructure, the team developed a design to use ice roads and sledges as an efficient transportation system between the habitat and exploration sites.

The operations required to establish and maintain a habitat on Mars are multifaceted and complex. Each aspect, from waste management and water recycling to power generation and radiation protection, plays a crucial role to ensure the safety and sustainability of human life on the Red Planet. The efforts presented highlight the ingenuity and resilience of required foundational steps to make living on Mars a reality with the long-term goal of establishing a Mars community.

Health and Safety Team[2]

Challenge

Design the community's supporting systems to meet the personal and community health and safety needs of inhabitants to protect against and treat environmental illness, physical hazard injuries, and provide community emergency preparedness.

Ideation and Initial Design Direction

The team recognized that just as ensuring health and safety is of paramount concern during a prolonged space mission, so too is ethical conduct and the ethical principles underpinning the establishment of health and safety standards. These include a spectrum of considerations related to environmental factors and care for the body and mind. Accordingly, the team's design process began with a comprehensive evaluation of health and safety factors to safeguard well-being. In doing so, the team made foundational assumptions to serve as cornerstones, including: preparation to operate within a <1g environment, a mission life-cycle lasting at least 30 months

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[2] Health and Safety team participants include: Dieter Avella, Hem Bhatt (Team Lead), Elaine Cohen, Alessandro Gigante, Eduardo Sanchez, Kaelyn Tindall, and Smera Venkateswar.

(journey plus 24 months stay), rigorous pre-mission health and psychological screening, prior successful unmanned Mars missions, onboard medical equipment, equipment and supplies adequate to sustain participants for the duration, and anticipated technological advancements, such as bio-3D printers for organ fabrication, cryogenic and remote surgical capabilities, generative AI, radiation mitigation techniques, robotics assistance, and synthetic blood.

To determine the requisite health and safety protocols that would define the initial design direction for community implementation plans it was essential for the team to apply a collaborative and iterative approach, involving intensive engagement with multiple teams. The process evaluated available on-site resources, clarified communication and transportation system communications, and aligned the design direction with overarching community objectives. Effective execution relied on a robust framework, including proper training, role and responsibility delineation, fostering preflight community cohesion, adhering to standard codes of conduct, establishing a hierarchical command structure, and ensuring available medical expertise across various disciplines.

Directional Pivots: Evolving Thought Processes and Work Iterations

The dust storm catastrophe and paired-team challenge exposed gaps and risks in the team's work, highlighting areas for further attention and a need to refine emergency protocols. Needs and gaps identified: advanced laboratory equipment, an on-Mars blood drive, pharmacy services, gravitational equipment, bio-3D printers, tissue harvesting capabilities, ambulance and rover units, and unexpectedly being regarded as the *de facto* planner of security and law enforcement measures. Identified risks related to ethical considerations, resource utilization in cases of terminal illness or pregnancy, the adequacy of backup equipment and the distribution of teams and cargo, and the availability of sufficient medical facilities were all carefully assessed and addressed within the final design framework.

To formulate comprehensive health and safety plans and to facilitate efficient allocation of cargo items and available resources, the team undertook iterative deliberations with other teams, Earth Experts and Mission Control. The plans tailored emergency management protocols to community needs, establishing special isolation care units, dedicated communication channels, emergency rescue vehicles, and triage procedures with measures delineated across three key domains: prevention, preparedness, and emergency response.

Prevention protocols included pre-flight, in-flight, and post-flight stages, sanitation and hygiene guidelines, routine medical assessments, and maintaining environmental quality within the habitat. Preparedness efforts established paired-team emergency drills, crisis management strategies, protocols for contingencies such as medical emergencies, pregnancy, and death, and adequate training in <1g environments. Robust emergency response protocols addressed fire outbreaks, dust storms, radiation exposure, communicable diseases, and medical emergencies.

Final Design

The Health and Safety team's design served as a pivotal hub for resource utilization and habitation, offering a technologically advanced habitat tailored to sustain life in the Martian environment. The design incorporated features to enable operational efficiency while ensuring well-being, safety, and productivity. The key elements of the final design were guided and developed through sharing and discussion of health and safety requirements among teams. Attention focused on space suit design, life support systems, structural integrity, radiation shielding, and nutritional production modules, but extended to the function and maintenance of all body systems relating to the impact of such factors as gravity, radiation, oxygen use, and temperature. The team further integrated into its design environmental quality control, energy generation and distribution, along with a design of living quarters with a sanctuary for rest to create a comfortable and conducive living environment.

To promote psychological and psychosocial well-being, resilience, positivity, and to mitigate the potential mental impacts of a long-duration mission, the team designed a regimen of physical and psychological fitness and exercise, offered conflict negotiation training, and proposed strategies to foster community spirit and monitor social interactions that considered ethics related to sexual relationships, co-habitation, pregnancy and reproduction, law enforcement, and rule-breaking.

To accommodate future needs and developments, the team considered capabilities to expand and adapt. Emergency preparedness measures equipped each landing module (integrated with others as station components) with a degree of autonomy to ensure life support and allow for physical compartmentation to isolate single modules without compromising the station's overall safety and functionality. Design efforts prioritized communication and connectivity to ensure seamless crew and Mission Control interaction. Redundancy measures were implemented in key systems to maintain operational continuity with an emphasis on sustainable resource utilization to reduce reliance on external supplies.

One of the team's most important discoveries was this: in the beginning, each individual team tried to ensure its success without consideration of any of the other teams. Over time, as the simulation and challenge scenarios presented increasing difficulty, a more cohesive bond formed amongst all teams toward ensuring the success of the whole mission and all crew members, irrespective of team. Just as a team collectively relies on the individual strength of each member, the whole community relies on the strength and the cohesiveness of each team.

Human Services and Recreation Team[3]

Challenge

Outline activities and design the community's supporting infrastructure to positively nourish the personal thoughts, emotions, behaviors, and interpersonal interactions of inhabitants toward living and co-existing as a cohesive and well-adjusted community.

Ideation and Initial Design Direction

The team initially considered the specific challenges that astronauts currently face, and those that could arise during an extended mission to Mars. The challenges mostly centered on issues

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[3] Human Services and Recreation team participants include: Paige Arnold, Pedro Correa, Alexaidan Knowles, Renata Kobylinski, Ricardo Latta (Team Lead), Stephanie Navarro, and Nicholas Wiseman.

related to mental well-being and physical wellness. Each issue was broken into sub-issues to identify specific objectives and outline tactics to meet those objectives, including:

1. A need for privacy and to establish a sense of autonomy within the crew habitats;
2. Preventing and addressing effects of isolation and confinement;
3. Creating infrastructure to foster healthy inter-crew relationships and related challenges.

Directional Pivots: Evolving Thought Processes and Work Iterations

The team's early design efforts aimed to create individual rooms dedicated to such needs as art, exercise, recreation, and counseling. Identified resource constraints and coordination with other teams compelled the team to reconsider its approach. While the initial concept design stressed shared spaces for holistic well-being, Earth Expert insights revealed a privacy priority. The team's wish for everyone to have separate rooms became unattainable after considering available resources and other teams' needs, so small private rooms were designed. The dust storm required a quick pivot to secure the habitat and ensure crew safety by working with the Habitat Operations team to implement safety and well-being procedures and emergency protocols.

Final Design

The team's underlying final design goal was to provide the infrastructure to support comprehensive programs that address the physiological and psychological needs of crew, and to promote and foster a well-adjusted and cohesive community. In support, the team coupled an Emergency System announcement protocol to communicate procedures during environmental emergencies, with post-emergency system announcements aimed to offer reassurance and alleviate anxiety in the aftermath of emergency situations. Spacesuits and the habitat were designed in phases with human functionality and wellbeing in mind. Similarly, the team designed a phased approach to implement comprehensive programs to maintain physical health, along with community-wide events aimed to increase engagement.

> **Phase 1**: Starship habitat, community hub, personal plants, customized spacesuits; tailored fitness plans, tailored meal planning, and scheduled hours for relaxation time.
>
> **Phase 2**: Private sleeping quarters, customizable aesthetics, community garden and observation deck; community hall fitness calendar, and personalized schedules and curfews.

The team's final design included a structured, hierarchical, chain-of-command governance model for internal operations, with community-wide decisions guided by democratic principles. A six-Commander council would be formed to represent the respective interests of the crew and to allow for autonomous community courses of action. Mission Control would serve in an advisory capacity and be the deciding vote in cases of a tie. This structure would adhere to the Artemis Accords and remain adaptive to community needs and alignment with adjustments to international treaties. A set of applicable laws and declaration of rights would assist with governance as follows:

Applicable Laws

National/International Laws	Martian Rights Declaration
- National Space Laws: if applicable - Outer Space Treaty (OST): ensure the peaceful use of space and international collaboration - ISS Agreements: valuable habitat design insights - Moon Agreement: minimize environmental impact - Human Rights: protect rights, privacy, dignity - Liability Convention: minimize risk of damage to space objects or on Earth - Registration Convention: ensure accountability for property damage and space debris - Informed Consent: ensure awareness of the risks	Safeguard the dignity and well-being of every community individual. - Article 1: right to life, liberty, and security - Article 2: equality and non-discrimination - Article 3: right to health - Article 4: right to privacy - Article 5: right to cultural identity - Article 6: right to participate in government

Inspired by the Finnish penal system, the team likewise designed for phased training to prevent and mitigate crime and conflict. To be determined through consensus among representatives, the approach emphasized anger management, community service and rehabilitation, crew education, identifying and implementing conflict-resolution strategies, and offering emotional support toward preventing crime stemming from unpredictable distress.

> **Phase 1**: Emergency response (kits, drills), pre-recorded Earth communications, and proactive psycho-education (expectations, response).
>
> **Phase 2**: AI recognition and reporting and updated protocols through research and evaluation.

Finally, as there is no viable method for nurturing children on Mars the team considered a procedure to recognize relationships with provisions for the use of contraception, and innovative solutions to ensure means to meet the health and nutritional needs of young inhabitants.

Nutrition and Agriculture Team[4]

Challenge

Outline a physiologically-based nutritional guide, including a sample meal plan exemplifying the established nutritional guidelines, and outline and design the community's supporting infrastructure and systems to sustain a regenerative food production ecosystem to feed and nourish inhabitants on Mars.

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[4] Nutrition and Agriculture team participants include: Susie Bennett, Tyler Campbell-Rattan, Spencer Hedlund, Ruth Nicols (Team Lead), and Taylor Nugent.

Ideation and Initial Design Direction

As crop production is dependent on the development of various infrastructures, the team used existing food stores brought from Earth to sustain the community during the development of long-term agricultural solutions. The team discussed both hydroponic and aeroponic techniques and selected hydroponic farming, as it paired well with the Habitat Operations team's planned closed-loop life-support system. That system, intended to collect and purify wastewater, was considered as a possible method for cultivating spirulina, a type of algae that can function as a biofertilizer. As spirulina is also high in protein and rich in vitamins and minerals, the team intended to create a dietary supplement for the community.

Although high levels of perchlorates and other toxic metals make regolith toxic to humans, the team arrived with enough Earth soil to begin the plant growth process. With it, the team designed an experimental regolith testing site. Using bacteria for perchlorate remediation, testing explored methods to remove regolith toxins and testing differing percentages of regolith-soil mixtures to identify the best method for agricultural growth. Sensors for monitoring carbon dioxide, oxygen, ethylene, ammonia, humidity, temperature, and pH all proved crucial for both crop production and food preservation. After considering sustainable techniques to preserve and store food, the team selected a dehydrator and lyophilizer to process crops after harvest.

Directional Pivots: Evolving Thought Processes and Work Iterations

The team initially assumed that all materials and methods for crop production were available for consideration. Once the simulation fully revealed limitations, hydroponic and aeroponic systems were no longer viable options, leaving only Mars' natural resources available for plant production. Accordingly, the team pivoted toward devising a plan to use the Martian regolith. Spirulina, which was initially selected for its wide range of use in both agriculture and nutrition, was also no longer an option due to the limitations of supplies and cultures. The team was, however, provided with various plant seeds and fungal spores to aid in the crop production process.

Within a short time, the team's agricultural system underwent several iterations to sustain the community. Significant collaboration with several teams was necessary to establish parameters and a sustainable plan. As resources were limited, the team sought to convince others of its need to secure development materials and space. The team did secure a moderate area of space to grow crops and remediate regolith, but not the full area needed to convert resources into food, resulting in less than the required space to grow crops for the community.

As part of its paired-team challenge, the team located an ideal site for crop experimentation and production that was low in toxic substances and had a large presence of water ice. However, the Resources Development team claimed the same site's water ice to extract water resources. By a majority, the community voted for the Resources Development team to use the site. While this was initially seen as a loss for agricultural production, the team later designed a more ideal use of indoor space. Affirming the plans for indoor production, a sudden dust storm that isolated all teams highlighted the importance of comprehensive agricultural systems that feature temperature control and artificial lighting to maintain growth during such frequent and inclement weather.

Final Design

After much discussion, the team designed in-situ resource utilization as the most sustainable, long-term option to support the present and a future Martian community. Crop production would use natural regolith resources, but with necessary remediation to address its toxic concentration of perchlorates and heavy metals. To process the regolith into a usable growth media, the team proposed perchlorate salt removal *via* water dissolution, iron oxide removal *via* electro-magnet, and aluminum oxide removal *via* fungi metabolism.

Within the community greenhouse module that consisted of two repurposed Starship fuel tanks, the team was designated two 9m x 9m x 9m structures; just less than the minimum area needed to grow enough community food for a year. To always ensure requisite levels of available resources and nutrients, crops would grow in rotation; one structure to remediate and prepare the regolith, while crops grew in the other. The team established that per day, each community member would need approximately 101g of protein, 350g of carbohydrates, 90g of lipids, and 1.2 Kg of food, with an estimated total of 2,700 kcal. These estimates projected a daily required consumption, per person, of 2.5 servings of vegetables, 2 servings of fruits, and 6 servings of grains. By consultation with the other teams regarding meal options and personal preferences, the selected crops were aligned with NASA recommendations, including: alfalfa, soybeans, strawberries, potatoes, lemon grass, lettuce, cabbage, peppers, arugula, basil, spinach, beets, peas, broccoli, carrots, and kale. In addition, oyster mushrooms were added for nutrition and as a means for regolith remediation.

Like nutrition and consumption, food safety was of utmost importance. To address food safety concerns, seeds would be sterilized following NASA guidelines, plants to eat raw would be cleaned using sterile wipes, and all other foods would be cooked to eliminate food borne pathogens. For the long term, the team recommended that any resupply mission include supplies to construct hydroponic and aeroponic systems to both supplement existing agricultural systems and limit the burden of excess water usage and utilization.

Resources Development and Management Team[5]

Challenge

Design the community's supporting infrastructure and outline an operational plan for using and managing planetary resources based on anticipated availability, demand peaks, continuous requirements, and the time between replenishment of such consumables as water, oxygen, and energy, among others.

Ideation and Initial Design Direction

The team recognized early on that understanding how everything could work together was crucial to achieving its goals and the mission objective. For a closer examination of available resources and tools, the team researched the function of each cargo item instrument.

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[5] Resources Development and Management team participants include: Shirley Auxais, Levon Kirakosyan, Cindy Montgenie, Brian Nelson (Team Lead), and Carlos Tamayo.

Additionally recognizing the importance of teamwork and the need to support one another, team members selected a liaison to assist with determining the resources that could be released to other teams toward mission success, and to ensure smooth communication between teams. So that every team member contributed and was looped-in to stay informed, the team listed identified Earth Experts for consultation and carefully chose a rotation for who would participate in Earth Expert discussion and who would lead Mission Control updates. The team then focused on understanding the resources required to expand the community, delving into research to pinpoint exactly what was needed, such as water, iron, oxygen, and other resources.

Directional Pivots: Evolving Thought Processes and Work Iterations

The team identified some gaps and risks and operated under certain assumptions. Gaps included inaccurate sandstorm forecasting and insufficiently large tools to drill and extract material. Risks centered on solar power unreliability, and unsustainable resource consumption of existing rocket infrastructure. Operating assumptions included nuclear-powered Starships. While space-based power generation was considered, solar power was projected to fuel day-to-day activities from storage fuel cells harnessing hydrogen and oxygen from frozen water, and geothermal options were dismissed due to Mars' dead core. Prospective innovations included the manufacture of algae-based polymers for 3D-printed filament and converting water from a solid to gaseous phase through sublimation for purification and transport.

The team reached a breakthrough during its paired-team challenge when the scenario proved the value of the team's surveying instruments obtained through trade. Without a large water deposit, the community had only a slight chance of survival. The instruments were used to locate a large deposit of subsurface ice. If the ice consisted of frozen carbon dioxide, water, or ammonia, these could be detected and separated at the extraction point using gas chromatography and vapor diffusion. Absent information as to the presence of simple organic compounds in the ice deposit, the scenario confirmed the site to have a sufficient total mass to make harvesting worthwhile. Additionally, consultation with Earth Experts confirmed that deuterium and tritium are stable isotopes of hydrogen, making water an effective shielding material with only minimal risk of radioactivity. Recognizing the inherent risk of cosmic radiation to biology, humans, and plants the team made active or passive shielding a high priority.

The team quickly learned to alter course when unexpected weather conditions, audio disruptions, and emergencies delayed tasks when timely responses were needed. Such disruptions occurred while obtaining proper materials to gather and transport resources, the technical tools in the team spaceship, and an understanding of fuel cells as an alternative power source to generate energy. In response, the team proposed a town hall meeting, attended by all teams, to align efforts so that everyone was on the same page to ensure the community would “pass the test”.

Final Design

Solutions to harvest and refine water were more fully developed than for other resources due to time constraints created by unanticipated challenges. Collaboration with other teams discussed the use of ice for community needs as a building material and to create an ice highway transport system, with particular utility for habitat operations, habitat structures, and agriculture. Earth-established procedures to handle and recycle hydrogen, oxygen, carbon, and nitrogen are mostly replicable on Mars. At ambient Mars temperatures and pressures water can exist only in a solid or vapor state. The design to extract water from subsurface deposits was to collect vaporized solid ice above the surface as frost at the end of a tall vertical tube. The frost would be packed into solid blocks, ~1m^3. Blocks would slide to the habitat on a long sled track of regolith with frozen water as a binding agent, topped with a layer of smooth ice. The customizable path and degree of incline would transport large ice masses with relatively little energy. A lifting station of pulleys and ramps would lift blocks between slides to cover greater horizontal distance. For temporary routes or distances not warranting slide and ramp construction, a small robotic tractor would pull sleds along a smooth ice track. Once ice reached the habitat, it would be purified and liquefied indoors.

From an understanding that energy management on Mars can be accomplished with pumps, fluids, heat exchangers, and reservoirs, and that all refining processes depend upon reliable thermal and electrical energy sources, the team decided to rely upon modular micro fission reactors delivered on subsequent missions from Earth. Modular microreactors are proven to deliver up to 45 MW in a combination of thermal and electrical outputs. Inert gases were needed to maintain an artificial atmosphere close to 110 kPa within the habitat. As the habitat volume expanded above Starship volumes, a lower total pressure of ~75 kPa was maintained until nitrogen could be produced from decomposing solid waste. A composting bioreactor's decomposition of urine and feces waste from a diet of high protein food provisions produced residual nitrogen, providing nitrate-rich fertilizer to the Agriculture Team, supplementing the habitat's atmospheric pressure, and inflating the Habitat Operations habitat liners upon arrival.

The Life on Mars simulation underscored the team's commitment to innovation, resilience, and a collaborative spirit as it extracted valuable lessons in overcoming its challenges. Collaboration emerged as a pivotal element, emphasizing the importance of aligned and streamlined operations. Technical discoveries on other Starships proved instrumental, particularly to understand fuel cells for energy generation. The significance of timely emergency responses, careful distribution, and navigating human dynamics became apparent. The experience highlighted the need for continuous learning, adaptability, and a holistic approach to resource management, with lessons paving a way for future missions from a richer understanding of the inherent complexities of Mars inhabitation.

Structure and Suit Design Team[6]

Challenge

Design the community's habitat structures and protective suits, source their respective materials, and provide a visual representation of the habitat's structure and its relative location to other Mars community operations and facilities.

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[6] Structure and Suit Design team participants include: Lucas Alderette, Joshua Habka, Kristin Petersen (Team Lead), Amber Rose Porteous, Mashfiqur Rahman, Alita Regi, and Abigail Threatt.

Ideation and Initial Design Direction

The team planned to create a sustainable modular system of habitat structures to maximize space while prioritizing a high degree of adaptability and ease of deployment and future repair. Thought processes went through multiple phases, each incorporating new usable structures. Phase 1 designed a trench system to safely travel between Starship structures. Phase 2 designed a trench cover. Phase 3 designed pressurization of the trenches. Each phase designed an additional layer of protection from the environment while being used by the community throughout all phases.

The team focused suit design on community needs, dust mitigation, and repairability, including the pressurization and protection ("pressure vessel" and "fabric exterior") layers. A discussion of specialty requirements with other teams identified available planetary resources for adaptive use. The team considered future advances in silica-to-silicone production for use in the pressure vessel layer. For the fabric exterior layer, near term processing implied the production of basalt-to-basalt fibers. Though silica and basalt processing were not available at the landing site, if suits already had aspects of those materials incorporated into them, fewer design adaptations would be necessary for the additional modular components once processing became available.

For ease and continuity of ideas throughout the design process, the team assigned a liaison to work with each other team. Teams communicated by directly visiting other team habitats, or by two-way radio. Additionally, the team created a structure and suit design requirements questionnaire that was delivered to the other teams. Based on responses and feedback, aspects of the initial habitat modularity design were approved or revised, with a majority of the initial design being revised to better align with community needs.

Directional Pivots: Evolving Thought Processes and Work Iterations

On the second day of planning the team undertook a major pivot when it realized that aside from the cargo items, no supplies were brought to Mars. In response, the team made iterative redesign changes to habitat structure materials as well as to suit capabilities. From speaking with Earth Expert, David Cheuvront, the team pivoted from a highly manufactured structure design, to using available planetary materials. This idea was sparked by a reminder from Mr. Cheuvront that simple can still be durable, while discussing ancient architecture and building methods.

Initially suits would be solely focused on scientific technological capabilities. From a Mission Control check-in, however, suits were redesigned after realizing they could also offer mental and emotional well-being support functions. The redesign included a haptic layer allowing one to essentially "receive a hug" from a family member. This was shared with the community and received high approval. The dust storm challenge initiated another design pivot to factor in additional suit and structure dust prevention and mitigation measures.

Final Design

Agreement on the final base structure layout was reached through consultation with the Habitat Operations team, Nutrition and Agriculture team, and Earth Expert, Parks Easter. Each Starship would land horizontally and be moved to surround a central Community Hall. Each Starship itself would provide main living quarters with their fuel tanks removed to use for supply storage, maintenance, and agricultural operations. Barriers would be constructed using planetary resources, such as clay and regolith to aid shielding from radiation and the environment. Six separate sectors would be created from the layout with a tunnel system designed to connect each sector over time, beginning during Phase 1.

In Phase 2, the base's final form would begin construction and primary operations would be relocated underground. With new equipment delivered by a resupply mission, the team would be able to dig 1-2 meters underground for better radiation protection and to erect inflatable module structures for use as living and working quarters. These could be connected to create greater square footage for Agricultural use.

Agreement was reached on suit functionality through consultation with the Health and Safety team, the Human Services and Recreation team, and Earth Expert, Miroslav Rozloznik. Mission Phase 1 would be based on standard Earth design assumptions for living and working on Mars in 2049. Because suits are vital whenever outside of a habitat, they need to be robust enough to last until Mission Phase 2 since the cargo item suit repair and functionality resources were scarce. Phase 2 suit design would identify technical and practical functionality gaps informed by community activities and incorporate advanced modular features of various tools and attachments to improve life on Mars. The team's final design reflected a highly modular suit with the following layers:

> **Layer 1**: *BH (BioHarness) Layer* – a shirt-like smart garment housing monitoring devices, communications, and emergency response equipment for daily wear.
>
> **Layer 2**: *IHA (Intra Habitat Activity) Layer* – a lightweight suit to be worn during activities inside the habitat where/when depressurization or other emergencies are reasonably feasible, including work on habitat/vessel hull structures. The IHA layer is worn over and utilizes features of BH layer.
>
> **Layer 3**: *EHA (Extra Habitat Activity) Layer* – a layer for Mars surface activity worn over and utilizing features of the IHA layer.

Conclusion

From a direct contributing-participant perspective, this white paper presented a narrative synthesis of team thought processes, pivots, work iterations, and final designs, recounting their culminating team-based and collective mission achievements. What is substantively clear from the collective perspective of participants is that over time teams experienced a need to pivot from an initial approach towards achievement through team individualism, to an embrace of cooperative and collective means to both individual team and mission success. The impetus for pivots in team perspectives, iterative work processes, and outcomes is generally identified across teams as resulting from the unexpected challenges they had to resolve, learning about other team plans and designs, researching and using cargo items, and consulting with others, including Earth Experts. Each team's actual findings, solutions, and outcomes were the product of such identifiable key words as: innovation, ingenuity, ethics, efficiency, sustainability, scalability, collaboration, iterations, risks, gaps, teamwork, agreement, consultation, and voting, among others. And in the end, in these ways, the six teams successfully achieved the mission objective to design a self-sustaining permanent first community on Mars.

From the perspective of Space Commerce Institute, the *Life on Mars* habitat simulation exceeded expectations. Participants ranging in age from college students to retirees attended from multiple countries, several states, and from all walks of life to join in a collective mission. Some arrived questioning whether they truly belonged. Others were eagerly costumed with anticipation of role-playing the part. All were engaged throughout the three days by the high expectations that were established from the outset, the sensorial physical environment that was tailored for their experience, the realistic gamification of collaborative problem-solving using cargo items, and the challenge of resolving unexpected events as they occurred in real time.

As the frequency and scope of real-time challenges presented opportunities for teams to rely upon each other for success, what was first perceived by teams as an exercise of individual team effort pivoted to become a cooperative and collective approach toward achieving team and mission objectives. Through this collaborative approach, individuals clearly found a meaningful role and contribution of their own voice to self-validate their participation. As teams consulted with available experts their initial ideas and design directions altered course in response, iterating several times throughout, sometimes affecting multiple team designs as a result. It was not long before each of the six teams had coalesced together to become a single community to be venerated as “Audacity” and with the needs of all reflected in final designs. Affirmed by NASA and industry expert judges as achieving team and mission objectives to successfully sustain life on Mars, in the words of Habitat Operations Team Lead, Terry Trevino, “It was a team effort, and still can’t get past how we planned something that might actually work!!” Congratulations Audacity.

Appendix A

Habitat Operations Team Visuals

Images used during team ideation.

The team originally submitted this layout to the community for review. It uses horizontally-landed Starships as an operations center and habitat operations for the landing party.

Figure 1. Solar Farm

Figure 2. Team Consensus Habitat Design

Figure 3. Central Communications Operations

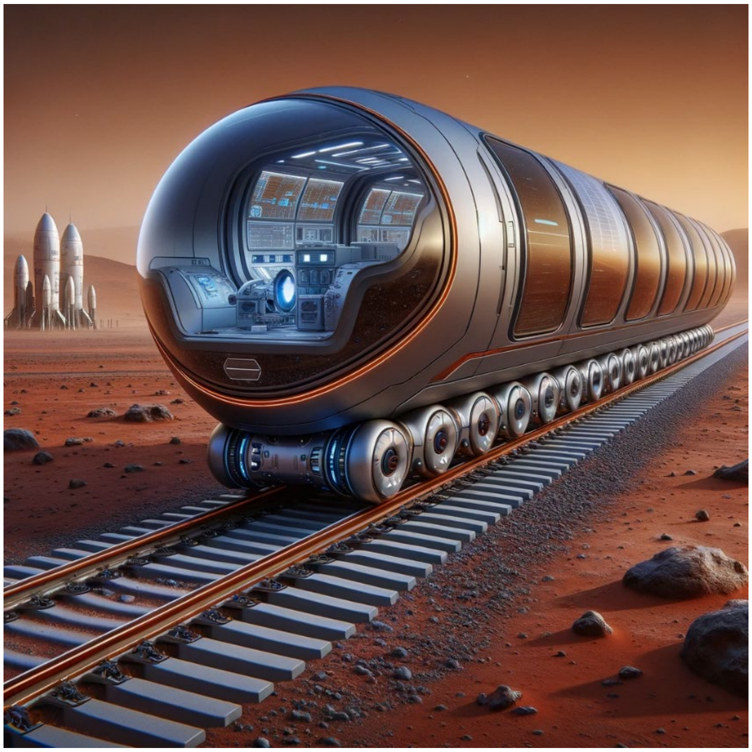

Figure 4. Proposed Pressurized Rail System

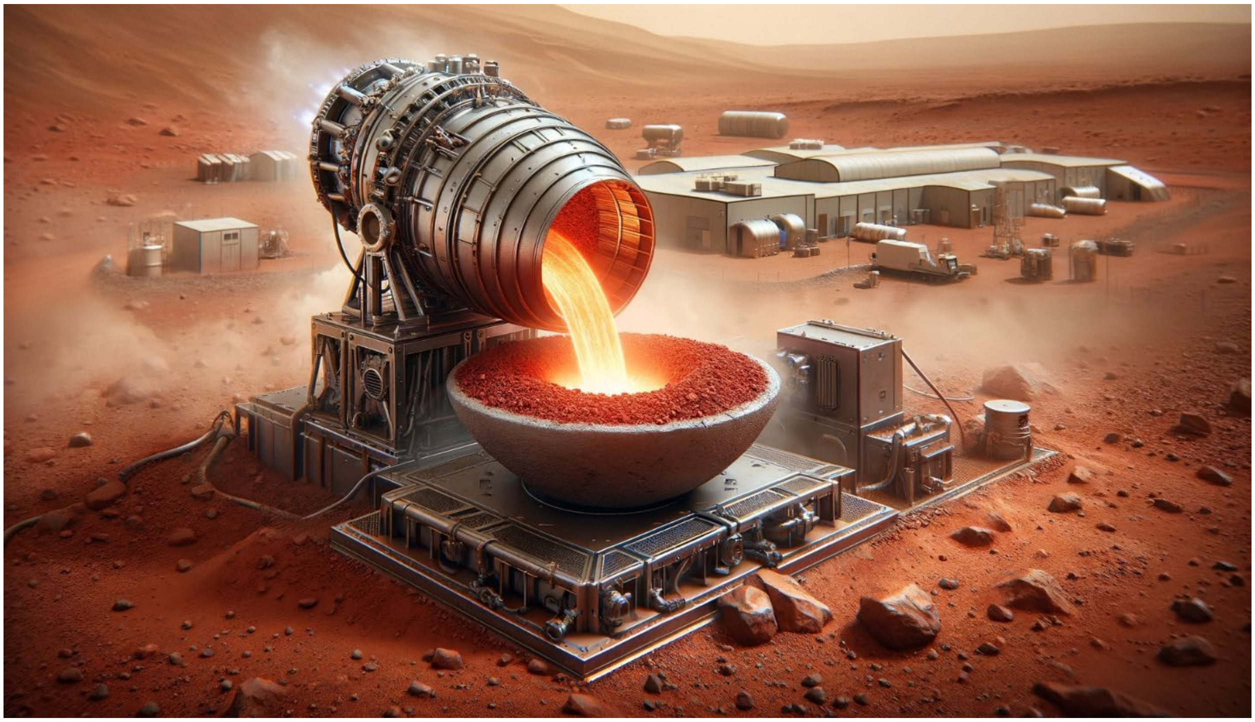

Image References: ChatGPT with DALL·E (OpenAI). (2024). "Life on Mars" [All Digital images generated by AI].

Authors: Habitat Operations Team (Nicolo Pinzan, Arijit Sengupta, Kristiyan Stefanov, Dani Payan and Terry Trevino)

Appendix B

Human Services and Recreation Team Visuals

Figure 1. Initial Team Cargo Item Cards

Figure 2. Final Team Cargo Item Cards

Appendix C

Structure and Suit Design Team Visuals

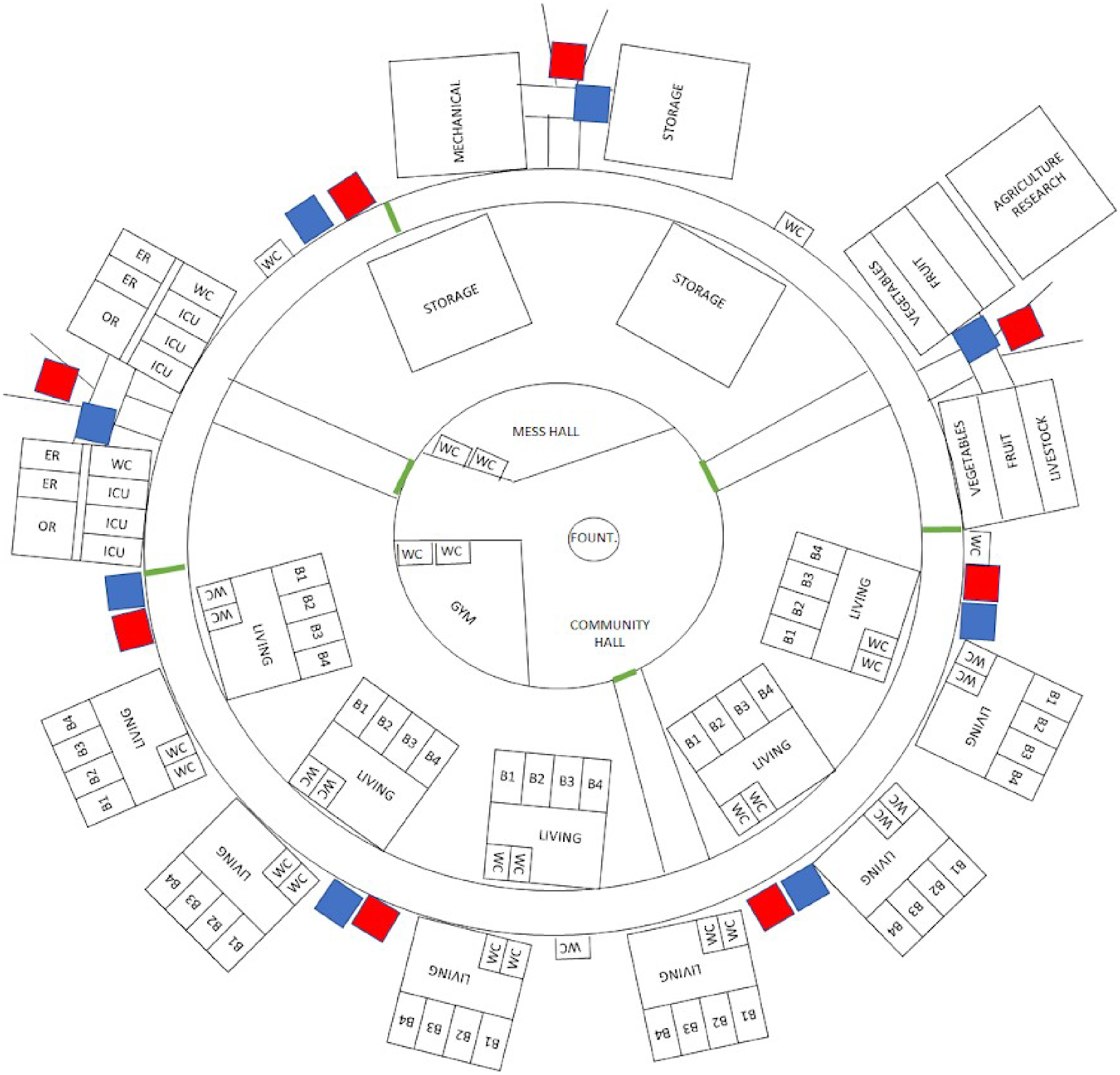

Figure 1. Floor Plan

Figure 2. Proposed Agriculture Wing

Figure 3. Proposed Medical Wing

Figure 4. Proposed Resources, Operations, and Maintenance Wing