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ANALOG SPACE MISSIONS

PART 2

NOTES FROM THE CEO

PART TWO: ASTROSOCIOLOGICAL BENEFITS OF ANALOG SPACE MISSIONS



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FOUNDER OF ASTROSOCIOLOGY & THE ASTROSOCIOLOGY RESEARCH INSTITUTE

"...a radical reframing: the integration of Astrosociology into STEM frameworks not as a complementary add-on, but as a foundational engineering discipline. We must move beyond asking how to keep crews alive and begin asking how to help them thrive as complex social systems in the most extreme environment humanity has ever faced" - Albino Civitillo

Prologue

Astrosociology belongs in the analog space habitat for a myriad of reasons. Part Two provides additional reasons why this is true while bringing into the conversation some of the important quotations from Part One because they add important reminders about the importance of analog astronauts. It is important to include the voices of the authors from Part One who found it important to move this narrative forward in both parts of this series as humankind moves ever closer to migrating into space beyond current actions.

> *"Our authors [in Part One and now in Part Two] bring perspectives from sociology, psychology, the arts, and the humanities – and in doing so, they remind us that no single discipline holds all the answers. The future of human spaceflight will be built not in just in laboratories and launch facilities, but in the conversations, we have across disciplinary boundaries" (Parkinson, 2026, p. 6).*

These two issues demonstrate how and why the voices of analog astronauts must not be silenced because what they have to teach us affects those who venture into space and those on Earth.

Introduction

"Astrosociology in the analog space habitat" can be defined as the integration of the social, cultural, and behavioral patterns related to the simulation of issues pertinent to living beyond Earth. "By bridging astrosociological perspectives to the forefront of analog mission research, we ensure that future space endeavors are designed not just for human survival but for human flourishing." (Richard, 2026, p. 21). The astrosociological approach provides attention to the human dimension that contributes to the STEM approach by integrating sociocultural and psychological factors among other social-scientific variables to the physical-oriented approach so that more holistic outcomes can be achieved by converging the social sciences with the traditional physical and engineering concerns, as the such outcomes are not possible with the convergence of the social and physical sciences (Pass and Harrison, 2014).

Astrosociology represents a key academic field that seeks to bring together those working and interested in the social and behavioral sciences, humanities, and arts. A key to its growth lies in bringing in students, perhaps especially those who served as analog astronauts, as they can provide first-hand knowledge based on their personal experiences including the behavioral patterns involving interactions with their crew members. While other students cannot provide their own beneficial experiences, they can benefit from analog astronauts' first-hand knowledge that cannot otherwise be found in the classroom.

Every aspect related to space exploration exists as integrated into humankind's very existence. This reality has increased in slow downs and spurts ever since Sputnik launched successfully into Earth orbit. The STEM-related fields and disciplines took the lead in education and research from the very start. However, the impacts of outer space on the lives of humans and their societies ever since this groundbreaking moment in history have become increasingly evident that they are necessary, but not sufficient. The social and behavioral sciences, humanities, and arts demonstrated that the other branch of science is also necessary. Humans venturing into space since the Soviet and American race to the Moon reach orbit today represent the obvious examples even while humans living and working on Earth also became affected socially, culturally, psychologically, and in a myriad of other ways along the way to not only the present day, but also guiding humankind into the future.

The Two Branches of Science

Analog space missions continue to provide evidence that the two branches of science must increase their collaborative communication and increased convergence (Pass and Harrison, 2014) in order to truly develop understandings related to what issues are vital to sustainable space settlements of every size from Moon bases, to communities, to space societies. Interestingly, neither the social scientists through their failure to participate in adequate numbers nor the STEM-related engineers and scientists through their failure to adequately accept the social sciences have continued to perpetuate a status quo that will undoubtedly result in hardships and perhaps total failures of social life beyond Earth. This type of outcome can easily produce negative repercussions without a new unique approach that does not exist to the extent necessary for ultimate success.

An increased focus on generating empirical astrosociological research findings is sorely needed and beneficial from an astrosociological perspective in order to enhance those that STEM-related researchers focus upon.

> *"The historical narrative of space exploration has been dominated by technocratic values such as efficiency, conquest, and innovation, as progress. However, these frameworks fail to also account for the cultural and ethical entanglements of the space frontier. Astrosociology can correct this imbalance by embedding interdisciplinary expertise from: anthropologists, artists, sociologists, and ethicists; into analog missions from the start" (Trinidad and Shah, 2026a, p. 27).*

The collaboration between the social and physical branches of science can best produce the most holistic and therefore the greatest understanding of the issues that astronauts will face. Analog astronauts can produce the data that will ensure that success and sustainability of future bases and settlements to the highest degree possible. This is possible, of course, if the convergence of the two branches results in a new status quo that incorporates all of the necessary variables into research, education, and practice.

The Status Quo

The social sciences exist in terrestrial settings and societies to better understand human behavior as it impacts intimate, group, economic, psychological, cultural, organizational, and international levels of analysis because complexities exist that cannot fully be explained by rocket science or habitat maintenance as two important areas of concern.

> *"Humanity's return to the Moon and its aspirations toward Mars highlight a reality often overshadowed by engineering achievements: space exploration is also a human and social project." (Cinelli, 2026, p. 34).*

Human behavioral patterns in space habitats will become similar, but they will also produce new and unexpected psychosocial and cultural realities that result in space-based situations in which a person cannot even walk outside a habitat or escape outside a spacecraft without life-saving equipment, whether a space suit or some sort of transportation on the surface.

Analog space missions must break free of the existing status quo so that social scientists become accepted participants in analog space missions on a level as equal to STEM researchers and practitioners as possible. The required impact will never come to pass when social scientists conduct research mostly alone without a substantial interaction with those linked more integrated into the space community.

> *"By facilitating the pooling of complex, specialized datasets from around the world, HIBERIA [the Hibernation Intelligence Base for Education Research & International Alliance project] aims to accelerate the TRL, allowing a geographically dispersed community of analog managers, physicians, and astrosociologists to function as a unified global research team" (Kostioukhina et al., 2026, p. 41).*

Education of social scientists in astrosociology classrooms is required, which means that the astrosociological frontier -- which represents the lack of astrosociology in academia – needs to be settled in classrooms throughout society in both the social and physical science curricula, including those that cross pollinate between the two. Integrating astrosociology more fully into space habitats remains vitally important, of course, although doing so into both STEM and social science classrooms to tie the two at a much more ultimate level must not be undervalued, as space impacts continue to increase wherever humans reside in our solar system.

Important Considerations and Questions

Thus, one consideration requires formal attention, not only as an isolated factor, but how well social-scientific inquiry is integrated into STEM-related foci. Important considerations and questions require immediate attention as the following examples illustrate. Determine how much social science is actually being accomplished, how well it is taken seriously, and to what degree it is valuable in the eyes of engineers and physical scientists. Here are some of the important questions to consider.

How well does it advance STEM research when both branches of science – that is, the social and the physical – become focused on the same set of problems to solve? What insights can social scientists contribute that exist beyond the physical realm yet prove to be vital for a holistic approach to understanding all of the variables that actually describe a complex set of issues and parameters? How can current analog space missions be restructured to the extent needed to reach a convergence at a level that will prove invaluable to future missions in which humans migrate from their home planet for even a short duration excursion?



made with A.I.

"In reflecting on how we will be good ancestors to the futures we are already shaping, we begin to understand the profound astrosociological truth of our time: that to reach for the stars responsibly, we must first learn to think across generations, cultures, and worlds" (Trinidad and Shah, 2026b, p. 28).

In what ways will the social sciences prove increasingly important the farther, more isolated, and longer distances away from Earth that human groups become as they continually transform themselves? How accurately can analog astronauts predict accurately the behaviors and social structures that those beyond Earth produce without extensive input from the social sciences?

How well does crew selection take into account potential hardships related to inequality? Later on, how well do social interactions among crew members mitigate related social problems in the midst of conflict? How are other forms of social problems that present themselves addressed and what can be learned from them? Social structures that can result in social class, stratification, racial, ethnic, cultural, and other distinctions among crew members can escalate over time into social problems that can affect sustainability of the settlement over time. Role differentiation is impossible to eliminate, so it is important to study its effects as sociocultural patterns evolve over time. Simulations that encourage analog astronauts to talk about their differences while interacting can produce data that will become helpful for those who venture into space.

The length of the analog space mission will determine what types of outcomes will be produced. Longer missions will more likely produce more social problems, health concerns, and more negative crew member interactions such as stress, conflict, and behavioral patterns that fail to support mission objectives.

> *"As we advance toward long-duration missions to the Moon and Mars, understanding the social dynamics of both flight crews and ground support teams becomes absolutely critical. This is precisely where astrosociology proves its indispensable value, and analog space missions provide the ideal laboratory for this emerging field" (Mukherjee, 2026, p. 45).*

Such interactions already provide with crews in Earth orbit. However, when the distance from Earth creates greater hardships such as those related to communication, especially when emergencies develop, then astrosociologists among those in the settlement must be there to contribute to the solutions along with their STEM-oriented citizens. How likely will they actually be there, though? Will AI interfaces alone be adequate to provide therapeutic interactions? Is it a good idea to find out only when astrosociologists remain on Earth without the ability to communicate with space settlement citizens who live too far away?



Sociocultural support, psychological analysis, and collective coping strategies must be identified and studied beyond simply documenting them. Only then, will the benefits of astrosociological knowledge become adequately recognized. The crew members need to discuss them when they become necessary so that future analog missions can take advantage of them, not to mention for those settlers who establish space bases and settlements in the future.

A Pertinent Example

Consider this example... Lunar and Martian soil and dust are toxic with perchlorates among other harmful characteristics to humans and can produce illnesses such as lung cancer, which would require both space medicine and medical astrosociology to interact by integrated both biomedical and psychocultural elements into treating patients in social settings that are characterized by isolation, confinement, limited resources, religious factors, and other non-medical variables that are common even in terrestrial hospitals. Food grown in these soils would also make any plants grown there toxic as well. These toxic compounds are rare on Earth, but they can be simulated so as to design testbeds for finding reasonable solutions. Will those in charge take this route or perhaps disregard this approach to save resources before launching into space? Can analog astronauts prove definitively that taking shortcuts to lesson the weight of a rocket is worth it in the long run? Compromises between social and physical requirements must be made on a continual basis, and therefore in the forefront of ongoing decision making.

Conclusions

The social and behavioral sciences, humanities, and arts largely remain outside of the current education and research dialogs within even the international status quo. While they have increased their penetration into analog space mission planning and architecture, the two issues in this series demonstrate that much more needs to be accomplished. Setting a reasonable groundwork for future astronauts is more complex than many may have expected before delving into this particular area of research.

> *"The integration of Astrosociology into STEM frameworks is not just about improving analog missions. It is about preparing for a new era of space exploration. An era in which humans do not just visit space but an era where they live there, they build communities, and they create new societies" (Civitillo, 2026:5)*

Part Two of this short Analog Space Missions series proves that while not all those in the STEM disciplines and fields can envision why astrosociology in the analog space habitat is necessary along with the engineers and physical sciences, it is clear that a growing number of both the social scientists and physical scientists who study space issues represents a growing trend.

> *"Functional hardware alone does not result in a functional society. The human dimension, which involves social interactions and reactions to living conditions, is just as important on a medium and long-term basis" (Pass, 2023, p. 11).*

Therefore, rocket science and human science can, and must, get along much better on Earth and definitely beyond Earth. It should never have been a contest, but the two branches of science must increase the current status into an innovative truly formal collaborative relationship!

Enjoy these fascinating articles and don't forget to check out Part One if you haven't already. 😊

Dr Jim Pass

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References

Cinelli, Ilaria (2026). Analog Space Missions: Part One. URL: https://www.astrosociology.org/Library/PDF/Forum/Astrosociological-Insights-Forum_Volume-10_Issue-1_Spring2026.pdf.

Civitillo, Albino (July 18, 2026). "The Human Equation in Deep Space: Integrating Astrosociology into STEM Analog Frameworks" Available at SSRN: https://ssrn.com/abstract=7544526 or http://dx.doi.org/10.2139/ssrn.7544526.

Kostioukhina, Ekaterina, Do Carmo, Veronica, Flickinger, Katharyn L., and Shekhar Peri, Raj (2026). Analog Space Missions: Part One. URL: https://www.astrosociology.org/Library/PDF/Forum/Astrosociological-Insights-Forum_Volume-10_Issue-1_Spring2026.pdf.

Mukherjee, Sumana (2026). Analog Space Missions: Part One. URL: https://www.astrosociology.org/Library/PDF/Forum/Astrosociological-Insights-Forum_Volume-10_Issue-1_Spring2026.pdf.

Parkinson, Mia Belle (2026). Analog Space Missions: Part One. URL: https://www.astrosociology.org/Library/PDF/Forum/Astrosociological-Insights-Forum_Volume-10_Issue-1_Spring2026.pdf.

Pass, Jim (2023). "Astrosociology on Mars." Chapter in Mars Exploration - A Step Forward. Publisher: Intech Open. URL: https://www.astrosociology.org/Library/PDF/JPass_AstrosociologyOnMarsChapter.pdf.

Pass, Jim, and Harrison, Albert A. (2014). "Astrosociology (Social Science of Space Exploration." Handbook of Science and Technology Convergence. Springer International Publishing, Switzerland.

Richard, Clara (2026). Analog Space Missions: Part One. URL: https://www.astrosociology.org/Library/PDF/Forum/Astrosociological-Insights-Forum_Volume-10_Issue-1_Spring2026.pdf.

Trinidad, Brenda, and Shah, Nevin, N. (2026). Analog Space Missions: Part One. URL: https://www.astrosociology.org/Library/PDF/Forum/Astrosociological-Insights-Forum_Volume-10_Issue-1_Spring2026.pdf.

FROM THE EDITOR

When we think about analogue missions, or even real ones, we tend to focus on the faces of them: the brave astronauts. They are without a doubt a vital part of any mission, but we often overlook the teams of people who make them possible. Every mission begins as an idea, one that takes shape through the perspectives and contributions of many. As we imagine humans living permanently in orbit or on other worlds, we must consider the importance of astrosociology alongside many other disciplines.

This issue continues that conversation with insights from analogue astronauts, lawyers, engineers, scientists, writers and artists, each bringing their own experience, knowledge and research. One of my favourite things about astrosociology is its universality (literally), and our authors represent it perfectly. Any upcoming mission to make humans interplanetary will have to address challenging living conditions, group dynamics, legal questions and sociological impacts long before astronauts fly or settlements are built.

Analogue missions are such a crucial part of astrosociology that the subject demanded a second issue. It has been an honour to read each submission and curate this collection for those curious about the topic. I hope you enjoy every article, and every author, each different from the last, and see in them a shared aim: a better future for those who will one day live among the stars.



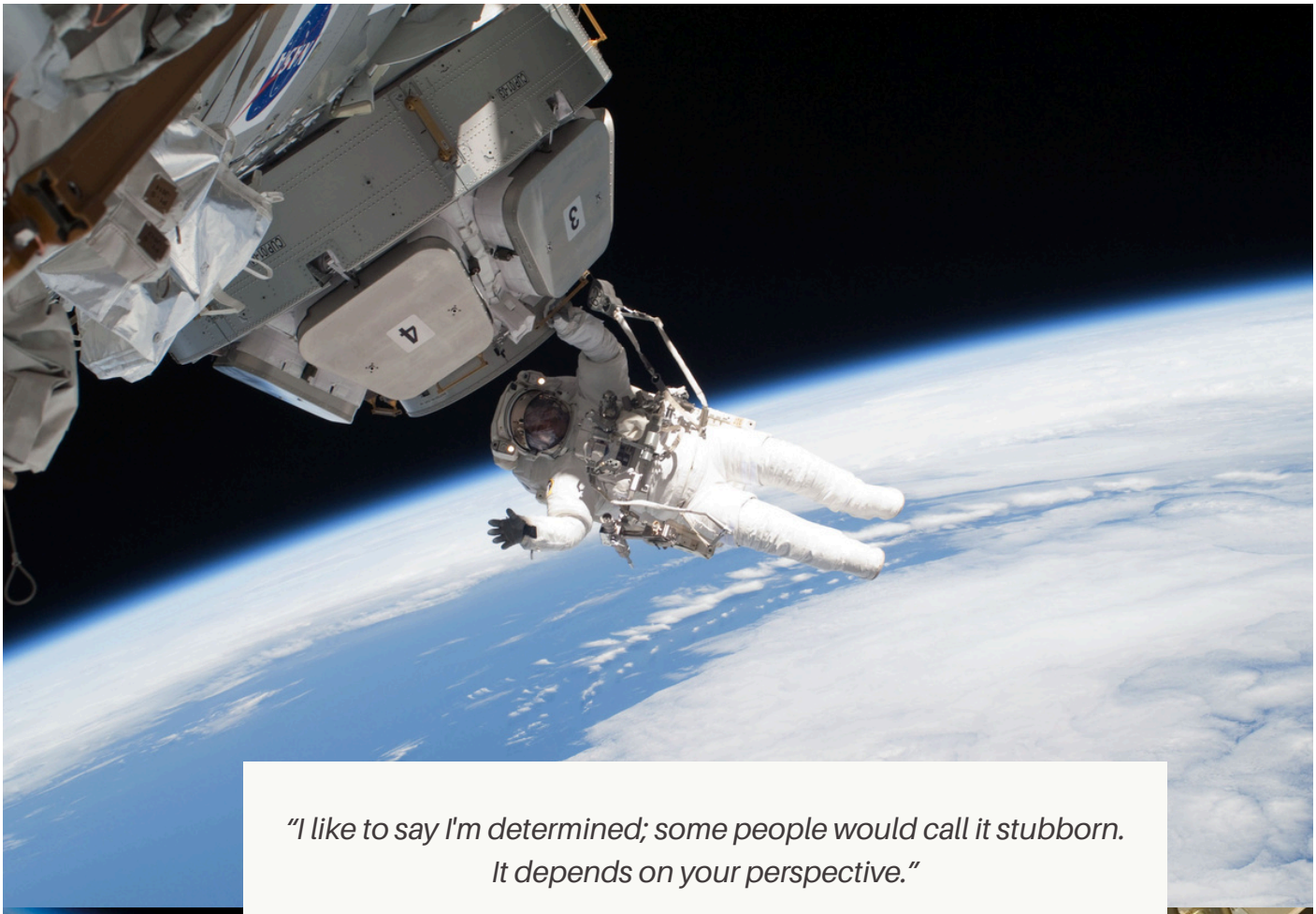
With warmth and curiosity,

Mia Belle Parkinson

EDITOR IN CHIEF

ASTROBIOLOGIST & SCIENCE COMMUNICATOR

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THE UNIVERSITY OF EDINBURGH



"I like to say I'm determined; some people would call it stubborn. It depends on your perspective."

— ***Peggy Whitson***
NASA astronaut and biochemist



A BRIEF STATEMENT



KEILY CRUZ
INTELLIGENCE & CRIME ANALYSIS STUDENT WITH A CYBERSECURITY FOCUS AND ALUMNI OF NASA L'SPACE AND THE BARBOZA SPACE PROGRAM

As we strive forward to explore the curiosities of space and its discoveries, we must first understand the complexity that comes along with it. Analog space missions are crucial when preparing for the next big space exploration. These space missions provide a simulated and structured environment in which analog astronauts train and perform simulated scenarios that will test physical endurance and operational skills. In these controlled environments, scientists, engineers, and social researchers can study the human experience of space long before it becomes a lived reality.

By supporting analog space missions, we create a safe and controlled environment to fully grasp how humans can adapt, live, and work in space-like conditions. Analog space missions allow us to examine the psychological, social, and cultural challenges that crews may face in analog environments. This allows the crew to build critical experience well before those challenges escalate into life-threatening situations. By investing in these missions, we strengthen the human side of exploration, ensuring that astronauts are prepared, experienced, and capable of adapting as we advance toward more ambitious space missions. This topic relates to my work and broader interests because of my involvement in the NASA L'SPACE Program, specifically the Mission Concept Academy (MCA) and the NASA Proposal Writing and Evaluation Experience (NPWEE) as well as the Barboza Space Program. These programs strengthened my passion for space exploration and opened the door to immersive, one-of-a-kind opportunities.

Through them, I gained hands-on experience designing mission concepts based on planetary environments, learning how to write NASA-style proposals, and working effectively in collaborative, mission-driven teams. This background connects directly to analog space missions because the skills I developed mirror the ones astronauts depend on when training in simulated environments. Astrosociology brings the human side into space research by focusing on how people behave, communicate, and work together during missions. By adding this human perspective, it helps researchers understand decision-making, stress, teamwork, and group dynamics in ways that engineering and physical science alone cannot. Instead of looking only at the engineering aspect, it shows how teams function, adapt, and maintain performance in challenging mission environments. Further development of astrosociology in analog space missions requires stronger integration of social-science perspectives into mission planning and crew training.

Astrosociology is essential to the work of analog space missions. In analog missions, astrosociology ensures we are not only preparing the technology for space, but also preparing the people who will rely on it. Without astrosociology, analog space missions would overlook the human aspect of exploration, focusing entirely on engineering, technology, and physical performance, while ignoring how crews communicate, handle stress, and adapt to isolation. We cannot fully prepare for space missions without assessing human behavior first. You cannot send humans into space without understanding the social and behavioral dynamics that allow a crew to function. As space exploration continues to evolve, the importance of understanding the human dimension becomes ever more urgent. Analog missions and astrosociology together reminds us that every advancement in spaceflight depends on the people who carry it forward. My experiences in the L'SPACE Program and the Barboza Space Program have shown me firsthand how essential it is to consider both the scientific and human sides of mission design. In the end, the success of space exploration will not be measured by the worlds we reach, but by how well we prepare the humans who dare to leave this one.



THE CREW IS THE SYSTEM: AN AEROSPACE ENGINEER'S CASE FOR ASTROSOCIOLOGY IN ANALOG SPACE MISSIONS



CALEB STROM
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My days are spent on a narrow and unforgiving problem: how to make a spacecraft do exactly what it is told. As a doctoral researcher in guidance, navigation, and control, I write the control laws that let one vehicle approach and capture another in orbit, rotating targets, uncooperative geometries, the kind of maneuver where a few degrees of error end a mission. It is work that rewards precision and punishes sentiment. So, it has surprised me, over the past few years, to find my attention drifting from the hardware to the human beings who will live inside it. I have never been on an analog space mission (yet). I intend to undertake my first in 2027. I write this, then, not as a returning analog astronaut with a diary of hard-won lessons, but from the threshold, the vantage point just before the habitat door closes, when one's own assumptions are still visible. And the assumption I most want to examine is the one I was trained into: that the human dimension of spaceflight is somebody else's department.

What We Are Really Rehearsing

We tend to describe analog missions in technical terms, testing equipment, validating procedures, characterizing habitats. That description is true and incomplete. An analog mission is, above all, a society compressed into a small volume: a handful of people who must sleep, eat, work, disagree, and improvise together, cut off from the world that normally absorbs their frictions. The Mars-500 study, run at Moscow's Institute of Biomedical Problems in 2010-2011, sealed six crewmembers in a 550-cubic-metre chamber for 520 days to simulate a round trip to Mars.[1] Its headline finding was that behavioral health (mood, motivation, sleep, the slow erosion of cohesion) is among the most serious and least tractable risks of long-duration spaceflight.

Read the records from the Antarctic stations, from HI-SEAS on the slopes of Mauna Loa, from NASA's HERA chamber and the Mars Desert Research Station in Utah, and the same pattern recurs.[2] Crews move through phases. They experience a well-documented "third-quarter phenomenon," a dip in morale that arrives once the novelty is gone and the end is not yet in sight, and which appears to be driven by psychosocial factors instead of by anything in the physical environment.[1]

[1] M. Basner et al., "Psychological and Behavioral Changes during Confinement in a 520-Day Simulated Interplanetary Mission to Mars," PLOS ONE 9, no. 3 (2014): e93298.
[2] Recurring psychosocial findings across isolated, confined, and extreme (ICE) environments, see the research conducted at the Mars Desert Research Station (Utah), the Hawai'i Space Exploration Analog and Simulation (HI-SEAS), NASA's Human Exploration Research Analog (HERA), and the Concordia and other Antarctic stations.

In other words, the subsystem that most reliably degrades under stress is the human one. We have built machines that can survive the journey. Whether the people inside them can survive each other is a separate question, and analog missions exist largely to ask it.

The Crew is a System, Too

Here is where my own discipline changed my mind. An engineer is taught to think in systems: states and inputs, feedback and disturbance, stability margins and failure modes. We do not ask whether a control loop "feels" stable; we model it, bound it, and test it to the edge. What analog missions show, with uncomfortable clarity, is that a crew is also a system in this exact sense. It has states (trust, morale, role clarity), inputs (workload, communication delay with the ground, leadership), disturbances (conflict, monotony, bad news from home), and failure modes that look a great deal like instability, small perturbations that amplify instead of damping out.

The mistake I was trained to make was to treat that human system as noise: real, perhaps, but outside the model, to be handled by someone with a different degree. The reframing I now accept is that the social sciences are doing for the crew precisely what control theory does for the spacecraft, building the models, identifying the parameters, and finding the stability margins of the human subsystem. This is the heart of what astrosociology, the field founded by Jim Pass in 2003 to study the "social, cultural, and behavioral patterns related to outer space,"[3] contributes to an analog mission. It is systems engineering applied to the part of the system that is made of people.

This also dissolves a false opposition. Astrosociology is sometimes received, in engineering rooms, as a competitor to STEM, softer, vaguer, less rigorous. Pass has argued the opposite: that the human dimension belongs inside the STEM model.[4] An analog mission is the clearest possible demonstration. The actigraphy that measures a crewmember's sleep and the questionnaire that measures conflict are gathering data of the same kind, for the same purpose, as the sensors logging power draw. To wall them off from one another is not rigor; it is an incomplete model.

Why The Human Dimension Has Been Undervalued

If this is so plain from inside a habitat, why has the social and behavioral side of spaceflight been so persistently underfunded? Part of the answer is historical. Space programs were built by engineers, organized around hardware milestones, and legitimized by the photogenic drama of launch. The human dimension is harder to quantify, slower to yield results, and far less likely to appear in a press release than a rocket clearing the tower.

[3] Jim Pass, "Inaugural Essay: The Definition and Relevance of Astrosociology in the Twenty-First Century (Part One: Definition, Theory, and Scope)" (Astrosociology Research Institute Virtual Library, 2004). Pass founded astrosociology in 2003 and coined the term "astrosocial phenomena."

[4] Jim Pass, "Enhancing Space Exploration by Adding Astrosociology to the STEM Model," AIAA SPACE 2007 Conference and Exposition, Long Beach, CA (2007).

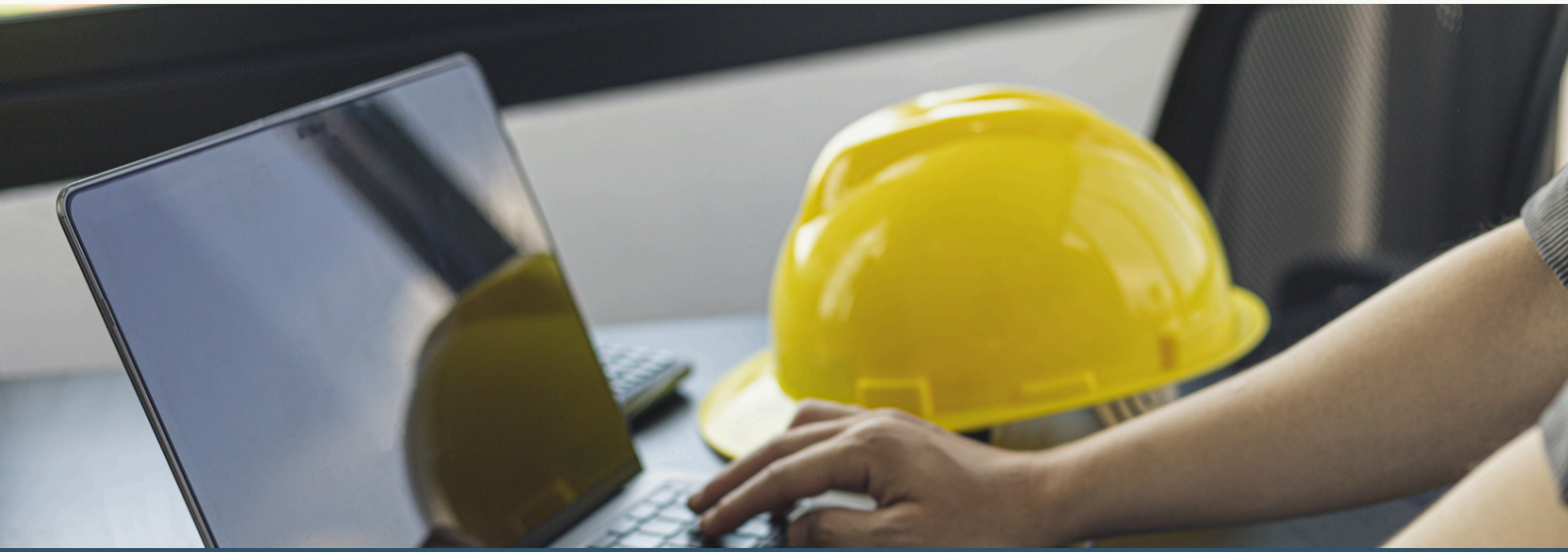
Who flies, and who rehearses, is an upstream question about whose assumptions get written into the template. Astrosociology has from its beginning insisted on asking who is chosen for missions, and for funding, and who is left behind.[7] An analog habitat is where that question stops being abstract.

Meaning is Load-Bearing

An analog habitat is also where the arts and humanities earn their place as load-bearing structure. Analog crews keep journals, make images, mark anniversaries, and invent small ceremonies to give shape to undifferentiated time. These are not indulgences; they are how human beings stay coherent in confinement, and the humanities are the disciplines that understand them. I am a pianist, and I already know which pieces I will want with me, because it is one of the oldest technologies we have for staying whole. A mission that plans its food and its oxygen but not its meaning has mis-specified the human system.

So, I will go into my first analog mission, when it comes, as an engineer, but I intend to go in also as a participant-observer of the human dimension, and to take the crew as seriously as I take the systems. That is the smaller resolution. The larger one is a request to the field I am joining: that analog programs deliberately recruit social scientists, humanists, and artists, and deliberately widen the geography and culture of the people who crew them; and that engineers like me stop outsourcing the human dimension to others and begin treating it as our problem too.

We are not only rehearsing how to keep people alive away from Earth. We are rehearsing who we will be when we get there and, because space reflects us back to ourselves, who we will be here at home as well. That is an astrosociological question at least as much as an engineering one. I would rather we got it right in a habitat in the desert than discover, too late and too far away, that we had instrumented everything except ourselves.



[7] Kathleen Toerpe, "Astrosociology: The Human Dimension of Outer Space," Centauri Dreams (2013). On the astrosociology of spaceports specifically, see Jim Pass and Albert A. Harrison, "From Airports to Spaceports: An Astrosociological Model of Social Change toward Spacefaring Societies," AIAA-2007-6067, AIAA SPACE 2007.

ORDER IN THE HABITAT: ASTROPRAESIDICS, CRIMINAL JUSTICE IN SPACE, AND THE ANALOG PROVING GROUND



TERRY R. WILLIS
INDEPENDENT SCHOLAR · ORIGINATOR OF ASTROPRAESIDICS, THE CRIMINAL-JUSTICE STUDY OF ORDER AND SECURITY IN HUMAN SPACEFLIGHT

Astrosociology asks us to take the human dimension of spaceflight as seriously as the engineering. One part of that dimension has gone almost entirely unexamined. What happens when someone aboard a spacecraft breaks the rules, endangers the crew, or has to be restrained? Who keeps order, and by what authority, in a sealed vehicle no one can leave and no outside police can reach? That is a criminal-justice question, and so far space has answered it only in the thinnest way. On the International Space Station a commander holds codified authority to keep order by any reasonable and necessary means. On a commercial suborbital flight no such figure exists at all, and the entire federal rule on in-cabin security amounts to two sentences. Between those poles sits an occupational territory no discipline has claimed. I want to give it a name: astropraesidics, from the Latin praesidium, the word for a guard or garrison. It names astrosociology's criminal-justice frontier: the study of how order is kept aboard human spaceflight, how entrants are screened and threats managed, and how a person is safeguarded, restrained when it comes to that, and finally handed on. My argument here is a narrow one. The analog space mission, the subject of this issue, is where a criminal justice fit for space has to be built and tested, long before the stakes turn irreversible.

Criminology has lately begun to look upward, asking how crime, justice, and order will travel beyond Earth.[1] That scholarship still lacks an operational core. It asks which court may prosecute, but not who prevents, restrains, or safeguards while the doors are closed. Space law answers the question after the fact. Astropraesidics is the in-situ criminal-justice function, the part that happens before a courtroom is ever reached. It is criminal justice reimagined for a place with none of the terrestrial apparatus. No responding officer to call. No jail, and no way to expel or remove anyone. That is why it cannot simply be carried up from Earth. It has to be worked out somewhere first, on the ground.

[1] Criminology has begun to look toward space. Eski, Y. (2025). "'Houston, we have a problem': The paucity and promise of an empirical space criminology." International Journal of Criminology, 12(1), 19–47. https://doi.org/10.18278/ijc.12.1.2 — argues for a proactive, "before-the-act" space criminology that anticipates space crime through tools including analog astronaut missions. Open-access author copy available via the Vrije Universiteit Amsterdam research repository (research.vu.nl).

A criminal-justice function with no laboratory

Astropraesidics begins from a simple observation: the protective function is practiced without being theorized. On the state side it takes what I call a sworn form: a commander vested with order-maintenance authority, an astronaut corps screened for years, a federal security architecture wrapped around the launch site. On the commercial side it must take a delegated form. A private operator cannot wield a state's police power, so its officer works on the model of the cruise-line security officer.

Authority is delegated from the vehicle's commander and the registry state, and it runs only until the ship returns and the offender is handed to the police on the ground. Two institutional forms, then, but one criminal-justice function. Someone has to screen who comes aboard, hold order once the doors close, and answer for a person in a vehicle no one can leave. The discipline's task is to treat those two forms as a single body of practice and to train for it on purpose, rather than leave it to whatever the commander improvises.

The function runs as a sequence across a mission. Screening and threat assessment come before flight. Order-maintenance presence carries through ascent and on orbit. A contingency calls for graduated, proportionate response. When the doors open on Earth, there is custody and handoff. Each phase is a competency, something that can be specified, taught, and assessed. But taught where? Knowledge that has never been rehearsed under realistic conditions is only a doctrine on paper, and that is the gap an analog mission can close.

The behavioral substrate is already the field's foundation

This is not a reach. The connection already sits in the field's foundations. One of the literatures astropraesidics leans on is the study of behavior in isolated, confined, and extreme environments: submarines, Antarctic stations, and the long-duration spaceflight analogs this issue celebrates. That work establishes something the protective function cannot do without. Interpersonal strain, the splitting of a crew into factions, a mid-mission slide in mood and cohesion — these are not flukes. They are what confinement reliably produces, and they show up even in the most rigorously screened professional crews.[2] HERA studies show sleep restriction in a confined habitat dulling cognition, and even the reading of a crewmate's face. HI-SEAS traces the biobehavioral signature of prolonged isolation, its worst effects clustering after the midpoint. Eight-month SIRIUS runs record how mind and body wear down under sealed conditions. And a systematic review of analog crews found that by roughly the forty-percent mark of a mission, every team studied had logged at least one conflict.[3] The analog record, in other words, already hands astropraesidics its risk model.

[2] Bell, S. T., Brown, S. G., & Mitchell, T. (2019). "What We Know About Team Dynamics for Long-Distance Space Missions: A Systematic Review of Analog Research." Frontiers in Psychology, 10, 811. https://doi.org/10.3389/fpsyg.2019.00811 (open access, CC BY). On strain, conflict, and the mid-mission decline in mood and cohesion documented even among rigorously selected crews: the review finds that by roughly 40% of mission completion, every analog team studied reported at least one conflict.

But a risk model is not a practice. The behavioral sciences characterize when and how order breaks down. They do not supply the response that manages the breakdown once it starts. So far the analog literature has given the field its substrate and stopped there, short of the practice that substrate calls for. That is exactly the line an analog mission could cross.

From substrate to proving ground

So here is the move. Treat the analog habitat not just as an instrument for measuring behavioral risk, but as the laboratory where this criminal-justice function gets developed, tested, and taught. A habitat offers what no real flight and no thought experiment can: a sealed environment at genuine psychological fidelity, where the four phases can be run, can fail, and can be rebuilt with nothing irreversible at stake. Criminologists have begun to read analog environments as a preview of how order and justice will behave off-world. If they are right, the analog mission is more than a window onto that future. It is the workshop where the response to it can be built.

Consider each phase in an analog setting. Screening and threat assessment can be validated against what a rotation actually produces. Do the instruments that flag behavioral risk predict the friction that surfaces by week six? Order-maintenance presence, the monitoring and quiet de-escalation of trouble, can be watched as it actually unfolds among people who cannot walk away from one another. Graduated response, the hardest phase to study anywhere, can be rehearsed against scripted trouble: a crew member who turns dangerous, a quarrel that will not resolve, a controlled item that goes missing. Afterward the crew gets debriefed instead of endangered. And custody and handoff, the documented transfer of a detained person and the record of an incident to whoever receives them, can be practiced end to end, evidence discipline and all, exactly as a distant jurisdiction will one day demand.

The habitat can model both regimes, and the seam between them, where the problem gets sharpest. Run one rotation under a sworn commander's authority and another under a delegated, cruise-line-style officer, and you can compare how well each holds order without giving up fairness. You can even rehearse the handoff that increasingly defines real missions: a screened crew member crossing from one authority regime to another partway through. That seam may be the single strongest reason the discipline needs to exist. On a real flight none of it can be tried without accepting the very risk the discipline is meant to prevent. In the desert, on the seafloor, or on a sealed mountainside, all of it can.

[3] Open-access analog and confinement studies. Nasrini, J., Hermosillo, E., Dinges, D. F., Moore, T. M., Gur, R. C., & Basner, M. (2020). "Cognitive Performance During Confinement and Sleep Restriction in NASA's Human Exploration Research Analog (HERA)." Frontiers in Physiology, 11, 394. https://doi.org/10.3389/fphys.2020.00394. Dunn Rosenberg, J., Jannasch, A., Binsted, K., & Landry, S. (2022). "Biobehavioral and Psychosocial Stress Changes During Three 8–12 Month Spaceflight Analog Missions with Mars-like Conditions of Isolation and Confinement" (HI-SEAS). Frontiers in Physiology, 13, 898841. https://doi.org/10.3389/fphys.2022.898841. Elmoselhi, A. B., Shankhwar, V., Qaisar, R., Hamoudi, R., Brix, B., Salon, A., & Goswami, N. (2024). "Retinal Vascular Changes and Arterial Stiffness During 8-Month Isolation and Confinement: The SIRIUS-21 Space Analog Mission." Frontiers in Physiology, 15, 1374309. https://doi.org/10.3389/fphys.2024.1374309. All three are open access (CC BY).

Make it concrete. Consider a two-week rotation in a Mars-desert habitat, an officer embedded in a crew of six. Before the doors seal, the officer runs screening: a structured behavioral and fitness review of every crew member, the results logged as a baseline. Through the first week the work is presence: unobtrusive monitoring, a private word when two crewmates start grating on each other over sleep and chores, the quiet securing of the habitat's few controlled items. In the second week a scripted contingency lands. A crew member, worn down and convinced the logs are being altered, refuses a safety directive and squares up to another. Now the officer works the graduated response: de-escalation first, then a plain statement of delegated authority, and only if that fails, the least physical intervention a cramped module allows, every step narrated for the record. When the rotation ends, the officer carries out custody and handoff: a written account of the incident, the baseline and post-incident screening, the chain of custody for any evidence, all packaged for whatever authority would take it on a real return. None of that needed a courtroom, a cell, or a badge. It needed a trained practitioner, a sealed habitat to practice in, and a debrief at the end. That is what an analog mission can give, and an actual flight cannot.

Where the practitioner is formed — and belongs

There is one more reason the analog mission is the field's natural home. It is where the practitioner is formed. Most of what astropraesidics asks of a practitioner is already taught somewhere, scattered across protective security, criminal justice, and transportation security. Nobody combines it for this purpose. And a stubborn remainder is taught nowhere at all: order maintenance in a sealed cabin, screening of a confined population, custody in a vehicle that cannot divert, and, strangest of all, proportionate restraint in microgravity, where the terrestrial assumptions about floor and weight and friction simply fail. That remainder has to be learned by doing. Short of orbit, the analog habitat is the only place to do it.

This issue has argued, rightly, that astrosociology belongs inside analog missions from the start, with anthropologists, ethicists, and social scientists in the habitat rather than commenting on it from outside. The criminal-justice disciplines belong there too. People who have spent careers on legitimate authority, procedural fairness, the restraint of force, and the protection of the vulnerable belong on analog crews and design teams. That means peace officers, correctional and protection professionals, and the scholars who study them. The point is not to haul the squad car and the cell block into a habitat, where neither can exist. It is to recover, for a place stripped of Earth's apparatus, the older knowledge those tools were only ever meant to serve: how order is kept justly among people who cannot leave one another's company. Put that expertise inside an analog mission, and the Astropraesidial Officer, the field's central role, starts to become a real job rather than a proposal on a page.

[4] 4.The 2007 arrest of a serving astronaut prompted an independent review — the NASA Astronaut Health Care System Review Committee, chaired by Col. Richard Bachmann (report publicly released July 27, 2007) — which reported anecdotal accounts of heavy preflight alcohol use and instances in which medical or behavioral advice about crew fitness was disregarded; NASA subsequently instituted standing behavioral-health evaluations for the astronaut corps. Findings and NASA's response are documented in the public congressional record: "NASA's Astronaut Health Care System: Results of an Independent Review," Hearing before the Subcommittee on Space and Aeronautics, Committee on Science and Technology, U.S. House of Representatives, 110th Cong., Serial No. 110-52 (July 27, 2007). Free at govinfo.gov (CHRG-110hhrg37640).

The evidence the field needs

There is, finally, an evidentiary reason, and it should matter to anyone who takes the field seriously. The case for astropraesidics today rests on analogy and proxy. It leans on aviation's stubborn rate of unruly conduct, on maritime offenses, on the candor of the review that followed a screened astronaut's felony arrest in 2007, and on the behavioral base rates of confined crews.[4] Those proxies show that the need is durable and structural. What they cannot show is its shape in space, since the direct record of in-cabin incidents is still thin, as it will be for any young activity. Analog missions are how that thin record turns into real evidence: controlled, repeatable, and gathered before the population outgrows any improvised response. And the risk runs highest exactly where confinement lasts longest and return is impossible on demand, on the deep-space and lunar missions the analog community exists to prepare for.

Astropraesidics names this criminal-justice function and fixes its place within astrosociology. Analog astronautics is where it can actually be built rather than merely asserted, its doctrine rehearsed and its practitioner trained and its evidence gathered here on Earth, before the first serious incident aboard a real spacecraft forces us to invent the whole thing at once. We already have the proving ground. What is left is to use it.



FEAR LOGICS AND LEGAL DYNAMICS IN SPACE



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"When humans are lost in space, it takes only five minutes to reach totalitarianism."
Sebastian Schneider, Death's End, Liu Cixin.

Introduction

Space is a site of legitimate fear, especially and including fundamental Fears of the Unknown (FOTU) that shape the production of law and legitimate authority both formally and informally. A 2016 study of Fear of the Uknown (FOTU) suggests that it may be one of the foundational fears experienced by humanity (Carleton, 2016). This has clear implications for journeys into space, where the unknown is a site of promise, but also a realistic vector of fear.

Analog space missions would benefit from a fulsome consideration of space as a site for fear, including understanding how fundamental human fear of the unknown has effects on systems of law and punishment. In our previous research, we consider potential objects of regulation (be they people, places, things, or ideas) as tri-partite containing legal, tangible, and social dimensions. We found that the fear can serve as an accelerant to the project of regulation often in ways that reflect the dynamics of power struggle already endemic to society (Albrecht, Burns, and Bell, 2024). For example, the fears of a community, or its chief decision-makers, influence legal precedents, potentially immortalizing fears with little to no relevance in later eras. The longevity of such precedent is especially difficult as the fears of the past become the constraints of the future, even when the fear object that prompted regulatory action has abated.

We take up this fear regulation problem with specific consideration of what it means for space society building. In doing so, we look to pseudoanalogous cases like the colonial project in North America and speculative fiction-scapes for lessons and strategies about how to combat future fears in space society building.

Governing with Fear

Fortunately for future space colonies, there is much to be learned from the Earthen history of governing with fear. We take the Puritans and the Massachusetts Bay Colony of 17th-century New England as an example of how fear can become enmeshed with the law itself. While the colony is now far more infamous for the Salem Witch Trials of the 1690s, where the colonists themselves were prosecuted for witchcraft, the persecution and prosecution of Quakers demonstrate a preoccupation with preventing challenges to their authority from external forces (Erikson, 1966).

The leadership of the Puritans of Massachusetts Bay maintained a rigid social hierarchy characterized by an intense social control of mind, body, and deed through the complete enmeshment of civic and religious life (Pestana, 1983). While the enmeshment of civic life and religious dogma was characteristic of the Puritan mission to foster a godly "city upon a hill," some of the strict control of social norms was likely influenced by real and perceived precarity and uncertainty from the colony's isolation, fear of indigenous peoples in the area, and internal conflicts within the colony itself (Mazzacano, 2011). Challenges to the preeminence of Puritan hegemony within the colony itself were met with suspicion, accusations, court intrigues, and harsh penalties, including banishment and execution (Erikson, 1966; Pestana, 1983).

Questioning Puritan doctrine, for example, was taken as a potential sign of witchcraft. The earliest major instance of this was a woman named Anne Hutchinson who publicly questioned Puritan doctrine and patriarchal elder leadership, and was accused of witchcraft, though she would go on to be convicted of heresy in 1637 (Erikson, 1966, 71-99).

The Quakers were thoroughly alien to the Puritans of Massachusetts Bay. Quakers favored spiritual guidance from an "inner light" over the Bible and rejected the rigid social hierarchy and rules of comportment explicit within the Puritanism of the colony. Quaker women regularly interrupted congregational meetings, ranting naked or covered only in ashes; "going naked for a sign" to demonstrate that, in fact, it was the Puritans who were naked, unclothed as it were in the divinity of God (Carroll, 1978; Pestana, 1983). Women held equal relevance and status to men within Quakerism, and the sect adopted distinct linguistic and discursive modes of speech that further insulted Puritanical sensibilities; namely, refusing to speak in deference to anyone, regardless of social rank (Birch, 1995; High, 2020). The various heresies of the Quakers and their collective breach of law and order proved, according to the Puritans, that the sect served an infernal master (1983, 330).

According to Reed (2015), Massachusetts Bay elders reinterpreted challenges to their theocratic power and autonomy into something they could better comprehend and potentially counteract: witches in their midst. In effect, then, the arrests, trials, and executions of those accused of witchcraft, predominantly young women, served to objectify the otherwise looming, intangible fears of the colonial leadership.[1]

The feared objects of witches and demons of the Puritans might have stood in for the real and historically documented social and political change, shifting the issue from mundane to supernatural (Reed, 2015, 74-76). The concrete threats to Puritanical theocracy in the colony — encroachment from the nearby indigenous groups, impudent women, rival religious sects interrupting congregational meetings, or an unfavorable edict from the monarch of the day — all signifying chaos and uncertainty, were resignified into the machinations of a Devil seeking to combat the holy endeavors of Puritan saints.

[1] Neither Reed, nor we, are claiming that these were the only causes of the Salem Witch Panic and Trails. However, we do usefully describe three key events that show how fear of the other became resignified into religious anxieties which, in turn, became legal decisions and acts.

While fearful of the Devil and witches, the Puritans of Massachusetts Bay found evidence of these fear objects in the actions and ideas of people. Many of the inciting incidents of the Salem Witch Trials, involved women acting abnormally; a few young girls experiencing fits of convulsion, a woman of "ill Fame," Amy Duny, and another, Rose Cullendar, said to have multiple witches teats may have served as useful scapegoats for elders to blame for their anxieties, even though the true source was the political upheaval that challenged their authority (Erikson, 1966; Mather, 1862).

The persecution and criminalization of deviantized groups like the Quakers and those deemed witches by Puritan elders serves as an example of the type of social and cultural influence that high control of norms has on justice and legal functions. Relatedly, moral panic associated with social change can place legal restrictions on otherwise neutral actors (Lett et al., 2011). We may consider how, like the Massachusetts Bay colony, dominant groups historically create laws and policies that target feared or despised groups, legitimizing their marginalization, persecution, or annihilation (Cohen, 2011).

Despite their historical era, the Puritans of Massachusetts Bay offer considerable strategic gains for understanding the future of governing fear in space. First, we should recognize the role of the unknown inherent in space exploration, and its potential to instill fear-based rulemaking.For example, philosopher and futurist R. Buckminster Fuller is quoted as stating, "the universe is comprised of non-simultaneously apprehended events" (Bauscher, 2003). Under no circumstances may the universe be understood in its totality, and that vast unknown means that the scope of potential existential threats is also beyond comprehension.

The historical cases of the Salem Witch Trials and earlier Quaker criminalization and prosecutions demonstrate that in societies with rigid social expectations and a high degree of anxiety about anything unfamiliar, abnormality may be considered a crime punishable by death. Due to the remoteness, isolation, and the several known and unknown risks associated with space exploration and colonization, fear will necessarily be a factor in the organization and administration of human life and activity off-planet.

Anticipating Space Law through Speculative Fiction

The words of Buckminster Fuller should not necessarily mean that the risks associated with widespread human engagement in space are incomprehensible. There is, in fact, a wide body of speculative fiction, including science fiction focused on space travel and colonization, that serves as useful heuristics for imagining and anticipating the potential situations and conditions that might be mitigated through systems of law and justice. Considering this source and its creation as being meant for an audience, and thus not necessarily focused on accurately assessing the true potential of an event, it is worthwhile to consider the situations as within a range of possibilities, rather than the most likely outcomes. Popular speculative and science fiction has the added implication that many people who may one day hope to explore space or participate in its colonization likely already draw expectations from these works of fiction.

One recent and well-known series, a trilogy by Liu Cixin known collectively as the Remembrance of Earth's Past or the Three-Body Problem trilogy, tells of an Earth plunged into an interplanetary conflict with the Trisolarans, an alien species approaching over four centuries with the intention to eradicate all humanity and settle on Earth (2014). Humanity, thrown into deep existential turmoil, splits into distinct camps; including a group of humans that support the annihilation of humanity and ceding the planet to the incoming invaders, and escapists who wanted to leave Earth and seek safety from the Trisolarans by fleeing Earth (Liu, 2014; Liu, 2015). As humanity developed space fleets, ideological camps developed with consequences rooted in criminalization and military action.

When a small Trisolaran "droplet" probe destroys nearly all of Earth's space fleet in mere minutes, a few ships flee to deep space, imagining all hope, and the planet itself, lost. The architect of the plan to attack Quantum, weapons officer Sebastian Schneider later explained that in the moments leading up to the crew of Bronze Age deciding to sacrifice Quantum for their continued survival, "When humans are lost in space, it takes only five minutes to reach totalitarianism" (Liu 2016).

Liu's second (2015) and third (2016) books pose a still more chilling threat: that any detection of life from another extraterrestrial civilization may imperil all life on Earth. The "dark forest" theory suggests that any attempt to communicate with life on other planets will bring certain doom (Liu 2015). Every civilization is hunting, and every civilization must also evade detection. What this might suggest for humanity, well before entering space, is a complete reorientation of engagement with the universe and its other potential inhabitants.

Conclusion

The scenarios in Liu's trilogy pose extreme conditions, and some of the darkest images of human spacefaring imaginable. Of course, there are other, far less disturbing visions (such as Gene Roddenberry's utopian vision in his Star Trek series). Each vision discussed here suggests its own laws, level of rigidity, and, hearkening back to the Puritans of Massachusetts Bay Colony, behavioral and ideological restrictions and prohibitions.

These examples, both real and fictional, demonstrate that reaching new frontiers opens new challenges for society building in combatting fear and the unknown, some of which might be accomplished through the formal institution of law and some that might be made much worse with a misuse of law. The instinct of law-wielding authorities often invokes quick and harsh paradigms of regulation that reify existing forms of authority with punishment. In the examples discussed here, there is dubious long-term success in these strategies. Future research should consider alternative regulatory frameworks or uses of positive fear as analog space missions continue to prompt us to consider other legal futures.

References

Albrecht, K., Burns, A., & Bell, S. (2024). Fear the law: Codifying fear through the objectification of the law. UCLA Criminal Justice Law Review, 8, 147.

Bauscher, L. (Director). (2003). Maybe logic [Film]. Deepleaf Productions.

Bergquist, M., & Ekelund, M. (2025). The role of emotion regulation in normative influence under uncertainty. BMC Psychology, 13, 731. https://doi.org/10.1186/s40359-025-02750-7

Birch, B. M. (1995). Quaker plain speech: A policy of linguistic divergence. International Journal of the Sociology of Language, 1995(116), 39–52.

Carroll, K. L. (1978). Early Quakers and "going naked as a sign." Quaker History, 67(2), 69–87.

Carleton, R. N. (2016). Fear of the unknown: One fear to rule them all? Journal of Anxiety Disorders, 41, 5–21.

Cohen, S. (2011). Folk devils and moral panics (3rd ed.). Routledge.

Erikson, K. (1966). Wayward puritans: A study in the sociology of deviance. John Wiley & Sons.

High, E. (2020). The devil and a disease: Early representations of Quaker women in the Atlantic world. ELH, 87(3), 637–677.

Lett, D., Hier, S. P., Walby, K., & Smith, A. (2011). Panic, regulation, and the moralization of British law and order politics. In S. P. Hier (Ed.), Moral panics and the politics of anxiety (pp. 155–170). Routledge.

Liu, C. (2014). The three-body problem (Vol. 1). Tor Books.

Liu, C. (2015). The dark forest (Vol. 2). Tor Books.

Liu, C. (2016). Death's end (Vol. 3). Tor Books.

Mather, C., & Mather, I. (1862). The wonders of the invisible world: Being an account of the tryals of several witches lately executed in New England. In C. Mather, To which is added, a farther account of the tryals of the New England witches. Project Gutenberg.



GOVERNED HABITATS IN ANALOGUE MISSIONS: HUMAN STABILITY SAFE WORK ENVIRONMENTS GRAVITY SUPPORT AND POWER SECURITY



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This paper presents the Governed Expandable Space Habitat (GESH) architecture in the context of analogue mission operations and early in-situ lunar construction. The governed subsystem stack provides structural stability, thermal uniformity, dust exclusion, environmental control and independent power, creating a predictable interior environment that reduces cognitive load and supports crew performance. Human factors implications are summarised for analogue mission designers considering governed habitat integration into programmes such as NASA CHAPEA, HERA or similar closed-environment facilities.

1. Introduction

Analogue missions allow us to study how humans live and work inside controlled environments that approximate off Earth conditions. The Governed Expandable Space Habitat (GESH) architecture provides a stable, predictable interior environment that reduces cognitive load, improves crew cohesion and supports construction teams building permanent structures either in analogue settings or in early in-situ lunar operations. Governance is provided by a three-tier autonomy control unit that monitors structural, thermal, atmospheric and power state across the habitat and executes safemode transitions without ground command.

The primary design objective is a safe, secure environment where crew can eat, sleep and socialise when they are not working. This directly addresses the environmental stressors observed in programmes such as NASA CHAPEA, HERA and HI-SEAS, where uncontrolled thermal variation, acoustic instability and dust ingress have been identified as cumulative performance degraders. Every governed subsystem is designed to remove environmental uncertainty and maintain a warm, clean, predictable interior that supports human performance.

GESH also stabilises interior behaviour in low gravity or partial gravity settings. This is essential for insitu construction where external gravity is weak variable or hostile.

2. Structural Governance and Human Perception

The governed spine stabilises the interior volume. It prevents flexing bowing or deformation under pressure changes equipment loads or low gravity effects. In analogue missions this produces a physical environment that feels solid and trustworthy.

Residents experience predictable geometry which reduces subconscious vigilance. They experience lower acoustic variability which improves sleep and reduces stress. They experience reduced cognitive load which allows them to focus on mission tasks without interpreting small environmental cues.

A stable structure creates a stable mindspace. This is essential for long duration analogue missions and insitu construction campaigns.

In conventional inflatable or tent-based analogue habitats, structural flex produces low-frequency acoustic signatures that occupants cannot consciously identify but which elevate baseline cortisol levels over multi-week missions. The governed spine eliminates this class of stressor entirely. The interior acoustic signature remains constant regardless of external wind loading, pressure cycling or crew movement between compartments. For construction teams operating high-consequence EVA tasks, returning to a structurally silent interior accelerates the cognitive transition from high-alert external work to rest and recovery.



Figure 1. Governed habitat architecture showing internal living, social and work zones supported by a governed spine, thermal uniformity, environmental control and triple-redundant power.

3. Gravity and Interior Stability

Gravity changes how people move how they work how they rest and how they recover. GESH removes gravity driven instability inside the habitat so crews can operate at full capability.

3.1 Structural behaviour in low gravity

Floors do not flex. Walls do not shift. Equipment does not drift. The interior stays stable even when external gravity is low or variable. This gives workers a reliable reference frame for movement and daily tasks.

In partial gravity environments such as the lunar surface at 1.62 m/s2, unsecured equipment and loosely mounted fixtures migrate over time. The governed spine and ring-frame attachment system anchors all interior fittings to structural hardpoints. This eliminates the cumulative drift of tools, supplies and personal items that degrades workspace organisation and increases task completion time in low-gravity habitats.

3.2 Thermal behaviour in low gravity

Heat does not rise in low gravity. Hot air does not stratify. GESH uses governed thermal routing to keep the interior warm and even. This prevents cold pockets and hot pockets and keeps the living space comfortable.

The governed thermal loop uses a heat-pipe manifold routed through the central spine to distribute thermal energy evenly across all deck levels. In low gravity, convective mixing is negligible, so the manifold becomes the primary mechanism for thermal equalisation. The control unit monitors temperature at multiple points across the interior and adjusts heat-pipe flow to maintain a uniform comfort band of 20 to 22 degrees Celsius throughout the habitable volume.

3.3 Airflow in low gravity

Air does not circulate naturally in low gravity. GESH uses governed flow paths to keep atmosphere clean safe and breathable. This prevents stagnant pockets and supports long duration occupancy. Without forced circulation, CO2 can accumulate around a sleeping crew member in low gravity, creating localised hypercapnia risk. The governed airflow system maintains continuous low-velocity circulation patterns that prevent CO2 pooling while keeping air movement below the threshold of perceptible draught. This balance is maintained automatically by the control unit based on occupancy sensors and atmospheric composition monitoring.

3.4 Dust behaviour in low gravity

Regolith floats. Dust clings. Dust migrates. GESH stops dust ingress and keeps the interior clean. This protects lungs skin equipment and morale.

3.5 Human recovery in low gravity

Workers need a stable place to recover after external tasks. GESH gives them a warm clean quiet interior where they can eat sleep and socialise without environmental stress. This is the most basic human necessity.

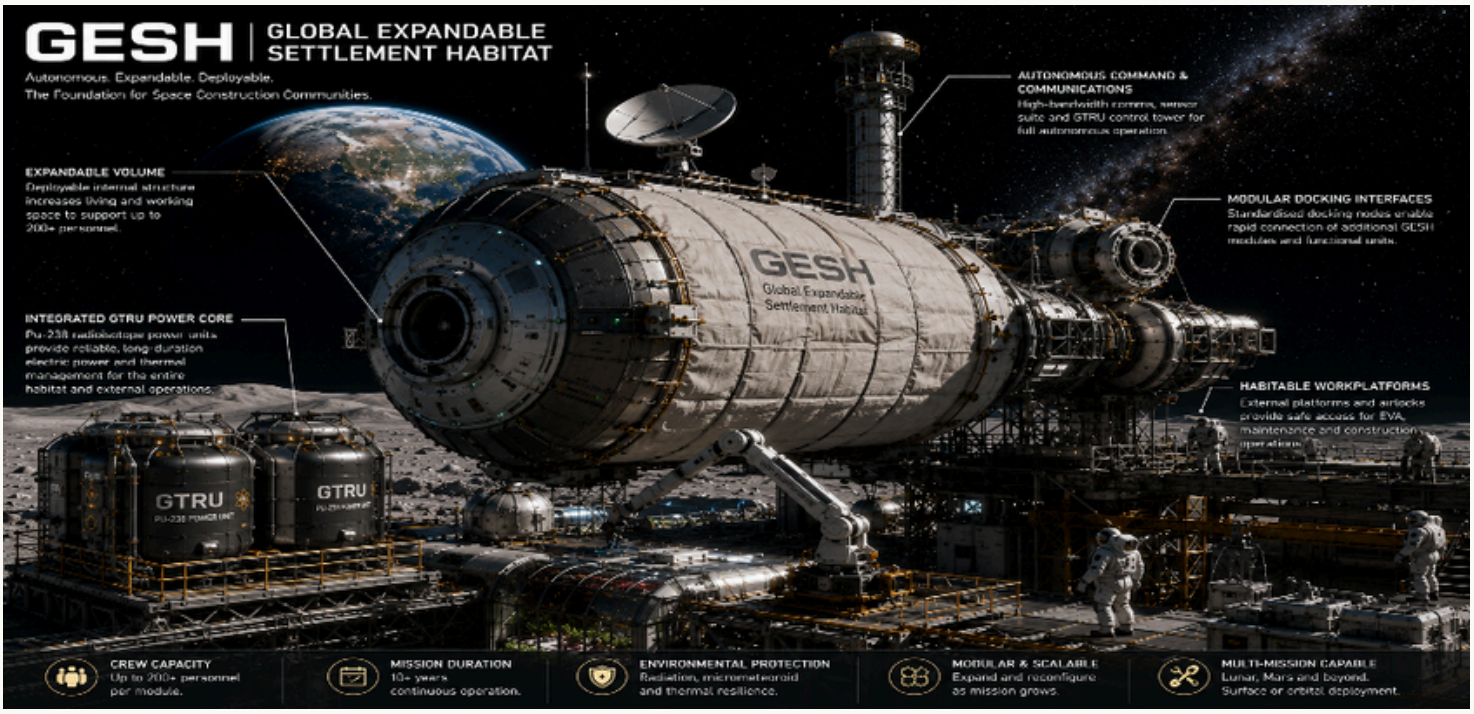


Figure 2. GESH exterior concept. Autonomous, expandable and deployable habitat architecture with integrated GTRU power core, modular docking interfaces and external work platforms for construction operations.

4. Thermal Uniformity and Crew Behaviour

The governed thermal loop maintains temperature within a narrow band across the entire interior. Hotspots and cold zones are eliminated. Residents experience uniform comfort which reduces territorial behaviour. They experience consistent daily rhythm which supports sleep and work cycles. They experience lower interpersonal friction because thermal discomfort is a known conflict trigger.

Thermal stability quietly reinforces social stability. It supports healthier crew dynamics and reduces stress accumulation.

Research from Antarctic overwintering stations and submarine deployments has consistently identified thermal discomfort as a leading source of interpersonal friction in isolated confined environments. Temperature complaints rank alongside noise and lighting as the most frequent environmental grievances in multi-month mission analogues. The governed thermal loop eliminates this category of complaint entirely by maintaining uniform conditions that require no crew negotiation or manual adjustment. The interior feels the same in every compartment, at every hour, regardless of external conditions or equipment heat load.

5. Interior Zoning and Social Geography

The radiation defence stack defines mass distribution and interior zoning. Even in analogue missions without radiation residents intuitively map thick wall zones to private sleeping areas. They map open zones to social areas. They map equipment dense zones to work areas.

This predictable interior geography reduces conflict over space. It supports healthy group dynamics and provides natural structure for daily routines.

The zoning architecture is reinforced by lighting gradients and acoustic separation. Private zones receive warmer, lower-intensity lighting to support circadian rhythm and rest. Work zones receive cooler, higher-intensity task lighting. Social zones are designed with intermediate lighting and open sightlines that encourage casual interaction. These environmental cues operate below conscious awareness but shape crew movement patterns and social behaviour throughout the daily cycle. In analogue missions, this passive structuring reduces the need for explicit scheduling of common spaces and lowers the frequency of territorial disputes.

6. Environmental Control Envelope

The governed environmental control envelope stabilises pressure atmosphere humidity and acoustic profile. Residents experience stable pressure which reduces headaches and fatigue. They experience clean atmosphere which improves cognitive clarity. They experience quiet interior conditions which reduce stress and sensory overload.

These factors create a calm predictable environment that supports psychological resilience and operational performance.

The environmental control envelope operates as a closed feedback loop. Atmospheric sensors continuously monitor O2, CO2, humidity and particulate levels. The control unit adjusts ventilation rates, filtration cycling and humidity control in response to measured conditions rather than fixed schedules. This adaptive behaviour means the interior atmosphere remains stable during periods of high crew activity (such as post-EVA suit doffing, cooking or exercise) without requiring manual intervention. Crew members experience a consistently clean, fresh atmosphere that responds to their presence without drawing attention to itself.

7. Dust Free Regolith Free Living

Construction crews face dust ingress as a major operational and psychological burden. The governed environmental control envelope prevents particulate infiltration through controlled pressure gradients governed filtration and isolated suit ports.

The result is a clean interior free of regolith or analogue dust. This improves comfort health and morale. It also protects equipment and reduces maintenance load.



Figure 3. Dust exclusion and clean living. Governed airlock maintains pressure differential and filters particulates, keeping the interior clean, healthy and predictable.

8. Recovery Environment and Operational Predictability

The governed habitat is designed for recovery after high risk external work. Crews return to a space that is warm clean structurally stable acoustically quiet and environmentally predictable. This reduces fatigue accelerates recovery and stabilises crew behaviour during demanding construction cycles.

A safe interior allows crews to reset mentally and physically. It supports planning eating sleeping and socialising without environmental stressors. Governed architecture removes environmental surprises. Residents experience stable lighting stable temperature stable pressure stable acoustic cues and stable power. Predictability reduces vigilance improves decision making and supports healthier social dynamics.

Analogue missions often reveal how small environmental instabilities accumulate into large social effects. Governance eliminates those instabilities.

The recovery function is particularly important during construction campaigns where crew members alternate between physically demanding EVA shifts and rest periods. Fatigue accumulation in construction workers is well documented in terrestrial high-risk industries, and the same patterns apply in space-relevant operations. A governed interior that requires no cognitive investment from returning crew (no thermostat adjustment, no filter changes, no power management, no dust cleanup) reduces the mental overhead of transition from work to rest. This allows crew to begin genuine recovery immediately on return rather than spending the first 30 to 60 minutes managing their living environment.

9. Power Security and Removal of Power Anxiety

Power anxiety is a silent stressor in analogue missions and insitu construction campaigns. The governed habitat removes this stressor through three independent backup power options. Residents experience zero transition failover with no flicker or environmental dip. They experience continuous environmental control and stable lighting and acoustic profile.

For construction crews power security is a psychological anchor. A habitat with continuous, uninterrupted power provides a measurable psychological anchor for isolated crews.

The three-tier power architecture provides survival power from radioisotope units that require no fuel resupply, thermal backbone power from a governed thermal retention unit, and primary electrical power from a fission power pod or solar array. If any single tier fails, the remaining tiers maintain habitable conditions indefinitely. The control unit manages load shedding and tier transitions automatically. Crew members are never required to make power management decisions during a contingency. This is a deliberate design choice: in high-stress situations, removing decisions from the crew reduces error probability and preserves cognitive capacity for mission-critical tasks.

10. Human Factors Implications

Table 1 summarises the governed subsystem stack and its projected human factors effects. Analogue missions using governed habitats can study how environmental stability shapes crew behaviour, leadership dynamics and mission culture.

Table 1. GESH Governed Subsystem Summary: Human Factors Impact

Governed Subsystem	Physical Behaviour	Human Factors Effect
Structural spine	Prevents flex, bow, deformation under pressure or gravity changes	Stable interior geometry reduces subconscious vigilance and cognitive load
Thermal loop	Uniform temperature within narrow band across entire volume	Eliminates thermal conflict triggers, supports sleep and circadian rhythm
Environmental control	Stabilises pressure, atmosphere, humidity, acoustic profile	Reduces headaches, fatigue, sensory overload; improves cognitive clarity
Dust exclusion	Governed filtration and pressure gradients prevent particulate ingress	Protects lungs, skin, equipment; improves morale and reduces maintenance
Interior zoning	Mass distribution defines private, social and work zones	Reduces conflict over space; provides natural structure for daily routines
Power security	Three independent backup tiers with zero-transition failover	Removes power anxiety; habitat never goes dark; psychological anchor
Gravity compensation	Governed thermal routing and airflow in low/variable gravity	Stable reference frame for movement, rest and recovery

11. Conclusion

Governed habitat architecture is designed to provide the foundational requirement for long-duration crew operations: a safe, secure environment where people can eat, sleep and socialise when they are not working. It provides structural stability thermal uniformity environmental cleanliness dust exclusion gravity stability and power security. These physical behaviours directly shape human experience reduce cognitive load improve social cohesion and support long duration mission success.

Governed architecture addresses both the engineering and human factors dimensions of habitat design simultaneously.

The subsystem stack described in this paper is not theoretical. Each governed subsystem (structural spine, thermal loop, environmental control, dust exclusion, power tiers) has been defined at engineering specification level in the companion GESH technical paper (AEMS-GESH-001).

The architecture is designed for fabrication, test and deployment using existing materials and demonstrated technologies.

Analogue mission integration represents the natural first deployment pathway, providing controlled environments where governed habitat performance can be measured against crew wellbeing, task performance and social cohesion metrics.

Analogue missions provide the perfect setting to explore how physical stability creates psychological stability and how predictable environments support safe effective human activity in space relevant conditions.

GESH provides a stable interior anchor for analogue missions and early insitu construction which allows crews to operate at full capability without environmental stress.



ANALOGUE SPACE MISSIONS AND THE HUMAN DIMENSION OF EXPLORATION



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If you live on Florida's Space Coast long enough, rocket launches begin to blend into everyday life. Long before ignition, engineers have verified thousands of components and every subsystem has been evaluated because spectacular launches are built upon the countless decisions made long before anyone hears the countdown. That realization stayed with me as I began studying human sustainability in space and beyond Earth, where analog missions may be great laboratories for understanding people.

Imagine two analog crews preparing for the same simulated emergency. Both crews have trained for months and know the procedures. Both crews carry identical checklists, work in thesame habitat, and face the same simulated equipment failure. On paper, they should perform almost identically, yet the outcomes are different.

One crew communicates calmly, catches a small error before it grows into a larger problem, and completes the exercise with confidence. The other crew becomes tense, leading to a missed confirmation that causes confusion among the crew. What began as a routine simulation gradually cascades into a series of small mistakes. The checklist remained the same, nothing about the engineering changed, and the habitat itself did not change, but the people did. The state of the human system changed. Analog space missions invite us to examine human performance not just from an individual lens, but from the human system in which those events unfold.

That is why analog missions are valuable in astrosociology, which focuses on the human social, cultural, and behavioral dimensions of outer space. Analog missions give researchers and participants a way to study that human dimension before crews face the longer isolation, higher stakes, and complex dependencies of future lunar or Martian settlements. One reason analog missions are useful is that they make hidden patterns visible. You are living inside the same system you are trying to understand.

The idea of a human system is important for future space settlement. If we hope to build sustainable habitats on the Moon, Mars, or beyond, we should design for more than survival. We may need to design for psychological safety, healthy communication, mutual accountability, and the capacity to recover from stress together. Engineers already monitor the performance of life-support and communications systems because they know that small deviations can become major failures if ignored. A habitat can function technically and still fail socially. Analog missions help us recognize the tension points and breakdowns in human systems before those lessons are learned at greater cost.

This is also why interdisciplinary collaboration among the social sciences, humanities, arts, and biological and physical sciences is important, because analog missions sit at that intersection. Engineers can design the habitat, but social scientists can help explain group dynamics. Behavioral health professionals can study stress and resilience, while humanists and artists can help us understand meaning, identity, and the stories people bring with them into extreme environments. Together, these perspectives help create a richer and more realistic picture of what life in space may actually require.

My own interest in this topic comes from the recognition that habitats shape the people inside them. On Earth, hospitals, classrooms, disaster response teams, submarines, and even families operate as living systems shaped by relationships, routines, expectations, and shared purpose. Analog missions compress those dynamics into a small, high-stakes environment where they may become easier to observe. They show that resilience is not only an individual trait, it may also be a property of the group and the environment supporting it. Analog missions reveal that the state of the human system may change the outcome of the work just as much as the technical design of the mission. A checklist is still a checklist, but the people carrying it out are never static. Environments shape people, people shape environments, and the two are always in conversation with one another.

Analog astronauts' experiences help prepare the space community for the social realities of future missions. They show us how people adapt to confinement, how crews develop trust, how conflict emerges, and how mission culture can either support or undermine performance. These are core conditions of human spaceflight and space settlement.

Astrosociology reminds us that the future of space exploration is about carrying humanity with us into the Solar System. Analog missions are valuable because they may help to reveal that the future of space will depend as much on the design of human relationships as on the design of hardware. Every habitat shapes the kind of people we become. If we design those habitats wisely, they may help humanity become more resilient, more collaborative, and more capable of thriving beyond Earth. The future of space is being built not only by experts, but by people who are willing to keep showing up, keep learning, and keep becoming.



TWO SIDES OF THE SAME COIN: WHY HUMAN CONNECTIONS HOLD ANALOG SPACE MISSIONS TOGETHER



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In the year 2022, I found myself sitting in a room in Kraków, Poland, at the Analog Astronaut Training Center. Surrounding me were five women I had never met before. We were six strangers representing three different nationalities and cultural backgrounds, brought together for the Mission JUNO, an all-female analog space mission simulation. There was an undeniable mix of quiet nervousness and unspoken excitement in the air. We were about to enter a completely sealed, mock up lunar habitat with no view of Earth, no natural sunlight, and no access to the outside world. Before we could earn our place inside the habitat, however, our team building began with an immediate challenge: a midnight trek. We were instructed to climb a mountain in pitch darkness with no phones or flashlights and no artificial guidance. All we had was each other and a shared objective. In the beginning, we walked in cautious silence, following the lead of Dr. Agata, step by step through the dark. But as the incline steepened, the physical effort mounted, the natural barriers between us broke. Silence gave way to conversation, shared laughter and mutual encouragement. By the time we reached the summit, we were no longer isolated individuals; we had transformed as a crew.

The real test came on the descent. Navigating down the mountain in the dark required absolute trust. We became each other's guides, anchors, and guardians. That night taught me a fundamental lesson about human behavior in extreme environments: structural cohesion is not created by operational manuals; it is forged through a shared vulnerability, patience, and direct human connection.

Life Inside the Isolated Loop: Time, Routine and Shared Spaces

The morning after our trek, we officially entered the habitat. We budgeted our food supplies for the duration of the mission, distributed operational roles, and I was appointed as the Commander for the crew. Inside the habitat, all reference points to the terrestrial world disappeared without windows; we had no idea whether it was day or night, sunny or storming outside. Our perception of time shifted entirely. Time was no longer governed by the sun but by a structured timeline coordinated directly by Mission Control.

Every morning began with a scheduled wake-up call from Mission Control, the dedicated crew member responsible for managing our primary communication loop with Earth. She would receive the call, wake me up, and we would initiate our daily routine. To ground ourselves in this synthetic environment, we established small human rituals.

Mission Control played a song every morning to set the tone of the day. We also adapted to medical monitoring protocols that quickly became second nature: waking up, measuring our vitals and logging biological samples.

Our daily rhythm was tight and disciplined:

- Morning: Initial operational briefing over breakfast, followed by habitat maintenance, cleaning duties, and running assigned scientific experiments.
- Afternoon: Mid-day status update, lunch and mandatory physical conditioning.
- Evening: Final daily debrief, psychological evaluations, and dinner.

To combat the physiological and psychological impacts of confinement, each crew member spent at least an hour every day in our small, almost claustrophobic gym. Space and privacy were almost non existent. Our private quarters consisted of small bunk beds with a simple curtain for isolation. There were no showers; we relied on wet wipes for the duration of the mission. While strange at first, these constraints quickly integrated into our baseline reality.

We brought our unique backgrounds into the shared space, especially during meals. Preparing dishes that represented our respective cultures became a way to honor our individuality while deepening our connection as a team. We logged everything: calorie intake, water consumption, psychological assessments, and cognitive testing metrics before and after sleep. Wi-Fi access was strictly limited to uploading scientific data to the drive. We had virtually zero communication with our families or friends. We were completely isolated, relying entirely on the five of us inside the habitat.

Leadership, Decoupled Ego, and Real Crises

As Commander, my primary responsibility was maintaining operational efficiency, ensuring timely data collection, and monitoring the physical and emotional well-being of the crew. Leadership in isolation, however, is rarely about asserting authority; it is about empathy, patience, and situational awareness.

When one of my crew members experienced an emotional breakdown due to the psychological weight of isolation. I had to balance two critical responsibilities simultaneously: providing genuine human comfort and support to my peer inside the habitat while maintaining clear objective communication with the Mission Support Center to track her condition and prepare contingency plans if her health deteriorated. True leadership requires holding space for human vulnerability while keeping the mission safe and moving forward.

Our greatest test came when a scheduled simulation unexpectedly merged with a real infrastructure emergency. Our scenario called for a simulated micrometeorite impact that caused habitat depressurization, requiring a rapid evacuation protocol and an Extravehicular Activity (EVA) to seal the breach. Mid-simulation, however, our habitat experienced a major electrical failure. The refrigerator lost power, our monitoring camera went dark, the CO2 monitoring systems shut down, the Wi-Fi dropped, and the main water pump failed.

The habitat's air purification system was offline, and elevated CO2 levels quickly began causing headaches among the crew. In a high-stakes scenario, true leadership required putting aside the ego. I knew that electronic devices were not my domain of expertise. Rather than attempting to command every detail, I took a backseat and let a crew member who possessed deep technical knowledge in electronics take the lead.

We organized ourselves around her technical expertise, working as an execution team to resolve failures systematically based on survival priorities.

- Refrigeration and Food Preservation: restoring power to protect our finite food supply.
- Water Infrastructure: Repairing the pump mechanisms to maintain hydration.
- Environmental Control: Reviving the air purification systems to clear the CO2 buildup.
- Comms and Telemetry: Bringing the Wi-Fi router back online to re establish contact with MSC, followed by system monitors and camera.

Once the habitat systems were fully restored and stable, the room fell silent. We sat together in quiet habitat, taking a moment to breathe and reflect. There was a profound sense of mutual respect, relief, and genuine affection in that room. We had navigated a real emergency not through individual heroics, but through trust, decentralized leadership, and clear problem solving.

When the mission ended, we completed our final experiment logs, cleaned the habitat for the next crew, and placed our mission patch on the wall as a lasting symbol of six women who turned isolation into a masterclass in collective resilience.



Figure 1: All Female Crew, Mission Juno at the Analog Astronaut Training Center Lunar Habitat.

The Other Side: Mission Support as the Grounded Anchor

My journey with analog space missions did not end inside the habitat. I later joined the Austrian Space Forum for the AMADEE 24 mission, serving as a volunteer within the Flight Planning Team. To prepare for this role, I completed both the basic and advanced Analog Astronaut Training courses, which shifted my perspective entirely.

I moved from the isolated environment inside the habitat to the analytical high-velocity environment of the Mission Support Center (MSC). Working on flight planning allowed me to meet and engage with passionate space professionals from across Europe. I learned the precise mechanics required to build a daily operational schedule for an analog space mission.



Figure 2: The Flight Plan team at the first Dress Rehearsal for the AMADEE 24 mission of the Austrian Space Forum.

- Determining activity priorities based on scientific value and crew energy expenditure.
- Scheduling complex scientific experiments and defining operational timeframes.
- Mapping out Extravehicular Activity (EVA) routes to guide astronauts safely towards high-value scientific sites of interest.
- Rotating crew responsibilities to prevent burnout and ensure balanced operational load.
- Developing robust backup plans and pre positioning resources before problems arise on the surface.

This experience revealed the second side of the coin. The survival, safety, and success of an isolated crew depend just as much on the vigilance, accuracy, and foresight of the team on the ground as it does on the crew inside the habitat. The mission support center acts as the cognitive and strategic anchor for the astronauts. Without clear, calm, and precise communication from the ground, even the most capable crew can become vulnerable.

Astrosociology Synthesis: The Human Element as the Core Engine

Analog Space Missions are often celebrated for testing hardware, spacesuits, life support mechanics, and habitat architecture. But hardware is only as good as the human beings operating it. I believe the ultimate success of deep space human exploration will not be demonstrated solely by the propulsion systems or life support engineering, but by how well we understand, utilize and support the human dimension of space exploration.

Whether sitting in an isolated habitat with no natural sunlight or tracking operational timelines at the flight control desk, one central truth remains: space exploration is fundamentally a human endeavor.

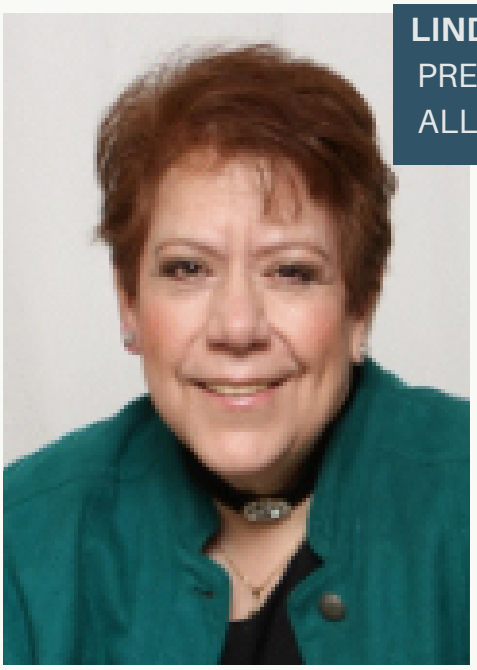
Isolation tests our adaptability, our patience, and our capacity to communicate under pressure. It forces us to redefine leadership not as a hierarchy of command but as a dynamic responsibility where entrusting your peers and stepping back is just as crucial as stepping forward. True resilience is built when individuals set aside personal ego in favor of collective survival.



Figure 3: Two Worlds, One Mission: Contrasting Space and Ground Perspectives. A comparative understanding of how time perception, leadership, and resilience through redundancy work differently.

As we prepare to establish long term bases on the moon and push forward towards Mars, analog space missions serve as our most vital testing ground. They prove that when you strip away terrestrial comfort, external communication, and familiar environments, the most important factor holding an entire mission together will always be the people who make it happen.

ANALOG SPACE MISSIONS AND ANALOG ASTRONAUTS (PART TWO): PERSONAL RESEARCH TRAJECTORY



LINDA F. KENNEDY
PRESIDENT AND CHIEF EXECUTIVE OFFICER
ALLIANCE FOR HUMAN SPACEFLIGHT

Dedicated to the generations of explorers—past, present, and future—whose courage reminds us that the greatest frontier has always been humanity itself.

As humanity prepares to establish a sustained presence beyond Earth, the greatest challenges ahead will extend beyond engineering and technological innovation. Long-duration missions to the Moon, Mars, and eventually more distant destinations will require the development of resilient human communities capable of adapting to isolation, confinement, cultural diversity, and environmental extremes. Understanding these human dimensions is the central focus of astrosociology, an interdisciplinary field that examines the relationships between space exploration and human society.

Earth-based analog missions provide an essential bridge between theoretical research and operational practice. By simulating the conditions expected during future planetary expeditions, these missions allow researchers to investigate leadership, cooperation, communication, conflict resolution, resilience, governance, and social adaptation within isolated, confined, and extreme (ICE) environments. Such investigations generate knowledge that complements engineering and biomedical research while helping prepare humanity for permanent settlement beyond Earth.

My own interest in astrosociology has developed throughout the six decades of professional and volunteer involvement with the United States human spaceflight program. Although my career began in public affairs and astronaut support, the experiences gained through working alongside astronauts, engineers, physicians, educators, researchers, and international partners gradually evolved into a broader scholarly interest in the social foundations of human space exploration. This paper represents both a reflection upon those experiences and a vision for future research that integrates lived operational experience with interdisciplinary scholarship.

Professional Background

Throughout my career, I have regarded the NASA Astronaut Corps' Code of Professional Responsibility as an enduring model of professional conduct. Its principles of competence, teamwork, integrity, stewardship, lifelong commitment, and personal responsibility have consistently guided both my professional activities and my scholarly approach to interdisciplinary research. These values remain directly relevant to astrosociology, where successful human exploration depends not only upon technological excellence but also upon ethical leadership, mutual trust, and effective collaboration.

In addition to my continuing association with NASA through educational outreach and public engagement, I am a crew member of Astronauts for America, a nonpartisan organization established by former NASA astronauts to encourage civic engagement, constitutional democracy, evidence-based decision-making, and respectful public discourse. Although independent of NASA, the organization reflects many of the collaborative principles that have long characterized successful human spaceflight.

Participation in Astronauts for America reinforces an important conviction underlying this research: the teamwork, trust, accountability, and shared responsibility required for successful space missions are equally important in addressing complex societal challenges on Earth. These same qualities will become increasingly essential as humanity develops permanent communities beyond our planet.

Personal Background

My interest in astrosociology is informed not only by scholarly inquiry but also by more than four decades of direct professional and volunteer involvement with the United States human spaceflight program.

For seventeen years I served in the Astronaut Office at NASA's Johnson Space Center as Astronaut Appearances Administrator and Publicist, coordinating more than 15,000 domestic and international astronaut appearances that connected NASA with educational institutions, governments, industry, the media, and the general public. These responsibilities provided a unique opportunity to observe the operational culture of human spaceflight while working closely with astronauts, flight controllers, engineers, scientists, educators, and international partners.

Beyond my official responsibilities, I participated in numerous operational and educational activities that broadened my understanding of human spaceflight. These experiences included three KC-135 reduced-gravity flights, three altitude chamber rides, observation of NASA Water Survival Training, sixteen years of volunteer service in the Flight Crew Operations Directorate Contingency Action Center supporting the Space Shuttle Program, NASA Public Affairs volunteer assignments during Blue Angels air shows, hot-air balloon chase operations during NASA Johnson Space Center Balloon Festivals, served as a volunteer test subject for astronaut vestibular testing,, led the initial coordination of the ISS Expedition II opening and closing segments of the 73rd Academy Awards, and initiated the first "Live Concert in Space" with Sir Paul McCartney and the Expedition 12 crew.



NASA KC-135 Zero-G Aircraft
Bob Grey, NASA Photographer
Linda F. Kennedy
Dave Dooling, Editor, Space World Magazine

As liaison for Apollo 17 Commander Eugene A. Cernan in conjunction with the Great Space Shuttle Exhibition of Japan, I accompanied Japanese delegates throughout NASA centers and major aerospace contractors across the United States, helping strengthen international understanding of the Space Shuttle Program and promoting public engagement in human spaceflight.



Astronaut Eugene A, Cernan
Apollo 17
Last Man to Walk on the Moon



The Great Space Shuttle Exhibition of Japan

I also attended numerous Space Shuttle launches at Kennedy Space Center and Shuttle landings at both Kennedy Space Center and Edwards Air Force Base, experiences that reinforced my appreciation for the extraordinary collaboration required to conduct human spaceflight safely and successfully.

My aviation experience includes certification as a private pilot with flight experience in the Piper Archer, Piper Warrior, Cessna 150, Cessna 172, Piper Navajo twin-engine aircraft, and Citation II business jets. Additional aerospace experiences include more than a dozen helicopter flights and participation in vestibular research conducted through the Kansas Cosmosphere, resulting in recognition by Guinness World Records for continuous rocking-chair endurance during investigations related to Space Adaptation Syndrome.

My professional contributions have been recognized through NASA's Silver Snoopy Award, multiple Space Flight Awareness Awards, and designation as a lifelong NASA Ambassador. Collectively, these experiences have provided an unusually broad perspective on the operational, organizational, educational, and human dimensions of space exploration. They continue to shape my research interests in astrosociology and reinforce my commitment to understanding how human societies will successfully adapt to permanent life beyond Earth.

Rather than viewing these experiences simply as milestones in a professional career, I regard them as the foundation for an ongoing research trajectory. They have demonstrated that successful space exploration depends not only upon engineering excellence but also upon the ability of individuals and communities to work together under demanding circumstances. As humanity moves toward permanent habitation of the Moon, Mars, and beyond, understanding these human factors will become increasingly important.

Personal Research Trajectory

My research interests have evolved from decades of professional experience within the United States human spaceflight program into a broader scholarly commitment to astrosociology—the study of the reciprocal relationships between space exploration and human society. While my earlier career focused on astronaut support, public engagement, and educational outreach, my current work seeks to examine the social, psychological, cultural, and organizational factors that will shape humanity's transition from exploration to permanent habitation beyond Earth.

Central to this research is the recognition that future lunar and Martian settlements will require more than advanced spacecraft and life-support systems. Sustainable extraterrestrial communities will depend upon effective leadership, resilient social structures, ethical governance, interdisciplinary collaboration, and the capacity of diverse individuals to live and work together under conditions of prolonged isolation and confinement. These human dimensions represent one of the most significant challenges facing long-duration space exploration and form the foundation of my continuing research.

As an extension of this work, I intend to pursue participation in NASA analog mission programs (application submitted July 2026) that investigate human adaptation to isolated, confined, and extreme (ICE) environments. These missions provide opportunities to study human behavior under conditions that approximate the operational realities of future planetary expeditions while allowing researchers to evaluate both individual and group performance in scientifically controlled settings.

Unlike traditional observational research, participation as both an investigator and an analog crew member would provide an opportunity to integrate empirical research with lived experience. Such an approach offers valuable insight into the complex relationships among leadership, communication, trust, identity, conflict resolution, resilience, and decision-making during long-duration missions. This integration of operational participation and scholarly analysis reflects the interdisciplinary nature of astrosociology itself.

NASA's analog research encompasses both short- and long-duration investigations. Short-duration chamber studies typically involve approximately fifteen days of confinement, preceded by participant screening, training, and baseline data collection, followed by post-mission evaluation and debriefing. Longer-duration investigations, including the Multi-Mission Earth Analog (MMEA), simulate approximately one year of planetary mission operations, requiring more than twelve months of participant commitment. These mission architectures provide exceptional opportunities to investigate social adaptation, psychological resilience, team cohesion, communication patterns, leadership development, and the organizational dynamics essential to future exploration.

Earth-based analog environments serve as indispensable laboratories for understanding the human dimensions of exploration. While engineering advances make deep-space travel technically possible, the long-term success of extraterrestrial settlements will depend equally upon our ability to develop healthy, adaptive, and cooperative communities. Research conducted within analog habitats therefore contributes directly to the development of evidence-based approaches for crew selection, conflict management, governance, cultural adaptation, and community sustainability.

Astrosociology occupies a unique position within this research landscape by integrating perspectives from sociology, psychology, anthropology, political science, organizational behavior, education, ethics, and systems science. Rather than viewing human spaceflight solely through technological or biomedical perspectives, astrosociology recognizes that future settlements will function as evolving societies whose success depends upon human relationships, institutions, shared values, and collective decision-making. My long-term research objective extends beyond participation in a single analog mission. Rather, I view such participation as the beginning of a broader scholarly program examining the evolution of human communities beyond Earth. Future investigations may include analog habitats simulating lunar and Martian environments, interdisciplinary studies of governance and organizational resilience, educational initiatives that prepare future generations for extraterrestrial settlement, and collaborative research that strengthens the role of social science within human spaceflight.

This research trajectory reflects a broader conviction that humanity's expansion into space must be guided by both scientific excellence and an informed understanding of human society. As exploration progresses from temporary expeditions toward permanent settlement, the social sciences will become increasingly important in helping create communities capable of flourishing across generations.

Expanding Analog Research Through Lifespan Diversity

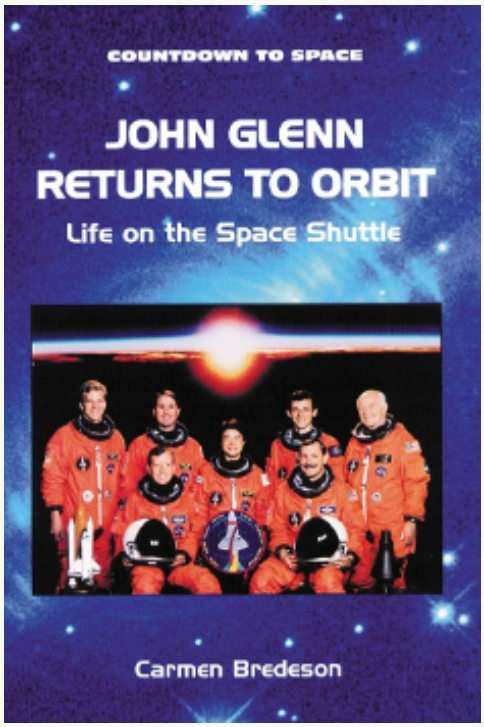
Current eligibility criteria for many analog missions emphasize younger participants because of operational and biomedical research objectives. While these criteria are understandable within existing research designs, they also raise broader questions concerning the long-term composition of extraterrestrial societies.

I recognize that current NASA analog participant guidelines specify an upper age limit that I exceed. Nevertheless, I respectfully suggest that chronological age should be considered alongside demonstrated physical health, psychological resilience, cognitive capability, operational experience, and the unique scientific perspectives individual participants may contribute.

NASA itself has previously recognized the scientific value of studying healthy older adults through the historic return of John H. Glenn Jr. to space aboard STS-95 at the age of seventy-seven. Although orbital spaceflight and Earth-based analog missions differ substantially in operational complexity and risk, both provide opportunities to investigate how aging influences human adaptation under challenging environmental conditions.



Astronaut John H. Glenn
Mercury 7 Astronaut - February 20, 1962



Astronaut John H,. Glenn and Crew
STS-95 - October 29 - November 7, 1998

The broader question extends beyond eligibility for individual missions. As humanity establishes permanent settlements beyond Earth, extraterrestrial communities will inevitably include people representing every stage of life. Scientists, engineers, physicians, educators, agricultural specialists, artists, policymakers, and community leaders will continue contributing long after traditional retirement age. Future settlements will mature just as communities on Earth mature. Their populations will age, diversify, and evolve across generations.

Understanding how healthy older adults contribute to leadership, mentorship, institutional memory, conflict resolution, decision-making, and community resilience therefore possesses genuine scientific relevance. Experience accumulated over decades may represent an important operational resource during prolonged missions requiring adaptability, emotional stability, and collaborative problem-solving.

Including greater age diversity within selected analog research projects could expand current understanding of human performance in isolated, confined, and extreme environments while complementing existing physiological and psychological investigations. Such research would not advocate replacing current participant criteria but rather broadening future research agendas to better reflect the demographic realities of permanent extraterrestrial settlement.

As astrosociology continues to develop, questions of age diversity, intergenerational collaboration, mentorship, governance, and social continuity will become increasingly important. Analog missions provide an ideal environment in which to begin investigating these issues before they emerge as operational challenges during sustained human habitation beyond Earth.

Ultimately, my interest in analog missions represents more than a personal aspiration. It reflects a commitment to contributing directly to the scientific understanding of how diverse human communities can successfully adapt to life beyond Earth. By combining professional experience, interdisciplinary scholarship, and participation in analog research, I hope to contribute to the growing body of knowledge that will help shape the future of human civilization in space that reflects the best of humanity.

Acknowledgements

The author also acknowledges the countless individuals, known and unknown, whose dedication behind the scenes has made every successful human spaceflight possible. Their quiet commitment reminds us that history is often written not only by those who fly, but also by those who prepare others to reach the stars.

Bibliography

Author, A. A., & Author, B. B. (2026). Title of the article: Subtitle of the article. Astrosociological Insights Forum, (Fall 2026 Issue), Pages–Pages. doi.org

Curator: HH&P App Dev Team NASA Analogs Recruiting
Responsible NASA Official: Brandon Vessev
National Aeronautics and Space Administration:
https://analogstudies.jsc.nasa.gov (Last updated: July 22, 2026)

Author: Astronauts for America. (April 21, 2026). 103 Former NASA Astronauts Launch "Astronauts For America" to Uphold the Constitution. Retrieved: April 22, 2026. https://www.astronautsforamerica.org/
Linda F. Kennedy, personal experience, April 22, 2026

NASA KC-135 Zero-G Program, NASA photograph
Linda F. Kennedy, personal experience, 1984

Subject; Astronaut Eugene (Gene) Cernan
Linda F. Kennedy, personal experience 1979 - 2017

Subject Astronaut John H. Glenn and the STS-95 Crew
Linda F. Kennedy, personal experience 1989 - 2026



THE LANGUAGE OF ISOLATION: PSYCHOLINGUISTIC ANALYSIS OF DAILY REPORTS ACROSS MISSION ROLES AND GENDERS IN ANALOG SPACEFLIGHT



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Introduction

Understanding human behaviour in isolated, confined, and extreme (ICE) environments [1] requires an integrated cognitive-neurobiological and astrosociological perspective. Living in restricted habitats produces expeditionary friction [2, 3] driven by chronic lack of privacy, sensory monotony, and disrupted social-distancing mechanisms. These stressors drain cognitive resources, heighten interpersonal tension, and transform daily written reporting into a psychological coping tool that supports emotional regulation and stability [4, 5].

This function aligns with Pennebaker's expressive writing theory [6, 7], which argues that converting diffuse emotional states into structured language engages prefrontal cognitive processes, reduces rumination, and improves affect regulation. Sociologically, written reports can also serve as a substitute for Oldenburg's Third Place [8, 9], offering a symbolic space where individuals temporarily step outside prescribed roles and maintain personal autonomy. Historical accounts reinforce this interpretation: prison writings by Nelson Mandela and Oscar Wilde, expedition diaries of Shackleton and Scott, and NASA's Journals Project on the ISS all demonstrate how narrative practices buffer stress and support group cohesion.

[1] Stahn, A. C., & Kühn, S. (2022). Extreme environments for understanding brain and cognition. Trends in cognitive sciences, 26(1), 1–3. https://doi.org/10.1016/j.tics.2021.10.005
[2] Shved D, Kuznetsova P, Rozanov IA, Lebedeva SA, Vinokhodova A, Savinkina A, Shishenina K, Rey ND and Gushin V (2022) Effects of isolation, crowding, and different psychological countermeasures on crew behavior and performance. Front. Physiol. 13:963301. doi: 10.3389/fphys.2022.963301
[3] Marcinkowski, M. A., Bell, S. T., & Roma, P. G. (2021). The nature of conflict for teams in isolated, confined, and extreme environments. Acta Astronautica, 181, 81–91. https://doi.org/10.1016/j.actaastro.2021.01.004
[4] Frederiksen, D. J. (2023). Connecting with the outside world: Psychosocially supportive aspects of operational communication between isolated crews in space and mission control on the ground. Journal of Human Performance in Extreme Environments, 18(1), Article 9. https://doi.org/10.7771/2327-2937.1155
[5] Dunn Rosenberg J, Jannasch A, Binsted K and Landry S (2022) Biobehavioral and psychosocial stress changes during three 8–12 month spaceflight analog missions with Mars-like conditions of isolation and confinement. Front. Physiol. 13:898841. doi: 10.3389/fphys.2022.898841
[6] Pennebaker, James & Beall, Sandra. (1986). Confronting a Traumatic Event. Toward an Understanding of Inhibition and Disease. Journal of abnormal psychology. 95. 274-81. 10.1037//0021-843X.95.3.274.

This study extends these insights into a quantitative astrosociological framework. Using psycholinguistic analyses of daily mission reports from 51 analogue astronauts across eight isolation missions at the Analog Astronaut Training Center (AATC) [10], we examine digital traces of communication in analogue spaceflight settings. We analyse syntactic structure, text length, error density, and the use of emojis and photographs to identify systematic differences in reporting styles across two sociological dimensions: mission role (commanders vs. engineers) and gender (women vs. men). By isolating objective behavioural markers associated with these factors, the study contributes to refining astronaut selection processes and developing evidence-based behavioural monitoring strategies for future autonomous missions.

2. Materials and Methods

2.1 Study Setting and Cohort

Data were collected during eight consecutive analogue space missions (AM-102 to AM-109) at the Analog Astronaut Training Center (AATC). The cohort included 51 international analogue astronauts with backgrounds in engineering, medicine, and information technology. Each participant completed a standardized 7-day (168-hour) isolation protocol inside a sealed analogue habitat replicating operational constraints of long-duration spaceflight. All participants provided written informed consent, and procedures adhered to the Declaration of Helsinki.

2.2 Data Collection Protocol

The primary dataset consisted of standardized digital Daily Mission Reports completed each evening. The reporting template comprised three structured prompts progressing from subjective to objective domains: (1) psychological/self-expressive reflection, (2) operational/task-oriented reporting, and (3) physiological/living-conditions assessment. This design ensured consistent daily documentation of emotional, operational, and environmental factors.

2.3 Linguistic Metrics and Operationalization

To identify non-invasive behavioural indicators, all reports underwent quantitative psycholinguistic analysis across two sociological dimensions: mission role (commanders vs. crew) and gender. Nine linguistic variables were operationalized within four diagnostic domains:

- Syntactic complexity: frequency of simple vs. complex sentences as a proxy for cognitive processing load.

[7] Pennebaker J. W. (2018). Expressive Writing in Psychological Science. Perspectives on psychological science : a journal of the Association for Psychological Science, 13(2), 226–229. https://doi.org/10.1177/1745691617707315
[8] Oldenburg, R. (1989). The great good place: Cafes, coffee shops, community centers, beauty parlors, general stores, bars, hangouts, and how they get you through the day. Paragon House.
[9] St. Germain, M. T. (2001). Sociability and The Coffee Shack: Testing Oldenburg's Concept of the Third Place (Master's thesis, Carleton University). National Library of Canada.
[10] AATC. (2026). Human Spaceflight Science and Education. https://www.astronaut.center/
[11] Mota, N. B. (2023). How can computational tools help to understand language patterns in mental suffering considering social diversity. Psychiatry Research, 319, 114995. https://doi.org/10.1016/j.psychres.2022.114995

- Affective expression: frequency of emojis and photographic attachments, reflecting digital affective coping strategies.
- Cognitive degradation: density of linguistic and typographical errors, used as an indirect measure of attentional depletion and neurocognitive fatigue.
- Social adaptation: narrative orientation assessed through pronominal focus (self- vs. group-oriented language) and a social deixis index quantifying explicit naming of crew members versus anonymized references, with higher anonymization interpreted as increased interpersonal distancing.

3. Results

3.1. Quantitative and Syntactic Profiles According to Mission Role: Commanders versus Crew Members

Quantitative analyses revealed marked differences in reporting behaviour between commanders and crew members (Table 1 and Table 2 respectively). On average, commanders produced substantially longer daily reports than crew members, with a mean total of 281.0 words per report compared with 177.0 words, respectively. This difference was most pronounced in Question 1 (psychological/self-expressive domain), where commanders wrote an average of 138.3 words, whereas crew members produced 73.9 words. Smaller, yet consistent, differences were also observed in Question 2 (operational domain), with commanders and crew members producing 101.0 and 78.6 words, respectively, and in Question 3 (physiological/living conditions domain), where the corresponding values were 41.7 and 24.5 words.

Analysis of syntactic structure further demonstrated greater linguistic complexity in commanders' reports. The mean density of complex sentences was 12.0 among commanders, compared with 7.7 among crew members. In contrast, the density of simple sentences was comparable between the two groups, averaging 2.3 and 2.1, respectively.

The overall mean density of linguistic errors was 1.9 for both groups. However, temporal analyses across the seven-day mission (Days 1–7) revealed distinct trajectories. Commanders exhibited a progressive decline in error density, from 2.8 errors on Day 1 to 1.2 errors on Day 7, indicating gradual linguistic stabilization over the course of the mission. Crew members, in contrast, began with a slightly higher error rate (2.93 on Day 1), which decreased to 1.78 on Day 3 and 1.62 on Day 4 before increasing again to 1.82 on Day 6. This pattern coincided with a marked reduction in text production, with the average report length declining from 264.27 words on Day 1 to 160.84 words on Day 4, followed by a further decrease to 131.22 words on Day 7.

The use of emojis was infrequent and did not differ between the two groups, with a mean frequency of 0.2 emojis per report for both commanders and crew members.

Mission Day	Words (Q1)	Words (Q2)	Words (Q3)	Total Words	Simple Sentences	Complex Sentences	Photographs	Emojis	Linguistic Errors
Day 1	214.5	122.5	56.5	393.5	2.8	18.5	0.2	0.3	2.8
Day 2	197.7	132.2	49.2	379	2.3	15.8	0.8	0.5	2.8
Day 3	124.2	128	39	291.2	2.2	12.3	0.2	0.3	1.2
Day 4	134.5	114	38.5	287	2.3	10.7	0.3	0	2.5
Day 5	132.3	114.3	85	331.7	2.5	14.3	0	0.3	1.2
Day 6	72.2	70.8	13	156	2	6.3	0.3	0	1.8
Day 7	92.7	25.2	10.5	128.3	1.7	5.7	0	0.3	1.2
Mean	**138.3**	**101**	**41.7**	**281**	**2.3**	**12**	**0.3**	**0.3**	**1.9**

Table 1. Mean daily psycholinguistic characteristics of mission commanders across the 7-day analogue mission. Note. Q1 = psychological/self-expressive domain; Q2 = operational/task-oriented domain; Q3 = physiological/living conditions domain. Values represent daily means for mission commanders.

Mission Day	Words (Q1)	Words (Q2)	Words (Q3)	Total Words	Simple Sentences	Complex Sentences	Photographs	Emojis	Linguistic Errors
Day 1	106.49	119.53	38.24	264.27	2.16	12.49	0.18	0.22	2.93
Day 2	69.91	101.16	29.6	200.67	2.49	8.76	0.09	0.29	2.04
Day 3	61.91	85.44	23.8	171.16	2.13	7.24	0.13	0.16	1.78
Day 4	68.76	69.8	22.29	160.84	1.89	6.84	0.13	0.09	1.62
Day 5	61.64	60.56	23.13	145.33	2.07	5.84	0.09	0.13	1.73
Day 6	81.64	63.78	20.33	165.76	2.04	6.93	0.07	0.09	1.82
Day 7	67.29	49.78	14.16	131.22	2.04	5.56	0.11	0.11	1.2
Mean	**73.9**	**78.6**	**24.5**	**177**	**2.1**	**7.7**	**0.1**	**0.2**	**1.9**

Table 2. Mean daily psycholinguistic characteristics of crew members across the 7-day analogue mission. Note. Q1 = psychological/self-expressive domain; Q2 = operational/task-oriented domain; Q3 = physiological/living conditions domain. Values represent daily means for all crew members excluding mission commanders.

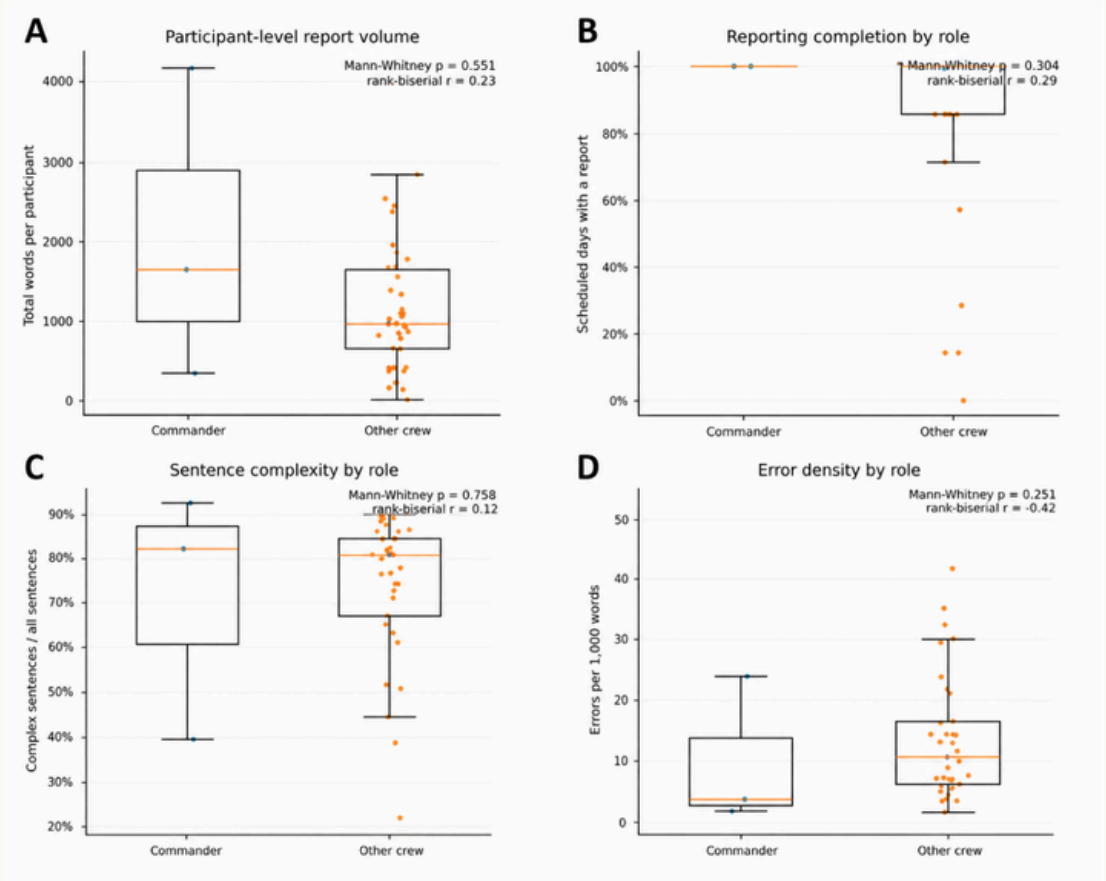


Figure 1. Linguistic characteristics of commanders and other crew members across analog missions. Chart A (upper left) presents the cumulative number of words produced by commanders and the remaining crew members throughout all analyzed analog missions. The complete corpus comprised 68,557 words, of which commanders contributed 8,198 words (12.0%) and the remaining crew members contributed 60,359 words (88.0%). This distribution primarily reflects the larger number of non-commander participants and therefore provides a descriptive overview of corpus composition rather than an inferential comparison. Chart B (upper right) compares reporting completion rates between the two groups. Although commanders exhibited slightly higher reporting completion than the remaining crew members, the difference was not statistically significant (Mann–Whitney U test, $p > 0.05$), with only a small-to-moderate effect size. Chart C (lower left) illustrates the proportion of complex sentences used in daily reports. Commanders showed a tendency toward greater use of complex sentence structures; however, substantial overlap between the distributions resulted in no statistically significant group difference ($p > 0.05$). Chart D (lower right) compares writing-error density expressed as the number of errors per 1,000 words. Commanders demonstrated a lower median error density than the remaining crew members, suggesting a trend toward greater linguistic accuracy. Nevertheless, this difference was not statistically significant ($p > 0.05$), despite representing the largest observed effect size among the analyzed linguistic measures.

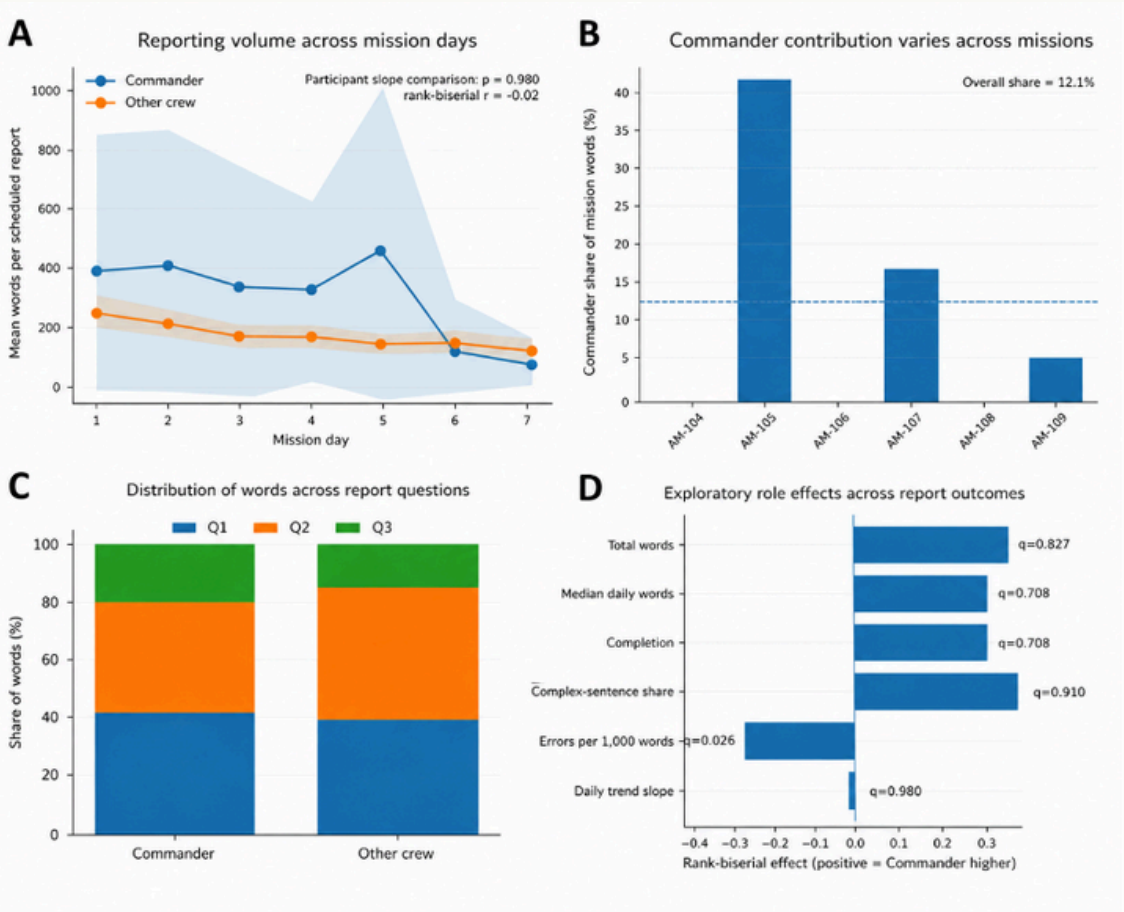


Figure 2. Temporal and linguistic characteristics of reporting behavior across analog missions. Chart A (upper left) illustrates changes in report length over successive mission days for commanders and the remaining crew members. Reporting behavior remained relatively stable throughout the missions, with only modest day-to-day fluctuations and no consistent increase or decrease in report length over time. Chart B (upper right) presents the proportion of the total written corpus contributed by commanders in each analyzed analog mission. Although the relative contribution of commanders varied between missions, they consistently accounted for a minority of the total report volume, and no systematic mission-specific pattern was observed. Chart C (lower left) summarizes the distribution of words across the three report sections (Q1–Q3). The majority of written content was concentrated in the primary reporting section, whereas the remaining sections contributed comparatively smaller proportions of the total text. This distribution was consistent across missions, indicating a stable reporting structure throughout the study. Chart D (lower right) summarizes standardized effect sizes for all analyzed role-related comparisons. None of the evaluated linguistic measures reached statistical significance after correction for multiple comparisons ($p > 0.05$). The largest effect was observed for writing-error density, followed by report length and reporting completion, whereas sentence complexity demonstrated only a minimal effect, indicating that crew role explained only a limited proportion of the variability in written communication.

4. Discussion

This study explored whether linguistic features of daily mission reports varied by crew role and demographic characteristics during short-duration analog missions. Although most comparisons were not statistically significant, several consistent patterns illuminate communication behaviour under isolation and operational stress.

Commanders generally produced longer and more syntactically complex reports, particularly in introspective and operational sections. These tendencies align with expressive writing theory and may reflect the heightened cognitive and emotional demands of leadership rather than differences in communication ability. Their lower error density further suggests relatively preserved executive functioning during confinement.

Crew members tended to use simpler structures and showed higher error density, likely representing adaptive linguistic simplification under cognitive load—a pattern consistent with prior ICE research. Demographic trends indicated that women produced more elaborate operational descriptions and used more visual elements, potentially reflecting alternative strategies for maintaining social connectedness [11]. Slightly higher error density among women may reflect greater expressive engagement rather than reduced linguistic competence.

Temporal patterns showed largely stable linguistic behaviour, with modest mid-mission reductions resembling the "Third-Quarter Effect," suggesting that even short isolation periods can produce measurable changes in written communication [12]. Because language integrates emotional and cognitive processes, longitudinal linguistic analysis may serve as a sensitive, non-invasive indicator of crew adaptation [13].

These findings highlight the potential of computational linguistics as an operational behavioural-monitoring tool [14]. Automated analysis of report length, complexity, and accuracy could complement traditional assessments by providing continuous, unobtrusive measures of cognitive load and emotional state during future missions.

Limitations include small sample size—especially among commanders—short mission duration, and uncontrolled individual differences in writing style. Thus, results should be interpreted as exploratory.

[12] Anikushina, V. (2024). The way we speak, the way we feel: How do language patterns reveal stress? A study on long-term human isolation (Doctoral dissertation, Heidelberg University). heiDOK. https://doi.org/10.11588/heidok.00035219

[13] Malgaroli, M., Hull, T. D., Zech, J. M., & Althoff, T. (2023). Natural language processing for mental health interventions: a systematic review and research framework. Translational psychiatry, 13(1), 309. https://doi.org/10.1038/s41398-023-02592-2

[14] Gomez-Perez, J. M., García-Silva, A., Leone, R., Albani, M., Fontaine, M., Poncet, C., Summerer, L., Donati, A., Roma, I., & Scaglioni, S. (2022). Artificial intelligence and natural language processing and understanding in space: A methodological framework and four ESA case studies (arXiv:2210.03640). arXiv. https://arxiv.org/abs/2210.03640

5. Acknowledgments

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WOMEN BEYOND EARTH: HEALTH, PSYCHOLOGICAL ADAPTATION AND CREW COHESION IN ANALOG SPACE MISSIONS



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The aerospace industry, once an exclusively male-dominated sector, is increasingly opening its doors to women. Yet, while more women than ever are actively involved in space exploration today, deep systemic data gaps and operational imbalances persist. From astronauts to engineers and planetary scientists, women continue to navigate institutional barriers despite their proven capabilities and critical contributions to the field. When we examine this sector through a gender-specific lens, we observe both the remarkable socio-cultural progress achieved over the last few decades and the substantial scientific work that remains to be done to ensure true equity and safety in long-duration space flight.

As of 2026, only four women have ever served as commanders of the International Space Station (ISS), beginning with Peggy Whitson during Expedition 16 in 2007, followed by Sunita Williams, Shannon Walker and Samantha Cristoforetti. While low Earth orbit (LEO) is slowly becoming more logistically and culturally diverse, our understanding of sex and gender differences regarding leadership, cognitive pacing, and psychosocial endurance in isolated, confined, and extreme (ICE) environments remains remarkably limited.

Historically, low female participation in both actual spaceflight and high-fidelity terrestrial analogs has severely restricted the volume of granular data available on how women lead, communicate, and adapt behaviorally to long-term isolation. (Elsangeedy et al., 2024) As a physician and an analog astronaut, I occupy a unique dual vantage point within this paradigm. My medical training demands an objective, evidence-based focus on the physiological and psychological biomarkers of stress and adaptation. Conversely, my operational experience within the habitat provides firsthand, subjective insight into the subtle socio-emotional dynamics, collective care routines, and interpersonal micro-behaviors that formal telemetry often misses. By blending hard medical metrics with astrosociological observation, we can better understand how the human dimension functions in isolation.

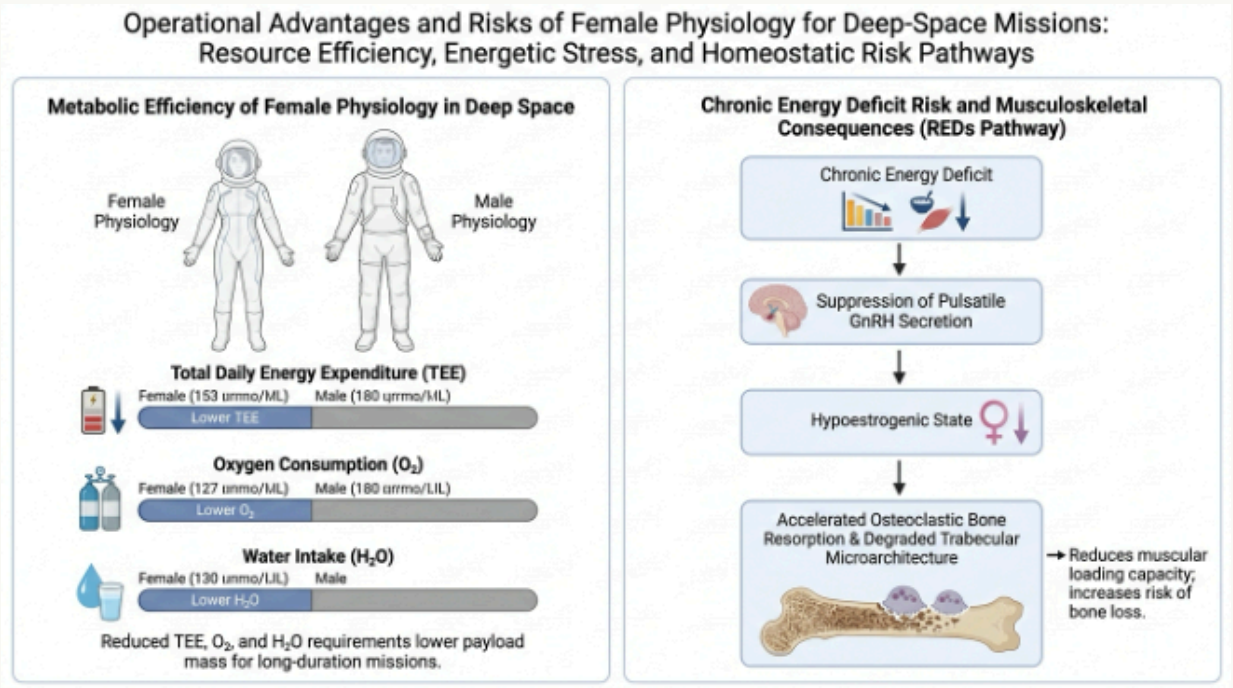
Space medicine and life-support systems have been developed primarily around male physiological models. As exploration missions extend to the Moon and Mars, integrating sex-specific physiological considerations into mission design has become an operational necessity, with space analogs serving as critical platforms for investigating female health and adaptation in isolated and confined environments. (Leon et al., 2011)

Far from being an operational liability, evidence suggests that female physiology possesses substantial metabolic and structural advantages for long-duration deep-space transit. Rather than adjusting male baselines post hoc, mission architecture must systematically integrate female physiological profiles from the foundational planning phase.

Circadian Rhythm Alterations and Transcriptomic Stress Signaling: Isolated, Confined, and Extreme (ICE) environments inherently disrupt the suprachiasmatic nucleus (SCN) pacemaker due to modified spectrum lighting regimes, high operational workloads, and rigid habitat scheduling. Longitudinal multi-omic profiling from the Space Omics and Medical Atlas (SOMA) shows that these environmental disruptions trigger sex-linked adjustments at the cellular level. When subjected to prolonged sleep restriction and microgravity analog conditions, female biological profiles exhibit distinct transcriptomic and metabolic adjustments. Specifically, spaceflight-induced stress leads to differential gene expression profiles linked directly to insulin regulation and estrogen receptor pathways. Concurrently, female biological systems show unique alterations in mitochondrial function and systemic oxidative stress responses. Rather than returning immediately to homeostasis, female physiological profiles indicate a protracted timeline to restore baseline metabolomic and inflammatory markers following severe isolation stress. Tracking these molecular markers in analog environments allows medical officers to anticipate cognitive fatigue and dynamically optimize crew scheduling.(Women's Health in Space, n.d.)

Resource Scaling, Metabolic Efficiency, and Lean Mass Homeostasis: From a logistics and mass-allocation perspective, female physiology offers unique operational advantages for deep-space missions. Principles of metabolic scaling and terrestrial telemetry demonstrate that women maintain a lower total daily energy expenditure (TEE) compared to men, consuming significantly less mass in oxygen O_2 and water H_2O, and requiring lower total caloric intake to execute identical task matrices.This metabolic efficiency reduces the initial payload mass required for multi-year Martian transits. However, this lower caloric threshold must be balanced against the risk of Relative Energy Deficiency in Sport (REDs) during high-workload surface operations. In closed analog habitats, restricted caloric consumption paired with intense physical expenditure can trigger a downregulation of the hypothalamic-pituitary-gonadal (HPG) axis. (Strock et al., 2023) The resulting chronic energy deficit suppresses the secretion of pulsatile gonadotropin-releasing hormone (GnRH), inducing a hypoestrogenic state that accelerates bone resorption and degrades muscular loading capacity.

Endocrine Manipulation and Menstrual Health Logistics: Managing menstrual physiology within closed, recycling life support loops introduces complex pharmacological and engineering challenges. To eliminate the logistical mass overhead of sanitary hardware and prevent the introduction of blood products into standard vacuum-based waste processing units, a significant majority of female crew members utilize continuous combined oral contraceptive pills (COCPs) or long-acting reversible contraceptives (LARCs), such as subdermal progestin implants or intrauterine devices (IUDs). While effective for amenorrhea, continuous exogenous hormone delivery modifies the baseline endocrine milieu. Estrogen plays an essential protective role in regulating bone mineral density (BMD) by inhibiting osteoclast activity and maintaining vascular endothelial compliance.(Platts et al., 2014)



High-resolution peripheral quantitative computed tomography (HR-pQCT) tracking reveals that spaceflight induces a threefold increase in bone resorption over bone formation, targeting trabecular microarchitecture.(Matuszek et al., 2026) If pharmacological suppression induces or exacerbates hypoestrogenism, the rate of trabecular bone loss accelerates. Analog research must monitor these cyclic and suppressed endocrine states alongside bone turnover markers (e.g., C-terminal telopeptide) to calibrate targeted mechanical resistance protocols.

Anatomical and Microbiome Manifestations in Extreme Environments: Preventive medicine in extreme isolation requires a detailed understanding of distinct anatomical and microbiological vulnerabilities:

- **Orthostatic Intolerance (OI):** Upon transitioning between gravity fields (or following ground-based bed rest analogs), returning female astronauts experience orthostatic intolerance and presyncope at a rate nearly five times higher than their male counterparts.(Summers et al., 2010) While previously attributed entirely to autonomic dysregulation, mathematical models of cardiovascular hydraulics reveal a primary structural mechanism: women possess an 8% to 15% lower longitudinal center of gravity (center of mass relative to height). This anatomical differentiation, combined with higher lower-extremity vascular compliance, leads to significant pooling of blood within the venous capacitance vessels of the pelvis and lower limbs. This severely limits venous return and causes a profound drop in mean arterial pressure (MAP) upon standing.(Summers et al., 2010)

- **Urogenital Pathology & Microbiome Shifts:** Postflight medical debriefs highlight an increased incidence of acute, ascending urinary tract infections (UTIs) among female crew members. Microgravity and isolation conditions induce significant shifts in the human microbiota, often reducing symbionts like Lactobacillus and promoting the growth of opportunistic pathobionts. Under microgravity conditions, primary uropathogens such as E. coli exhibit enhanced growth kinetics, upregulation of virulence factors, and increased adherence to uroepithelial cells via surface adhesion molecules. This risk is compounded by the fact that certain pathogens display a higher minimum inhibitory concentration (MIC) for standard antibiotics in space. If standard terrestrial dosing is applied, the antibiotic concentration may fall into a subinhibitory range, inadvertently increasing the expression of bacterial adhesins and driving recurrent, deep-tissue infections. (Urbaniak & Reid, 2016)

By utilizing terrestrial space analogs to evaluate these specific physiological variables—ranging from fluid shift mechanics to changes in the urogenital microbiome—space medicine can transition from reactive clinical care to proactive, human-centered mission architecture. A nominal three-year exploratory mission to Mars introduces a series of unprecedented neurobehavioral demands grouped under NASA's "Isolation and Confinement" risk category. Unlike low Earth orbit (LEO) operations on the International Space Station (ISS), an interplanetary crew will pass the "Earth-Out-of-View" phenomenon, a psychological tipping point where the home planet diminishes to a microscopic dot. This loss of visual grounding is paired with severe propagation delays in communications, ranging from 6 to 44 minutes round-trip depending on orbital mechanics. Because real-time synchronous conversation with family and mission control is logistically impossible, crews must rely on asynchronous emails, text transmissions, or prerecorded video files. Under these conditions, psychological resilience cannot be treated solely as a static, individual trait quantified during pre-mission selection; rather, it is an emergent property maintained through shared operational routines, deliberate reflection practices, and collective peer support networks.

Cognitive Adaptation Profiles and Narrative Disclosures: Analyses of historical spaceflight telemetry and high-fidelity terrestrial analogs reveal distinct, sex-linked patterns in cognitive pacing, coping mechanisms, and emotional processing within Isolated, Confined, and Extreme (ICE) environments. Content analysis of standardized astronaut journal entries indicates that male and female crew members process long-duration isolation through different narrative structures and behavioral profiles. While male crew members frequently exhibit a mid-mission drop in mood —often coinciding with the transition from highly structured operational phases to repetitive maintenance profiles—female counterparts demonstrate unique emotional endurance over extended mission timelines. This performance is characterized by an active willingness to utilize narrative journaling as a structured cognitive offloading tool.

Furthermore, psychometric evaluations and objective behavioral tracking, such as the Psychomotor Vigilance Test (PVT), indicate that while baseline cognitive performance, sleep architecture disruption, and acute stress perception remain uniform across genders, women often demonstrate a more extensive vocabulary for identifying and resolving interpersonal stressors within confined habitats.(Struster, 2013) This tendency allows for early interventions before interpersonal friction degrades mission safety.

Terran Analogs: Lessons from High-Latitude Overwintering: High-fidelity terrestrial space analogs, particularly polar overwintering research deployments, offer clear empirical data on how mixed-gender crews adapt to extreme, long-duration isolation. Longitudinal behavioral studies tracking personnel deployed with the British Antarctic Survey (BAS) across multi-month winter-over cycles demonstrate that gender is a statistically significant predictor for operational adaptation in isolated habitats. Within these cohorts, female personnel were consistently assigned an "exceptionally well-adapted" rating by their respective station commanders. This clinical observation correlates with distinct behavioral strategies: while male cohorts often excel in highly structured, immediate, goal-oriented mission blocks, female cohorts demonstrate superior adaptive capacity when managing unexpected, ill-defined habitat challenges and prolonged operational lulls. This socio-emotional adaptability is tied to a psychological concept known as "permeable personal space requirements." In tight habitat spaces like the Mars Desert Research Station (MDRS) or deep-space transit vehicles, personal privacy is limited. Early NASA human factors research suggests that women generally display higher comfort thresholds and lower interpersonal friction scores when operating in close, shared physical boundaries. This spatial flexibility directly limits the emergence of toxic subgrouping and spatial territoriality, which frequently disrupt crew cohesion during long-duration missions.

Preparing humanity for a long-duration mission to Mars requires a fundamental shift in aerospace architecture. Women's physiological, metabolic, and neurobehavioral profiles are not peripheral variations of a male baseline; they represent distinct, highly adaptive pathways that may offer significant advantages for deep-space transit and resource management. The data indicates that female crews present a highly efficient operational footprint. Preparing women for life beyond Earth requires a paradigm shift that looks far beneath the surface of physiological baselines alone. While sex-specific biomedical research, metabolic optimization, and pharmacokinetic tailoring are absolute prerequisites for mission safety, physical survival is merely the baseline of exploration. True mission success on a three-year journey to Mars demands equal attention to identity, interpersonal relationships, psychological well-being and the intentional development of social structures that enable human flourishing in isolation. Terrestrial space analogs serve as a powerful reminder of this reality: future interplanetary settlements will not be merely cold, mechanical outposts or rigid engineering projects. They will be communities. Preserving our humanity as we venture into deep space means discarding the historic, hyper-individualistic frameworks of early aerospace eras and embracing the full, diverse spectrum of human experience and leadership.

1.Elsangeedy, E., Yamaleyeva, D. N., Edenhoffer, N. P., Deak, A., Soloshenko, A., Ray, J., Sun, X., Shaltout, O. H., Cruz-Diaz, N., Westwood, B., Kim-Shapiro, D., Diz, D. I., Soker, S., Pulgar, V. M., Ronca, A., Willey, J. S., & Yamaleyeva, L. M. (2024). Sex-specific cardiovascular adaptations to simulated microgravity in Sprague-Dawley rats. Npj Microgravity, 10(1), 110. https://doi.org/10.1038/s41526-024-00450-z

2.Leon, G. R., Sandal, G. M., & Larsen, E. (2011). Human performance in polar environments. Journal of Environmental Psychology, 31(4), 353–360. https://doi.org/10.1016/j.jenvp.2011.08.001

3.Matuszek, I., Badowska, N., Wiśniewski, B., Pachnowska, D., Pluta, N., Nowak, K. A., Rutkowska-Nowosielska, A., Czekanow, O. N., Kania-Bonicka, Z., & Demkow, J. (2026). MICROGRAVITY AND SKELETAL DECONDITIONING: A NARRATIVE REVIEW OF BONE DENSITY LOSS AND EXERCISE COUNTERMEASURES IN ASTRONAUTS. International Journal of Innovative Technologies in Social Science, 3(2(50)). https://doi.org/10.31435/ijitss.2(50).2026.5793

4.Platts, S. H., Bairey Merz, C. N., Barr, Y., Fu, Q., Gulati, M., Hughson, R., Levine, B. D., Mehran, R., Stachenfeld, N., & Wenger, N. K. (2014). Effects of sex and gender on adaptation to space: Cardiovascular alterations. Journal of Women's Health, 23(11), 950–955. https://doi.org/10.1089/jwh.2014.4912

5.Strock, N., Rivas, E., & Goebel, K. M. (2023). The Effects of Space Flight and Microgravity Exposure on Female Astronaut Health and Performance. 2023 IEEE Aerospace Conference, 01–12. https://doi.org/10.1109/AERO55745.2023.10115765

6.Struster. (2013, August 24). Behavioral Issues Associated With Long Duration Space Expeditions: Review and Analysis of Astronaut Journals. https://ntrs.nasa.gov/citations/20100026549

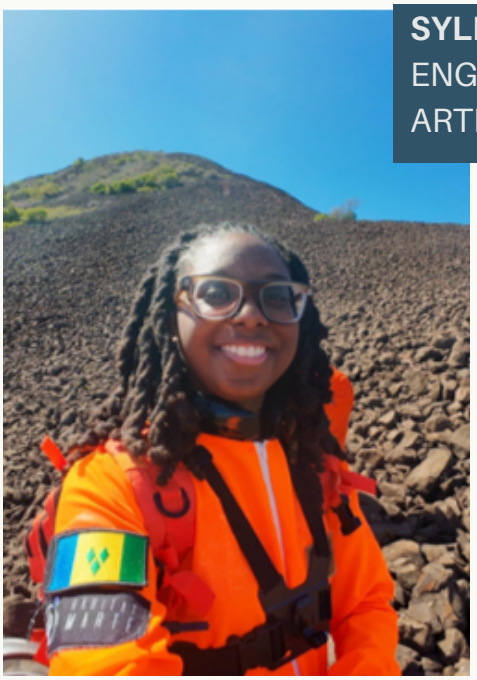
7.Summers, R. L., Platts, S., Myers, J. G., & Coleman, T. G. (2010). Theoretical analysis of the mechanisms of a gender differentiation in the propensity for orthostatic intolerance after spaceflight. Theoretical Biology and Medical Modelling, 7(1), 8. https://doi.org/10.1186/1742-4682-7-8

8.Urbaniak, C., & Reid, G. (2016). The Potential Influence of the Microbiota and Probiotics on Women during Long Spaceflights. Women's Health, 12(2), 193–198. https://doi.org/10.2217/whe.15.101

9.Women's Health in Space. (n.d.). Retrieved https://health.usf.edu/medicine/obgyn/research/womens-health-in-space



DIARY OF AN ANALOG ASTRONAUT: FEATURING BIOCENTRIC REFLECTIONS FROM THE EDGE OF ISOLATION



SYLEEN EDWARDS
ENGINEER AT COLLINS AEROSPACE SUPPORTING NASA'S ARTEMIS MISSIONS.

T-1 Sol: Breaking Bread
Pre-Mission Dinner
Location: Ponta Negra, Natal, Rio Grande do Norte, Brazil

After traveling from Hartford, Connecticut, to Ponta Negra, Natal, I finally met the crew for dinner at a restaurant called Camarões. We started with Pastel de Camarão, a light, bubbly fried pastry, before moving on to a massive serving of Camarão à Grega. This was breaded shrimp over "Greek rice" (tossed with peas, carrots, ham, and raisins), loaded with tomato sauce, melted mozzarella, and shoestring potatoes. It was a heavy, solid meal, but it felt right once Professor Rezende mentioned that the people of Rio Grande do Norte are actually called "Potiguares," an indigenous Tupi word meaning "shrimp eaters"[2]. Sharing the city's cultural lifeblood was a perfect way to ground ourselves in the local environment before the isolation of the mission begins tomorrow. We spent a good chunk of the night going over logistics and confirming the official pickup time for tomorrow morning.

Reflection

Physically, I'm exhausted. Fifteen hours in transit is no joke. Mentally, I'm feeling anxious, primarily because I just learned that the chamber for the ceramics for my experiment is cracked. I'm not sure if we have enough of a buffer to troubleshoot that and still get the results we need.

The human element adds another layer of complexity. While I'm here from the U.S. representing Saint Vincent and the Grenadines, I'm working alongside Omana Munoz, Espinosa Omana, and Eufracio Rojas (native Spanish speakers from Mexico) as well as Hazbun, Rezende, and Matheus (native Portuguese speakers from Brazil).

I'm not necessarily worried about "friction" in a negative sense, but I'm realistic about the fact that navigating deep cultural nuances and language barriers is incredibly tough to do in just a one-week span, especially when you're trying to run a technical mission. That said, there's a cool biocentric element to this that I'm trying to focus on. Even with three different primary languages and completely different backgrounds, we're all sitting here doing the same basic human things: eating, planning, and exploring.

It's a reminder that regardless of the language we speak, our biology and the drive to explore are identical. We are life trying to understand its own potential. Excited to get started, despite the hurdles. Tomorrow we head to the habitat.

Sol 1: Landing, Life Support, and Looking Up
Location: Commute from Ponta Negra, Natal, Rio Grande do Norte,Brazil to Caiçara do Rio do Vento, Rio Grande do Norte,Brazil
Body Weight: 52.16 kg (115 lb)
Cups of Water: [1] 6
Sleep: 7.8 hours
Arrival
The 45-minute commute from the pickup location to Habitat Marte served as our first real chance to mesh. We spent the drive discussing our professional backgrounds, and it's a heavy-hitting crew (Appendix A). Rezende, our coordinator, is a sustainability professor at the Federal University of Rio Grande do Norte; Espinosa Omana is a science teacher and, as Greenhouse Officer, will be specializing in greenhouse operations; and Omana Munoz, at just 17, is our Chief Scientist and already deep into biomedical engineering studies. Eufracio Rojas, a Forbes Mexico "30 Under 30" honoree, is a pioneer in space genetic microbiology and will serve as the Crew Scientist. Matheus, a physiotherapist, will be our Workout Specialist, while Hazbun, an aspiring Brazilian Air Force pilot, joins us as our Wellbeing Researcher. After listening to their impressive backgrounds, I, Mission Commander and Chief Engineer shared my own work as an engineer supporting the NASA Artemis missions, highlighting how my experience with space systems informs my approach to this analog environment.

Walkthrough and Systems Check
Upon arrival, we conducted a full walkthrough of the facility, followed by a comprehensive review of the previous crew's protocols for monitoring resource consumption.This audit was critical to establishing our baseline resource management; understanding the existing consumption curves and storage levels allowed us to identify potential efficiencies such as installing new lighting, upgrading the airlock for larger crews, and enhancing aspects of the greenhouse to improve crop survival in this Brazilian semi-arid region.

We also discussed our daily routines including exercise, meal prep, and EVAs alongside our specialized roles. As the Mission Commander and Chief Engineer, my focus will be split between mission oversight and my own research.

Over the 11 months I spent preparing for the mission—in addition to various physical endurance and strength training and practicing different leadership styles—I also designed an experiment to test the 3D printing of Martian regolith using microwave-based sintering. This is a potential game-changer for sustainable off-world construction, as it uses focused electromagnetic energy to fuse planetary soil into solid structures.

Beyond my primary research, I was put in charge of technological enhancements for the aquaponics system and greenhouse, while simultaneously evaluating the life support system upgrades for our suits.

From Greenhouse to Table: The First Harvest

Once the walkthrough was complete and our roles were clearly defined, Espinosa Omana began harvesting fresh vegetables from the greenhouse in preparation for lunch. Our first meal consisted of chicken, lettuce, onions, tomatoes, green peppers, peas, and rice (Figure 1).



Figure 1: Meal 1 (chicken, lettuce, onions, tomatoes, green peppers, peas, and rice).

Cultivating Microgreens

Following lunch, we took steps to replenish our food supply while supporting the maintenance of atmospheric oxygen levels. Espinosa Omana and I began cultivating microgreens in green floral foam, preparing them for transplantation into a specialized, automated growing box developed by Grobotic Labs (Figure 2). The system is designed to maintain precise growing conditions—such as humidity, temperature, and light cycles—while protecting the plants from the surrounding semi-arid environment



Figure 2: Grobotic Labs grow box.

Although this task typically falls under the greenhouse officer's responsibilities, I assisted in my role as Chief Engineer because the Grobotic unit had never previously been tested at the facility. Working alongside Espinosa Omana, I helped oversee its initial operation and performance. By creating an isolated microclimate, the system prevents rapid dehydration and heat stress that would otherwise threaten young seedlings in a desert-like atmosphere. To ensure the crop's success, daily watering of the microgreens was assigned to Espinosa Omana for the remainder of the mission (Figure 3).

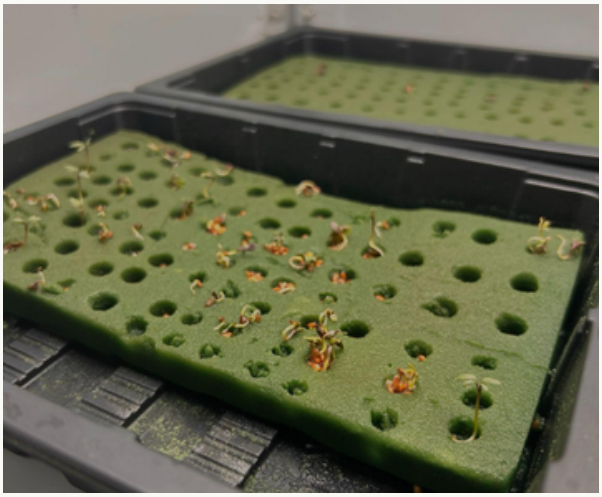


Figure 3: Microgreen development.

Conceptual EVA Life Support System Design

With our food production system stabilized, my attention turned to surface operations after I immediately identified several design and usability issues while suiting up for our first EVA. The suit quickly became uncomfortably hot, offered no practical access to drinking water, and its rigid geometry severely restricted my ability to look downward. In addition, operating electronic devices proved difficult, as the thickness of the gloves rendered touchscreens largely unusable.

While I was waiting for my crew mates to finish suiting up, I started making preliminary notes on suit modifications to address critical mission bottlenecks, focusing on a total integration of life support and interface.

My first priority was active thermal regulation, designed to keep the user's neck and back cool in 45 °C (113 °F) conditions. As shown in Figure 4, I conceptualized an integrated life-support system —essentially a "Smart CamelBak" with air-conditioning capabilities powered by high-density batteries and flexible solar arrays embedded in the suit. Reliable access to drinking water remains fully integrated, with a 3-liter bladder serving both as a hydration source and as a thermal buffer within the cooling loop, ensuring consistent hydration while enhancing the system's overall efficiency.

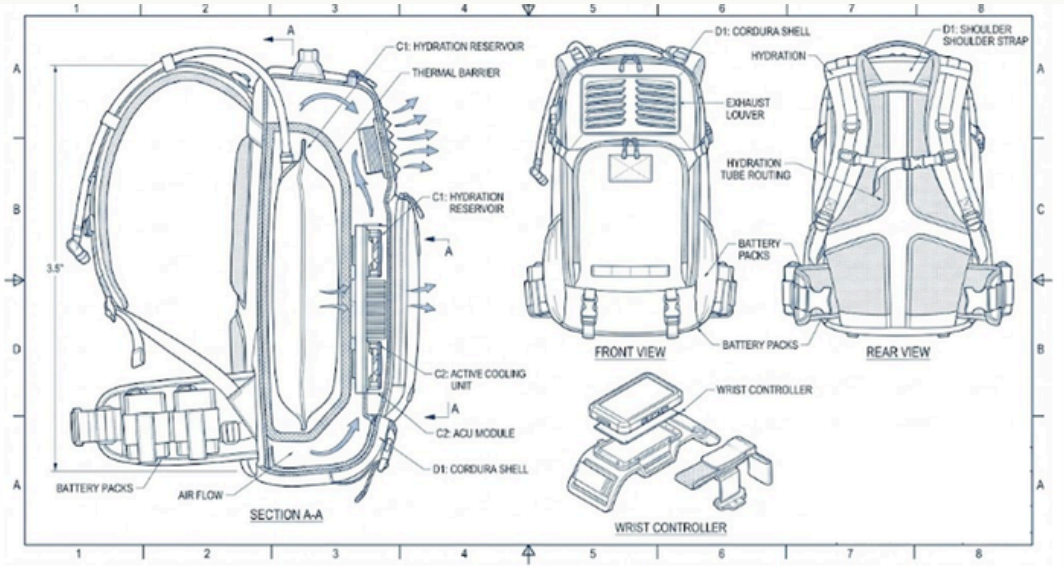


Figure 4: Conceptual life-support system for analog mission EVAs/hiking[5]

Unlike a standard CamelBak, which relies on passive insulation that eventually fails in extreme heat, my design incorporates a Peltier-based active cooling system. The Peltier module is housed inside a sealed bulkhead, creating a dual-loop system. Its cold plate sits within an insulated cooling chamber, while the hot plate is exposed externally in an exhaust flue. This separation prevents hot exhaust air from mixing with the cooled airflow.

The Peltier module contains n-type and p-type semiconductors connected in series. When a DC current is applied, electrons carry thermal energy from the cold plate to the hot plate. Heat is extracted from the cold plate faster than it can leak back in, keeping the cooling chamber lower in temperature. Three key features reduce "bleed-back":

1. Axial Exhaust Fan – continuously removes heat from the hot-side heat sink.
2. Sealed Bulkhead – physically isolates the hot and cold sides.
3. Water Bladder – acts as a thermal mass, absorbing stray heat and stabilizing the cold loop.

On the user side, a high-velocity blower pulls air through a filter and across the cold plate. The chilled air is routed through a sealed manifold and directed onto the user's neck and torso. Because the loop is sealed, hot air cannot mix with the cold airflow.

The hot-side loop operates independently. A secondary fan draws ambient air across the hot plate and expels it through louvers angled away from both the user and the cold intake, preventing recirculation of heat.

Hydration is fully integrated into the system. The 3-liter water bladder serves as the primary heat sink. Its high heat capacity absorbs excess heat from electronics and ambient spikes. The drinking tube is coiled inside the cold chamber, in contact with the cold plate. This "Cold-Sip" loop chills water just before consumption, providing both a refreshing drink and an additional thermal buffer.

The exo-chassis maintains a 1.5-inch gap between the pack and the user's back, creating a buffer zone. Hot air is expelled upward and outward, while the cooled air from the cold loop is delivered directly to the torso and neck.

Power comes from high-density batteries, supplemented by integrated solar panels. Smart Power Management pulses the cooling output in short bursts. While the cooling is intermittent at the device level, the user perceives it as continuous relief, reducing overall energy consumption without sacrificing comfort.

The total energy flow is:

Cooling Flow:

$$\text{Electrical Energy (Batteries + Solar)} \rightarrow \text{Peltier Module} \rightarrow \text{Cold Plate} \rightarrow \text{Convective Airflow + Water Bladder Heat Sink} \rightarrow \text{User Cooling}$$

Hydration Flow (Cold-Sip Loop):

$$\text{Electrical Energy (Batteries + Solar)} \rightarrow \text{Peltier Module} \rightarrow \text{Cold Plate} \rightarrow \text{Water Bladder / Coiled Drinking Tube} \rightarrow \text{Chilled Water to User}$$

While this active cooling system is the long-term solution, an ice-pack vest could serve as a short-term fix during shorter EVAs.

Regarding the downward-visibility problem, ranging from a complete helmet redesign to the quick, low-tech fix of strategically placed mirrors. On the higher-tech side, I'm considering downward-facing cameras that feed a live video stream to a display inside the helmet—or even a "virtual floor" projected onto the visor. Navigating a rocky, Martian-like terrain is challenging enough without losing sight of your own footing; we need a way to bring the ground back into the astronaut's field of vision.

Conceptual EVA Glove Design

As depicted in Figure 5, I also conducted preliminary research on specialized gloves with conductive fiber-weave pads, using silver or carbon-infused threads to bridge the body's bio-electricity to capacitive touchscreens.

I believe this approach can overcome the inability to operate digital mission tools while wearing standard protective gear. This "bridge" effect solves the insulation problem of standard textiles, allowing for high-precision tactile feedback and durability without the risk of corrosion from sweat or desert minerals, ensuring we can operate mission-critical tech without de-gloving.

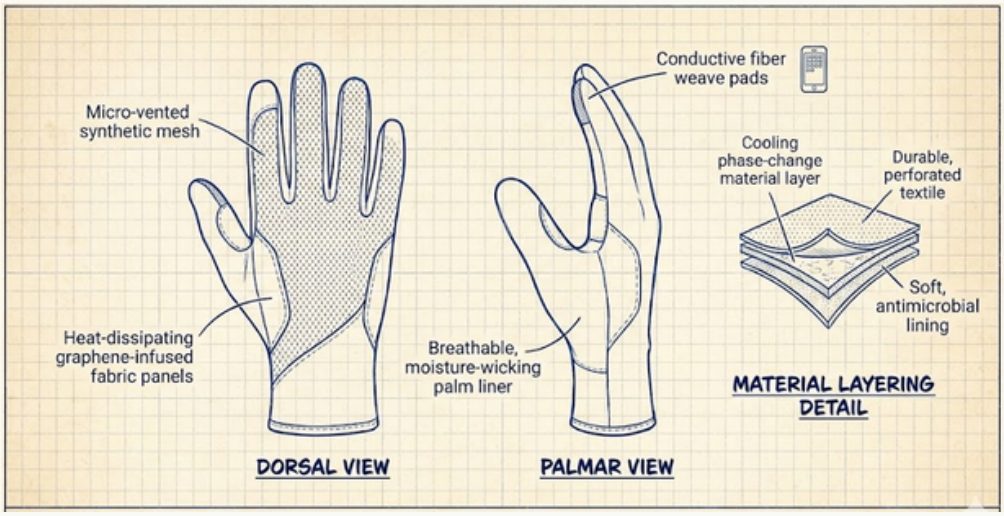


Figure 5: Conceptual EVA glove design[5]

EVA 1: Night Sky Observation

Soon after suiting up, we ventured out for our first EVA, climbing to the top of a dried-up riverbed to take in the night sky. This moment was significant not only for mapping our surroundings—tracking where the sun rises and sets, noting the constellations, observing the rhythm of the stars—but also for the quiet weight of perspective it offered.

The Brazilian night sky, almost untouched by light pollution, revealed tens of satellites drifting silently across the darkness, reminders of human presence scattered across an infinite universe. Also, for the first time in my life, I saw the Milky Way galaxy!

Lying there, I felt a deep connection to everything around me, contemplating the countless paths the atoms composing my body could have taken—and yet, here they were: part of Earth, part of life, part of me.

Above me, the night sky appeared calm and restrained, its stars scattered across the darkness in muted whites (Figure 6). My gaze settled first on Scorpius, arcing boldly across the heavens—ancient, unmistakable, and wholly mythic. From its earliest interpretations, Scorpius has been a creature of story: a celestial embodiment of danger and transformation, born from humanity's instinct to explain the unknown through narrative and symbolism.

Extending outward from Scorpius were the stars that would later become Libra, revealing the first shift in human perception. These stars began as part of the scorpion itself, imagined as its claws and bound to mythological form. Over time, this region of the sky was disentangled from the creature and reimagined by Roman astronomers as scales—an abstract symbol of justice, law, and equilibrium. The stars themselves remained unchanged, yet their meaning evolved, reflecting a transition from myth to concept, from story to principle.

Nearby lay Norma, faint but deliberate, marking a more decisive transformation. Named during the Enlightenment, Norma was never mythological at all. It represents a surveyor's square and rule—tools of measurement, precision, and rational inquiry. Unlike Scorpius, which tells a story, or Libra, which embodies an idea, Norma exists purely as an instrument. Its presence in the sky reflects a moment when humanity no longer sought meaning in narrative or symbolism alone, but in quantification and scientific reasoning.



Figure 6: The night sky (Scorpius, Libra, and Norma).

Together, these constellations traced a progression not of the stars, but of human consciousness: from myth, to abstraction, to measurement. In naming them, we did not alter the cosmos—we revealed how our ways of understanding it had changed. This realization echoed the principles of biocentrism. Meaning does not reside inherently in the universe; it emerges through perception. Just as cosmological theories such as the Big Bang are conceptual frameworks created by conscious observers to interpret the universe, constellations are cognitive constructs—maps shaped by life to impose coherence on an indifferent sky.

To the naked eye, the stars appeared pale and uniform, but the image captured by my camera revealed a richer truth—unexpected blues, cyans, and faint reds shimmering across the sky (Figure 7). These colors acted as cosmic thermometers: blue and cyan stars burning hotter and younger, red stars cooler, older, or more distant, radiating at longer wavelengths. The image underscored how perception filters reality, revealing that what we see depends on how we observe.



Figure 7: The night sky through a camera lens.

Just as the camera exposed wavelengths invisible to human vision, other forms of life may perceive the universe through entirely different sensory ranges—ultraviolet, infrared, or senses beyond our imagination. Yet despite these differences, the source remains shared. Beneath Scorpius, Libra, and Norma, I felt aware of the quiet thread linking all living things to the universe—each of us perceiving it differently, yet all shaped by the same ancient cosmic origins.

Post-EVA 1: Dinner and Bed

After the EVA, we returned to the habitat and carefully stored our suits. Dinner was simple—a reheated pan of leftover lunch, with a few candies from Mexico as a small treat for dessert. The day had been long, and the next promised to be even longer: a 4:30 AM wake-up to climb extinct volcano, Pico do Cabugi.

I took a quick shower, conscious of our limited water supply. Finally, I crawled into what would be my bed for the next five days, exhaustion settling into every muscle, tempered by a quiet satisfaction with what we'd accomplished today (Figure 8).



Figure 9: Pico do Cabugi[4].

The ground transitioned unpredictably from fine sand to solid rock, and eventually to loose, treacherous stones that slid underfoot (Figure 10). To add insult to injury, as Rezende predicted, the heat was not shy at all, radiating off the volcanic rock long before the sun reached its zenith.



Figure 10: Me surrounded by loose rock at the summit.

Initially, I led from the back to monitor the crew's pacing and offer motivation to those struggling with the incline. However, as the heat intensified, I hit a wall of familiar mental friction; a persistent thought that I simply couldn't go on much longer. Without the stability of hiking sticks, the sheer weight of my pack—the heaviest in the group—became a grueling anchor, and the physical strain, already exacerbated by my lack of sleep, began to feel insurmountable.

I soon realized that my mind was trying to quit long before my body was. I knew I had a lot more to give. I decided to shift my tactic and lead from the front to set a decisive pace, pulling the team upward through my own momentum.

I focused on the rhythm of my breath—deep in through my nostrils and slow out through my mouth—using that steady cycle to anchor my focus and quiet the noise of fatigue. Despite members of the crew, including myself, wanting to give up at various parts of the hike up the volcano, we all made it to the summit.

The Summit: Stories and Symbolism

At the top of the volcano, we took a well-earned break and refueled on Ritz cheese crackers I had packed—something the crew, to their knowledge, had never seen sold in Brazil nor Mexico. It was a small, unexpected cultural exchange, shared between deep breaths, tired smiles, and the view from the summit, one that Espinosa Omana returned when she began carefully stacking and balancing volcanic rocks atop one another.

She described in detail how, in some indigenous cultures, these stone towers symbolize the seven chakras—or energy centers—anchoring us to the Earth: the Root for grounding, the Sacral for flow, the Solar Plexus for inner power, the Heart for reciprocity, the Throat for truth, the Third Eye for insight, and the Crown for cosmic connection . She went on to recount stories of the Andean Earth Mother, Pachamama, whose presence embodies the profound interconnectedness of humans and the natural world—reminding us that every step we take, whether on familiar soil or these remote volcanic heights, is part of a larger web of life.

Standing on this ancient volcanic plug, the mission bridged a gap; we weren't just stepping away from the familiar, we were carrying the weight of our history and everything that makes us human onto a new frontier.

The Descent and System Refinement

By the time we concluded the hike at 11:30 AM, the descent had served as a mobile laboratory. As the crew and I navigated the unstable rocks, I devisedtwo major mechanical refinements for my conceptual life support system.

First, I noted that the bottom of the Exo-Chassis should incorporate a spring-suspension system. By mounting the main battery and water mass on a spring-loaded carriage, we can capitalize on the kinetic energy and vertical oscillation produced while walking. The counter-momentum from the springs helps minimize the effective load on the body, especially on steep inclines/declines where jarring impacts lead to spinal compression.

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Second, I made notes to integrate functional weatherproof zips and modular attachment points for tool storage. By the time we reached the base, my conceptual design had evolved into a fully integrated kinetic and thermal exoskeleton, designed to turn the environment's harshness into an engineering advantage.

Post-EVA 2: Return, Recovery, and Lunch

At around noon, we arrived back at the habitat, the dry heat of the peak finally giving way to the controlled environment of our base. We transitioned straight into a recovery lunch: tacos with minas cheese and fresh tomatoes on the side (Figure 11). It was the first moment of relative stillness since 4:30 AM, and I used the communal energy to transition from our morning climb into the high-stakes research ahead.



Figure 11: Lunch post-hike (tacos with minas cheese and fresh tomatoes on the side).

Introduction to Regolith Preparation, 3D Printing, and Sintering

While everyone ate, I began briefing the crew on the Martian Regolith 3D Printing Experiment (Figure 12). This isn't just a technical test; it's about proving we can build a future using the dirt beneath our feet. I handed out the technical dossiers I'd prepared before arriving in Brazil, which detailed the specific chemical and physical properties of Martian regolith, alongside the precise step-by-step instructions for the microwave sintering process.



Figure 12: Martian Regolith experiment briefing.

To avoid any confusion, I had printed both the regolith data and the experimental instructions in English, Portuguese, and Spanish. My goal was to eliminate any margin for error. Navigating deep technical missions is tough enough without a language barrier; by providing the documentation in everyone's native tongue, I wanted to ensure that when we move into the execution phase, the crew isn't just following my lead—they are fully empowered by the data.

Upon beginning the experiment, I noticed that the Martian regolith simulant was highly hydrophilic. Its affinity for water was so effective that it allowed us to skip the sifting step entirely, as the particles integrated into the mixture without clumping. We prepared a hydrated clay mixture and allowed it to sit overnight in a towel to ensure complete hydration and the removal of air pockets (degassing) within the material (Figure 13).



Figure 13: Martian regolith clay degassing.

Green Lab Upgrades

With the slurry settling, we shifted our focus to necessary upgrades in the Green Lab. We installed a new door handle to ensure a tighter seal, helping to keep the atmosphere of the environmentally controlled room stable. We painted the room white, which helped to increase the albedo effect and minimize heat absorption from the high external temperatures.

To further regulate the microclimate, we hung a layer of reflective material that successfully lowered the room's temperature by 5°C (Figure 14). It's a small victory, but in a mission where every degree of thermal gain is a threat to the biological systems, these engineering "quick fixes" are what keep the mission viable.



Figure 14: Omana Munoz and Eufracio Rojas applying adhesive to the habitat walls.

Dinner and Cultural Exchange: Brazilian Treats

After the upgrades were complete, we gathered for a dinner of spaghetti bolognese (Figure 15). Alongside it, we drank powdered lemonade—the same kind astronauts occasionally rely on when fresh juice isn't an option, a small but deliberate nod to life lived within constraints.



Figure 15: Spaghetti Bolognese for dinner.

For dessert, we shared a spread of Romeu e Julieta—a classic Brazilian pairing of Queijo Minas (minas cheese) and Goiabada (guava paste), representing a perfect union of contrasting sweet and savory elements (Figure 16).



Figure 16: Romeu e Julieta for dessert[1].

The Queijo Minas, a fresh, soft, white cheese from Brazil's Minas Gerais region, offered a mild, slightly salty taste and creamy texture. This was complemented by the Goiabada, a dense, sweet conserve made from red guavas and sugar.

Together, the sweet, floral notes of the guava paste and the salty, milky character of the cheese created a delightful textural contrast as the cheese melted slightly against the firm paste. It was a sweet, sticky blend of flavors that felt like a quiet celebration of our combined efforts. Before showering for bed, we took turns playing music from each of our cultures, letting the different rhythms and languages fill the common area. It was a beautiful way to end the day, a moment of soft connection that tethered us to our roots even as we pushed toward the future.

Reflection

I'm incredibly proud of myself and my crew for reaching the summit despite every obstacle we faced along the way. We relied on one another in countless small but vital ways—encouraging the slowest hikers, sharing water and snacks, navigating slippery rocks together, and marking each hard-won milestone as a team. Our persistence throughout the climb reminded me of Mark Knopfler's "Hill Farmer's Blues"—a song that captures the quiet, rugged dignity of those who endure against an unforgiving landscape. Like the farmer in the song, we moved through a world that felt indifferent to our struggle, yet we found purpose in the grit of the work itself and the stubborn refusal to quit.

Returning to the habitat exhausted but intact, it was refreshing to see that same teamwork carry over into the lab. Watching the crew engage so deeply with the experiment and contribute to Green Lab upgrades made it clear that our collective drive doesn't fade under pressure—it sharpens, even after the longest of days.

The 3D printing research we're conducting—using microwave sintering to transform regolith into usable structures—feels like a conduit between worlds. It's not just a solution for Mars; it holds real promise here on Earth. In resource-limited regions, a similar system could turn local soil into durable building materials, creating shelter and infrastructure without relying on heavy industrial processes. Running these early experiments to define the requirements for a future printer reminded me of the story Espinosa Omana shared on the volcano about Pachamama, the Andean Earth Mother, who provides the materials for life and protects those who honor her. In many ways, using technology to build life-sustaining environments from the earth itself feels like a modern echo of that legend—human ingenuity working with the world around us to build resilience and care for our communities.

In parallel, our work in the Green Lab focused on making the habitat more hospitable for biological life, reinforcing the idea that the environment is not a static backdrop, but something we actively shape and respond to. By fine-tuning the conditions to help our plants thrive, we're acknowledging that our own survival is inseparable from the health and vitality of the life we sustain. We are not just observers of the environment, but active co-authors of the reality we inhabit.

Sol 3: Floating, Forming, and Focus
Location: Caiçara do Rio do Vento, Rio Grande do Norte,Brazil
Body Weight: 51.52 kg(113.6 lb)
Cups of Water: [1] 9
Sleep: 8.3 hours
Breakfast and Fulfilling Traditions

After our hike and the habitat upgrades, I slept better than the night before, though I still had occasional episodes where it felt like I was falling—likely a combination of a common phenomenon called a hypnic jerk and my body's post-activity adjustment, similar to the "land sickness" people sometimes experience after being on a boat. I got up at 7 AM. For breakfast, we had omelets wrapped in tortillas with rice inside. We also continued a Habitat Marte tradition, where the commander—myself in this case—commemorates the mission by placing the mission patch on the fridge, a small but meaningful marker of our journey (Figure 17).



Figure 17: Mission DEIMOS patch.

Crew Workout and Conditioning

We then performed what was technically our first group workout, with Matheus' help leading us through the routines. I say technically because on Day 1, we had a brief introduction to exercise, focused more on learning protocols than physical effort. On Day 2, we spent the day hiking, so no formal exercise was required. The workout on Day 3 included various stretches and strength-training circuits, designed to keep our bodies in shape for the simulated conditions and upcoming tasks (Figure 18).



Figure 18: Group exercise (Left to right:Rezende, Edwards, Espinosa Omana, Omana Munoz, and Eufracio Rojas).

From Soil to Shape: Crafting Martian Clay

Once we finished cooling down from the workout, I went outside to check on the clay body. It looked solid, but after some discussions with Rezende, we decided it would be best to mix in some local dirt. The added organic material would help prevent cracking during the eventual firing process. Omana Munoz helped me sift the dirt to remove large chunks, and we added water before kneading it together with the regolith clay we had prepared the day before (Figure 19).



Figure 19: Omana Munoz sifting dirt.



Figure 20: Martian regolith inside silicone molds.

Next, we began pressing the clay into silicone molds (Figure 20). It proved trickier than expected. After a few attempts, I realized getting the clay out of the molds would be difficult, so I made small slits in the sides to ease the process. I also made a note to experiment with cookie cutters in the future to streamline the process.

We placed half of the clay-filled molds in the green lab, where the air conditioning kept the environment cool and controlled, while the other half was left outside in the heat. This experiment would help us determine the best method for air-drying the clay. Air drying is critical to the process because it allows the clay to lose moisture at a controlled rate, preventing cracking and ensuring it retains the proper consistency for shaping and firing. With that, we left the clay to dry and moved on to our next task: preparing lunch. Lunch consisted of spaghetti and chicken, a simple but satisfying meal that gave us energy for the rest of the day (Figure 21).



Figure 21: Lunch (Spaghetti and chicken).

EVA 3: Simulating Zero-G Underwater

After eating, we gathered to discuss our next EVA—an underwater simulation designed to test neutral buoyancy operations. By the third day of our five-day mission, the atmosphere in the habitat had shifted from the initial setup phase to a focus on mission wrap-up and preparation for our simulated return journey. This late-stage EVA was strategically scheduled to evaluate human performance under cumulative physical fatigue, simulating the contingency protocols and physical demands we might encounter on our journey home. We reviewed the protocols and then put on our swim attire before heading to the pool.

For our first activity, we practiced a spin maneuver using just our hands (Figure 22). Although it may seem basic, with enough force, the lack of gravity will cause the object to continue spinning indefinitely, and in turn, it can cause you to spin as well. This is because, in microgravity, there's no friction to slow down the motion. Being able to control and stop that spin with precision is crucial, as it allows you to maintain stability and avoid disorientation. It also instilled the importance of being tethered or holding onto something during spin procedures to prevent uncontrolled rotations. This skill would be useful during tasks like adjusting our position in confined spaces or maneuvering equipment during our flight back home.



Figure 22: Underwater EVA activity 1.

Next, we practiced capturing a small cube satellite and relocating it to a designated area, a skill that could prove crucial if we needed to repair or reposition any mechanisms during our journey (Figure 23).



Figure 23: Underwater EVA activity 2.

Following the satellite exercise, we performed a task in which we opened and closed valves and monitored a pressure gauge, a practical exercise for managing environmental systems on board the spacecraft. It helped us ensure that pressure and flow were within proper ranges and reinforced the importance of precision and attention to detail when maintaining critical life-support systems.

Finally, after all the physical exercises were complete, we each tapped into our mental endurance. We were tasked with staying face down in the pool for 15 minutes while music played, a surprisingly therapeutic experience that helped us focus and clear our minds. Throughout the entire EVA, breath and motor control were paramount. From a biocentric perspective, this exercise emphasized the interconnectedness of mind and body, highlighting the importance of inner balance and mindfulness, both of which are essential for sustaining long-term focus and efficiency in extreme environments. It was also crucial to rely on each other—helping each other navigate the depths of the pool, ensuring we were all performing the tasks correctly and supporting one another as a team.

Post- EVA 3: Dinner

After we got out of the pool, we all cleaned up and prepared beef, rice, and salad for dinner (Figure 24). For drinks, we had a native Brazilian fruit juice called guaraná. Dessert was toast with dulce de leche, accompanied by mint tea.



Figure 24: Post-EVA dinner (beef, rice, and salad).

Practicing Mindful Meditation

After dinner, once we had digested, Hazbun led us in a mindfulness meditation exercise. We turned the lights off to create a calm, focused atmosphere. During the session, we practiced releasing tension from our head down to our toes, scanning the body and letting each part relax. This meditation was important because it helped us recover from the physical and mental strain of the day, center our attention, and reinforce the mind-body connection—an essential skill for maintaining focus, resilience, and awareness during extended missions in isolated or extreme environments. With that, we went to bed, ready to rest and recharge for the next day's activities.

Reflection
In comparison to yesterday, today carried far fewer stressors. We began with a physical workout, a necessary way to care for our bodies and maintain readiness for the demands of the mission.
The underwater EVA built on that foundation, challenging us both physically and mentally. In the water, we had to maintain composure, control our breathing, and execute each task with intention, learning how to stay grounded under pressure and avoid panic. We ended the day with mindfulness meditation, a purely mental exercise that allowed us to release the accumulated tension and return inward.

Taken together, the sequence of the day—physical training, followed by a combined physical and mental challenge, and ending with mental stillness—reinforced the importance of balance, reminding all of us that caring for the mind is just as essential as caring for the body.

Maintaining this balance is especially significant because the body grounds consciousness in the physical world—it is the interface through which we sense, act, and survive. The mind, in turn, organizes those sensations into meaning, interpreting danger, pattern, time, and purpose. When one is neglected, perception becomes distorted: physical exhaustion can cloud awareness, while mental overload can detach us from our surroundings. In this framework, imbalance does not merely affect the individual; it reshapes how reality itself is experienced.

Sol 4: Enhancing Life and Exploring Caves
Location: Caiçara do Rio do Vento, Rio Grande do Norte,Brazil
Body Weight: 51.89kg (114.4 lb)
Cups of Water: [1] 7
Sleep: 7.8 hours

Breakfast and Exercise
I slept great, aided by the pool session and meditation. This morning started off similar to yesterday in terms of breakfast—eggs with basil—and our group exercise routine.
Pivoting from Experimentation to Observation

Following breakfast, I checked on the clay experiment. I noticed that the samples left outside had dried too rapidly and cracked; it must have been too hot. Conversely, I checked on the clay inside the Green Lab, which was still too wet, likely due to the low temperature and high humidity.
At this point, I decided to cut my losses with the experiment. There wouldn't be enough time to redo the process properly before our departure tomorrow, so I will just have to try again at a later date. The best I could do at this moment was take thorough notes on the temperature conditions and document the do's and don'ts of using the molds, reinforcing my realization from yesterday about needing alternatives like cookie cutters for better structural integrity. I also considered that using some type of lubricant in the mold might help the clay slide out easily. For future efforts, I can look into incorporating a binding agent or adjusting the clay-to-soil ratio to improve viability, and perhaps explore adding a vacuum mechanism to the 3D printer conceptual design to help aid in the drying process.

Upgrading the Aquaponic System

With my notes taken for a future attempt, I turned my attention to the aquaponics system in the greenhouse. The system is a series of large ponds where tilapia are fed in exchange for nitrates that nourish the floating vegetation (Figure 25). Needless to say, it is a major part of our food production system on this mission.

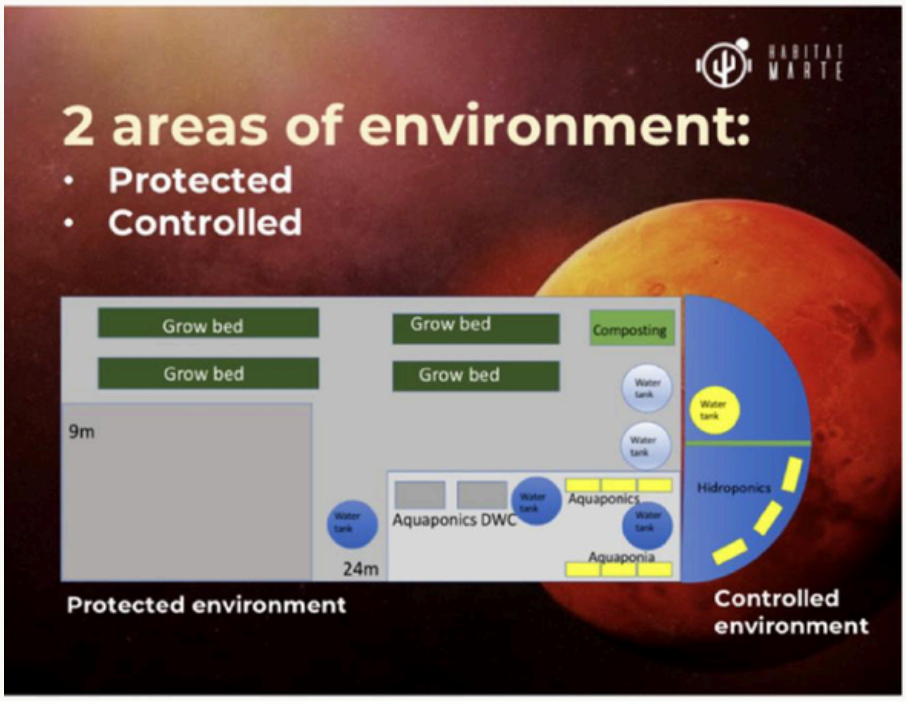


Figure 25: Habitat Marte Greenhouse layout[3].

The problem was that the fish weren't receiving the correct amount of aeration to live comfortably and, in turn, produce nitrates sufficient for feeding the plant life (Figure 26).



Figure 26: Old aeration system.

I removed the old hose and added a new one featuring a mechanism that acts as an airstone, both of which I found in the workshop (Figure 27). This new setup improves aeration by utilizing the preexisting pump to force air through the porous airstone, creating fine bubbles that maximize the surface area contact between the air and the water. This process significantly increases the dissolved oxygen levels, which is crucial for the fish's metabolic processes and overall health, while also aiding in the aerobic breakdown of waste into usable nitrates for the plants



Figure 27: Aeration system upgrade.

Upgrading the Airlock

With the aeration system fixed, I joined Rezende in upgrading the airlock to accommodate more people prior to our final EVA to the lava cave (Figure 28). Due to the increased volume of this upgraded airlock, we implemented a revised protocol dictating a 15% extension in depressurization time and a 20% extension in repressurization time. This gradual approach is critical to managing the pressure equalization process safely, preventing excessive structural stress on the habitat seals and hull during EVA transitions, and ensuring the integrity of the habitat just before the excursion.



Figure 28: Rezende upgrading the airlock to accommodate larger crews.

EVA 4: Lava Cave Analysis and Sunset

After Rezende and I widened the airlock, the crew and I set out for a nearby lava cave. Lava caves are natural geological formations on Mars. They provide unique shelter from cosmic radiation and extreme temperature fluctuations.

With this being said, Rezende had already been using it to the Habitat's advantage, as there were already a few bunks and a functioning bathroom inside. However, he briefed us on his future plans for creating somewhat of a loft above the underground section (Figure 29).



Figure 29: Rezende briefing us on future lava cave upgrades.

While he surveyed the area, adding indicators for where a future door and windows could go, I helped to secure access to the loft area by reinforcing the ladders (Figure 30).



Figure 30: Me repairing a shaky ladder.

After I finished drilling screws into the wooden steps of the ladders, I joined Rezende at the top to watch the sunset. It was our last night and boy was it breathtaking; I could see why he wanted to expand up here.

Though there weren't any people for miles, the area was buzzing with life: lots of cacti, lizards, and ground vegetation (Figure 31). It reminded me that life finds a way to adapt and thrive, even in seemingly inhospitable environments—just like we did here, and just like the human race will on Mars. I couldn't think of a better way to wrap up our mission.



Figure 31: Views from on the lava cave.

Post-EVA 4: Mission-Wrap up

Before exiting the lava cave, we each had a cup of ramen noodles and discussed departure logistics. Upon returning to the habitat, we dispersed to pack before retiring for the night. Tomorrow consists of a half-day schedule featuring breakfast and the award ceremony.

Reflection

As this is the final full day of the mission, I feel a tinge of sadness that my experiment didn't unfold exactly as planned—but that is the essence of science: it reminds us that the universe is never fully predictable, and sometimes the most valuable lessons come from the unexpected.

On a brighter note, I found great satisfaction in upgrading both the aeration system for the fish and the habitat airlock. Interestingly, they felt interconnected: just as more crew members require extra space and airflow in the airlock to prepare for EVAs, a larger fish population demands more oxygen and care. Both systems thrive on balance, attention, and foresight.

Looking at it through the lens of life itself, this is a profound reminder of our place in the web of life. We are not separate from other organisms; our survival, comfort, and progress depend on the health and stability of the ecosystems around us. Whether it is the fish, the habitat systems, or ourselves, existence is a shared endeavor, and cooperation is essential.

Finally, as I watched the sunset from the lava cave, I was struck by a deep sense of hope. Even in harsh, seemingly inhospitable places, life endures and adapts. That view—fiery, beautiful, and alive—served as a quiet but powerful testament to the resilience of life, and to the promise that even the most unexpected environments can sustain growth, connection, and wonder. I can't wait to see how Rezende continues to expand the facility, pushing boundaries and achieving what others have not, building on both the foundation we established during this mission and the work laid by those who came before us.

Sol 5: Final Moments, Lasting Impact
Location: Commute from Caiçara do Rio do Vento, Rio Grande do Norte,Brazil to Ponta Negra, Natal, Rio Grande do Norte,Brazil
Body Weight: 51.7 kg (114 lb)
Cups of Water: [1] 5
Sleep: 7.1 hours

Breakfast and Mission Debrief
For our final meal together, we shared a simple but satisfying breakfast of eggs and toast, followed by apples and dulce de leche. Over the meal, we held a mission debrief, reflecting on our experiences and highlighting our favorite moments. For me, the standout parts were enhancing the habitat and developing conceptual designs for future life support systems. We also discussed what could have gone better, including the challenges I faced with my experiment, acknowledging that setbacks are part of the scientific process.

As part of our closing traditions, we exchanged small gifts—mine were keychains from Saint Vincent, while the crew gave me candies and a stuffed astronaut, tokens of camaraderie and shared memories.

Signed, Sealed, and Certified
With that, we moved into our award ceremony, celebrating achievements big and small, before piling into the truck for our journey home (Figure 32). The morning carried a mix of nostalgia, accomplishment, and quiet anticipation, a fitting close to a mission that had pushed all of us to learn, adapt, and grow together.



Figure 32: Me receiving my Analog Astronaut Certificate.

Reflection

As the final day of the mission drew to a close, I felt a mix of exhilaration and longing. I had an amazing time—every moment in the habitat, every EVA, every experiment had been rewarding—but I also found myself missing my family and friends. I couldn't wait to tell them everything, to share the stories, the challenges, and the small triumphs that made this experience so memorable. I wondered if real astronauts feel the same way—carrying the excitement of their missions while longing to reconnect with the people and world they've left behind.

That reflection made receiving my analog astronaut certificate all the more meaningful. It was a moment of quiet pride, a tangible reminder of the work we had accomplished. It was equally heartening to see my fellow crew members receive theirs, each certificate representing their dedication, creativity, and resilience. Sitting there together, certificates in hand, I felt an overwhelming sense of gratitude—for the mission, for the people I shared it with, and for the opportunity to push myself in ways I had only imagined before.

Holding the certificate, I realized it symbolized more than just an accomplishment. It embodied the connection, purpose, and shared experience the mission had fostered. This day—and this mission—reminded me how much joy comes from exploration, teamwork, and curiosity, and how much we carry with us from the people we love, even when we're far from home, highlighting just how interconnected we all are.

Mission Takeaway

I initially planned to use this mission to gain firsthand experience of what astronauts go through, so I could better support the Artemis missions and contribute effectively to space exploration. However, as the mission unfolded, I realized that its lessons went far beyond professional training. It reinforced that exploration is not just about technical challenges or scientific experiments—it is equally about connection: between crew members, between humans and the environments we inhabit, and between mind and body.

This connection was evident in every aspect of the mission. Through physical exertion, mental focus, and collaborative problem-solving, I experienced how resilience, curiosity, and cooperation sustain life and enable growth, even in difficult or unfamiliar conditions. At the same time, I came to appreciate the delicate balance required to remain grounded—how caring for the body and mind together shapes perception, performance, and well-being.

What struck me most is how these lessons translate beyond the habitat. The strategies for staying calm under pressure, maintaining focus, and collaborating effectively are valuable whether in a spacecraft, an office, or daily life. Ultimately, the mission reminded me of the profound interconnectedness of all beings, showing that every action and decision reverberates through the systems and communities we are part of, and that nurturing both our inner and outer worlds is essential to thriving anywhere.

Acknowledgements

I want to express my sincere gratitude to Julio Rezende at the HABITAT MARTE Space Analog Station in Rio Grande do Norte, Brazil for giving me the incredible opportunity to design and command Mission DEIMOS.

His continuous support and expertise in human sustainability and analog missions significantly enhanced my ability to design for future astronauts, and even illuminated potential spinoff technologies that could benefit life on Earth.

I would also like to thank my crew for putting their trust in me to lead them throughout the duration of our mission and for their contributions at large.

Lastly, I would like to thank Robert Lanza and Bob Berman for writing “Biocentrism: How Life and Consciousness are the Keys to Understanding the True Nature of the Universe"[6]. Without this book, I would not have been able to convey my thoughts and reflections to their fullest extent.

Disclosures

During the preparation of this work, the author used Google Gemini and ChatGPT to enhance clarity and fluency of expression. After using the tool/service, the author reviewed and edited the content as needed and assumes full responsibility for the content of this work.

References

Fortaleza, J. (2011, March 14). Romeu e Julieta - Brazil's Traditional Quick Dessert. Flavors of Brazil. Retrieved February 9, 2026 from https://flavorsofbrazil.blogspot.com/2011/03/romeu-e-julieta-brazils-traditional.html

Glosbe. (n.d.). English - Tupí dictionary. Retrieved February 9, 2026, from https://glosbe.com/en/tpw

Google. (2025). Gemini (Version/Date) [Large language model]. https://gemini.google.com/

Habitat Marte (2025), Habitat Marte Space Analog Station. Retrieved February 9, 2026 from http:habitatmarte.blogspot.com/

Lanza, R., & Berman, B. (2010). Biocentrism: How life and consciousness are the keys to understanding the true nature of the universe. BenBella Books.

OpenAI. (2026). ChatGPT. Retrieved February 9, 2026, from https://chat.openai.com

PeakVisor. (n.d.). Pico do Cabugi. Retrieved [Insert Date You Viewed the Site], from https://peakvisor.com/peak/pico-do-cabugi.html















THE CREW THAT STAYS



DR. EMMA CAIN LOUDEN
ASTROPHYSICIST, POLICY AND STRATEGY EXPERT, WRITER, PRESIDENT OF SLOOH, TEDX SPEAKER, AND THE AUTHOR OF MIA AND THE MARTIANS.

Every analog mission begins with a kind of voluntary exile. A crew seals itself into a habitat in a desert or on a volcanic slope and agrees, for days or months, to live as though Earth were somewhere else. We do this to learn what human beings require in order to leave: how cohesion frays under confinement, how trust forms without the option of escape, how a person's sense of perspective shifts when the familiar world is taken away. It is some of the most important social-scientific work the space community has, and this issue rightly honors it.

But there is a complementary question the field also needs to ask. If we study so carefully what people need in order to leave the planet, how much do we understand about what they need in order to stay on it well? And what happens to a society's relationship with space when most of its members can no longer see space at all?

I argue that the night sky has always been a piece of social infrastructure—as load-bearing, in its quiet way, as roads or shared institutions—and that two simultaneous trends, one terrestrial and one orbital, are dismantling it in plain sight. Understanding that process is not a romantic detour from space exploration. It is one of the clearest present-day examples of how space activity shapes life on Earth, and astrosociology is the discipline built to see it.

Consider what gathering under a shared sky once did to people. Durkheim called the charged feeling of collective ritual collective effervescence: the sense, in a crowd moved by something larger than itself, that the boundary between self and others has briefly gone soft. A century later, Dacher Keltner and colleagues put awe under measurement and found it behaves like a social adhesive—quieting the ego, widening the circle of concern, and reliably increasing trust and generosity toward strangers. On this evidence, awe is not decoration. It is one of the mechanisms by which large numbers of unrelated people manage to cooperate at all. And for nearly the entire human story, the most dependable and most democratic source of it was simply the darkness overhead: available to everyone, costing nothing, demanding no shared creed or language. It set our calendars, populated our mythologies, and gave whole civilizations a common reference point for their own smallness.

That reference point is disappearing, and the disappearance is recent enough to date precisely. More than a third of humanity can no longer see the Milky Way; across Europe and North America the figure climbs toward the entire population.

We never decided to surrender the stars. We lit our nights for safety and commerce and convenience, fixture by fixture, until the glow from the ground erased the view from above—at almost the exact moment a far larger and stranger universe was being discovered behind it. The cost, when it is noticed at all, gets filed as aesthetic. But if awe is social infrastructure, then the spread of light pollution is an infrastructure failure: the gradual removal of an experience that used to remind people, nightly and for free, that they belonged to something none of them controlled. A culture already drifting toward isolation lost one of its last shared commons—and it is difficult not to suspect some relationship between that loss and the disconnection and meaninglessness now reported across so many societies.

Here is where space activity itself enters the story, and where the question this essay answers becomes most literal. Until now, the sky's degradation came entirely from the ground. That is changing. We are filling low Earth orbit with our own hardware—tens of thousands of satellites already, with far more announced. For the first time, the night sky is being altered not only by the light we throw up into it but by the objects we place within it. The one environment that every human culture in history has held in common is now being enclosed from above by the very enterprise that promised to widen our horizons. That is not a distant or hypothetical effect of space exploration on terrestrial society. It is unfolding this decade, largely unmeasured, and mostly outside the rooms where the social sciences have a seat.

The irony is sharp, because space exploration also handed us our most celebrated argument for why the view matters. Astronauts come home describing the Overview Effect—the reorganizing experience of seeing Earth whole and feeling, in the body rather than the intellect, that it is small, shared, and worth defending. Analog programs work to approximate that shift on the ground precisely because they understand its value to a crew. Yet the public has always had a humbler, inverted version of the same medicine: not Earth seen from outside, but the universe seen from within it, on any clear night. It points in the opposite direction and yields a kindred result—a felt sense of belonging to something vast, and from that belonging, an impulse toward stewardship. Restoring access to it has become its own field of effort, from the dark-sky ordinances spreading city by city to remote-observation platforms that can route a live telescope to anyone with a screen; at Slooh, where I work, that is the founding premise—that the cosmos should not be a privilege reserved for those who happen to live where it remains visible. The structural point worth drawing out for this field is this: analog missions ask what the human dimension requires of those who leave; the same human-factors lens, turned back toward the planet, asks what it requires of the billions who stay. The sky overhead is a large and overlooked part of that answer.

Which is, finally, why this conversation belongs to astrosociology in particular. No other discipline is positioned to treat the sky as a social variable—to ask what collective awe contributes to cohesion and stewardship, to set the social cost of a vanishing night beside its documented circadian and ecological costs, and to carry that combined evidence into decisions now being made without it: how cities choose to light themselves, how orbits are governed, who is left able to see the stars and who is not.

These are astrosocial questions in the fullest sense—behavioral and cultural patterns produced by our relationship to space—and they are being settled by default while the field that should inform them looks the other way. Naming the sky as infrastructure is the first move. Measuring what its loss does to us is the work.

We devote enormous, careful attention to the small crews who volunteer to leave the world in order to understand themselves. We must also spend time on the far larger crew that never leaves —the one presently running an unplanned, planet-wide experiment in what becomes of a species that loses sight of the sky. The result is not yet in. But the conditions are still ours to set, and the most consequential of them is whether we decide, before the view is gone, that it was worth keeping.



GOVERNANCE CASE STUDIES ON EARTH AS ANALOG EXPERIMENTS FOR FUTURE WORLDS



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UNIVERSITY OF NEBRASKA COLLEGE OF LAW, SPACE, CYBER, AND NATIONAL SECURITY LAW PROGRAM

Standing in front of room full of space enthusiasts explaining space law can be a challenge. While the audience is typically excited about exploration, they are usually – justifiably – less excited about the law. As I lecture animatedly, attempting to make treaties thrilling, they inevitably begin squinting, deep in thought. A hand shoots up.

"Say a group of Americans lands on Mars. They're still Americans, not Martians?"

Nodding encouragingly, knowing where this is heading, I say something like, *"That's right. Our nationality travels with us. I'm an American in space, as I am on Earth, under the law."*
"But what if they refuse to follow our laws once they're there? What if they just say, 'we're Martians now and we don't want to follow your rules.' Can they do that?"

There it is. The specifics change, but the spirit of the question remains: how is the law enforceable in extreme and distant environments? It's at this stage I deploy the oldest law professor trick in the book. I make up a hypothetical and ask them a question back,

"Let's imagine that together. If a private U.S. space company sends 20 people to Mars to build a habitation, that mission will be licensed and under the supervision of the U.S. government. Then, they get to Mars and declare they're not Americans and that they own the planet – noting that appropriation, or owning the planet, is something all space-faring nations have agreed not to do. What do you think the U.S. government would do?"

Crickets. Eventually someone timidly speaks up, *"How long does it take to get to Mars? Would it be worth the resources to put down an insurrection of 20 people so far away from our soil?"*

"*And that, my lovely audience, could be how we finally get Martians!*" I announce – and usually get some laughs. From here we wander into a discussion of international law and enforceability. We cover the United Nations Security Council, the International Court of Justice, and sanctions, ranging from economic to diplomatic to military force. In the end though, many of my non-attorney audience is at a loss, "*What really stops leaders from doing whatever they want?*" I suggest they try a political science or philosophy lecture next time.

Examining domestic law, the enforcement concept is easier. In most countries if you break the law, you get to meet their law enforcement, which is followed by a tour of their justice system. International law, which is the backbone of space law, feels a little more malleable. Politics, diplomacy, and economics are all at play.

How does this relate to analog space missions? To imagine what a governance structure may look like on a celestial object[1], we'll turn to existing structures on Earth. Terrestrial law serving as an analog to what may happen on a new planet in the not-so-distant future. To this point, we must acknowledge that the civilization on a new planet will not be perfectly analogous to the diverse cultures on Earth. That's a good thing! Politics and the law are all colored by centuries of humanity's best and worst moments. While that context will travel with whomever leaves Earth, the whole of Earth's space law won't perfectly map on to a new planet. However, our experiences in space governance on Earth can still serves as an important analog when examined as case studies.

One such case study is the intergovernmental agreement (IGA) that has supported the International Space Station (ISS) mission.[2] The IGA outlines the rules for international cooperation on a space station. From communication, ownership, and transportation the IGA provides guidance those working in space and to their supporters on Earth. The governance structure doesn't end with the IGA though. The ISS also depends on a series of memoranda of understanding (MOUs) or agreements between space agencies that outline the technical operations and daily responsibilities on board. Supporting the IGA and the MOUs are implementing arrangements. These highly specific technical or logistical agreements are established as operational issues arise.

This flexible three-tier system has provided agile and effective operational clarity. This can tell us a lot about what future missions may need to consider for effective governance. A broader scope agreement may outline the initial needs of the mission. This document should get as specific as possible but acknowledge that not all situations can be predicted and planned for. Key core elements should include things like ownership and liability.

Let's zoom in on liability, as an example. The ISS IGA relies on fundamental liability rules for space found in international space law treaties[3] but it goes further. The IGA establishes a cross-waiver of liability. This prohibits any of the partners from bringing a claim against another partner for damage that is sustained from ISS activities.[4] However, claims for things like damages caused by willful misconduct or claims made by a person for bodily injury aren't prohibited. As in, if damage is caused in the daily operation of the mission, no liability. If an individual willfully destroys things or hurts someone? Liability.

[1] Law professor sneaking in treaty language. See, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205.
[2] International Space Station Intergovernmental Agreement, T.I.A.S. 12927 (1998)

So close to Earth, the ISS is reasonably connected to our Earth-bound court systems. On a new planet, setting up a civil court system will not be the highest immediate priority. However, this approach to damage and harm may still be enlightening when thinking about the enforceability of rules. Future space farers can map their governance model on to the IGA's approach to identify questions and concerns. They will need to decide how they will determine qualities like 'willfulness' and what appropriate consequences for severity may be.

These broad governance practices can then be followed by the other two tiers: memorandums of understandings between parties for specific needs and implementing arrangements that help parties agree to processes for the day-to-day work of living off Earth.

While the ISS stares down its retirement, its governance structure is a shining example of cooperation. Enforceability challenges will remain for any far-off space governance system, but thankfully travelers (and the analog astronauts that come before them) can prepare for this eventuality by acknowledging the need for on-site governance that does not solely rely on the distant systems of Earth.



[3] See, Convention on International Liability for Damage Caused by Space Objects, March 29, 1972, 24 U.S.T. 2389, T.I.A.S. No. 7762, 961 U.N.T.S. 187.
[4] Article 16, International Space Station Intergovernmental Agreement, T.I.A.S. 12927 (1998)

THE ARCHITECTURE OF CONNECTION: UNIVERSAL HOSPITALITY, THE XENIAN NODE, AND ANALOG SPACE HUMANISM



FRANK PIETRONIGRO
FIRST AMERICAN ARTIST TO EXECUTE "DRIFT PAINTINGS" IN MICROGRAVITY

1 . Introduction: Disruption of the Arcane Metallic Paradigm

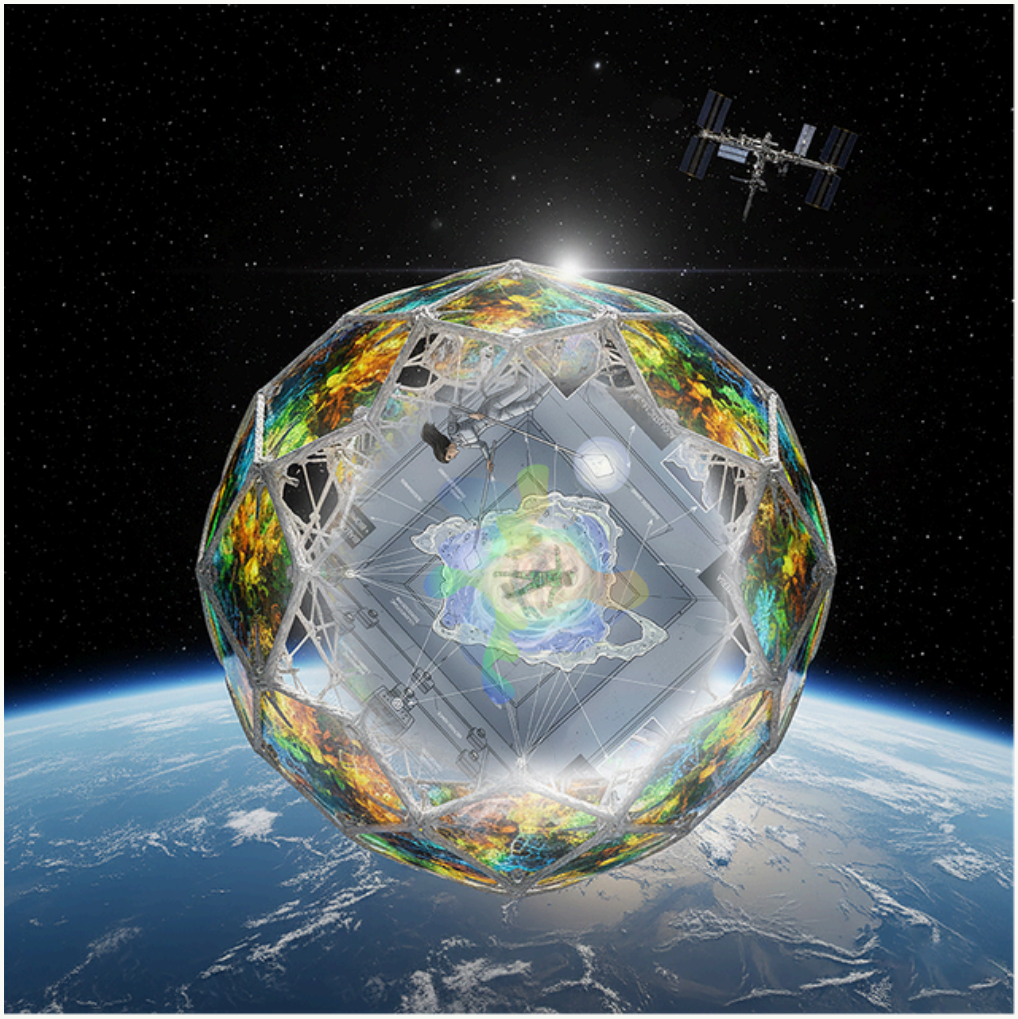
For decades, the human imagination regarding space exploration has been trapped in an arcane, machine-centric paradigm. We have envisioned our journey into the cosmos as an act of encapsulation within rigid, sterile, geometric metallic hulls—cold containers designed solely for mechanical survival. This rigid engineering philosophy inflicts profound sensory deprivation and psychological alienation upon human inhabitants, presenting a critical barrier to long-duration space migration and terrestrial analog missions. Amazing technologies of the space age and now we are moving onward. [1]

To step inside a contemporary space habitat or an isolated terrestrial analog module is to step inside a monument to cold geometry. The dominant paradigm of aerospace engineering treats the human being as a biological variable to be kept alive through mechanical life-support systems enclosed within sterile aluminum and titanium walls. This industrial-era mindset views space as a vacuum to be conquered and colonized through rigid technological enforcement.

From an astrosociological perspective, this rigid spatial architecture is deeply flawed. [2] It ignores the psychological and cultural dimensions of human existence. When we isolate individuals in extreme environments for months or years, the absence of organic variability—the shifting of leaves, the damp scent of earth, the unpredictable kinesis of living ecosystems—creates a profound sensory vacuum. The mechanical habitat acts as a psychological cage.

The trajectory of human civilization has always been tethered to our ability to imagine the impossible before we engineer it. As we stand at the threshold of The Frontier Age and of becoming a multi-planetary species, the integration of artistic vision with technical rigor is not merely an aesthetic choice—it is a functional necessity. To build sustainable communities on the orbital frontier, space architecture must transition from a dead container into a living partner, replacing the cold mechanical interface with an organic framework that redefines our relationship to the environments we inhabit, just like home.

[1]: Harrison, A. A., & Fiedler, E. D. (2002). Behavior and Human Performance in Space Environments. In Space Psychology and Psychiatry (pp. 11-34). Springer, Dordrecht. Explores how extreme spatial constraints and physical monotony in metallic space structures induce psychological fatigue, sensory deprivation, and interpersonal distress during long-duration missions.
[2]: Pass, J. (2004). The sociology of space exploration: The emergence of astrosociology. Sociology Practice: A Journal of Clinical and Applied Sociology, 6(1), 11-27. Establishes astrosociology as the multidisciplinary study of the social, cultural, and behavioral patterns of human civilization in space, emphasizing that human settlement requires social architecture beyond mere mechanical survival.



The Xenian Node, 2026, Pigment Print on Paper, 12.5" x 12.5"

2. Theoretical & Philosophical Foundations

30: Artistic Lineage	33: Zero-G Research	30 (Return): Historical Anchor
Jackson Pollock's "Number 30"	Research Project Number 33	SF Columbarium Spot 30
Liberation from Gravity	Document 34 Technical Proof	3 Niches Below Harvey Milk

2.1 Universal Hospitality & The Classical Roots of Zeus Xenios

The foundational philosophical tenet of LuminaVision Innovation Labs is a simple but radical premise: When humanity moves beyond the cradle of Earth, we must leave our terrestrial baggage, our histories of hate, and our extractive prejudices behind. [3] Space exploration cannot simply be an extension of geopolitical posturing or corporate resource hoarding. If we carry our violent terrestrial paradigms into the cosmos, we will merely construct high-tech greed prisons in the void. Therefore, we propose the ethics of Universal Hospitality not merely as a passive stance, but as a primary metric of refined levels of human intelligence and social organization.

The Xenian Node reimagines the ancient Greek concept of Zeus Xenios—the divine protector of travelers to foreign lands and strangers—as a modern operational framework for space habitat design. [4] In an analog or orbital habitat, every crew member enters as an 'other' navigating a high-stress, synthetic ecosystem.

Universal Hospitality dictates that the architecture must actively welcome, ground, and nurture the human spirit, recognizing that hospitality is a reciprocal relationship between the dweller and the dwelling. In extreme isolation, the habitat itself must offer a sanctuary of safety, psychological soft-grounding, and places cultural expression.

2.2 The STEAM Paradigm and Mycelial Intelligence (#fungiculture)

The philosophy of LuminaVision Innovation Labs is built upon the recognition that the STEAM (Science, Technology, Engineering, Arts, Music and Mathematics acronym—which Pietronigro coined during his residency at the STUDIO for Creative Inquiry in the College of Fine Arts at Carnegie Mellon University—is the primary engine for modern innovation. [5] Science, Technology, Engineering, and Mathematics provide the operational parameters, but the Arts and Humanities provide the human purpose.

As we move into an era defined by radical interdisciplinary collaboration, the emergence of #fungiculture represents the next vital leap in our intellectual and creative evolution. [6] Mycelial networks function as a vast, non-hierarchical intelligence, sharing nutrients and information across entire ecosystems. This is not merely biological survival; it is a profound precursor to the collaborative social structures required off world.

To adopt a fungicultural mindset is to embrace universal hospitality—the realization that growth is predicated on what we contribute to the network rather than what we extract from it.

2.3 Cultivation Rather Than Extraction: Biological Technology Ethics

This biological disruption requires a profound shift in our technological ethics. For centuries, human technology has been defined by an ethic of extraction—we mine minerals, burn fuels, and treat our tools as dead objects to be used until exhaustion and then discarded. LuminaVision Innovation Labs explicitly rejects this framework, operating instead under the Bio-Pixel and Living Technology Ethics of Cultivation Rather Than Extraction:

[3]: Pietronigro, F. (2026). Frank Pietronigro: Interdisciplinary Artist and Artronaut. Blurb Publishing. Monograph detailing Pietronigro's historical work, framing Universal Hospitality as an ethical and technological imperative for space exploration that leaves terrestrial animosities behind.

[4]: Pitt-Rivers, J. (1977). The Law of Hospitality. In The Fate of Shechem, or the Politics of Sex: Essays in the Anthropology of the Mediterranean (pp. 94-112). Cambridge University Press. Analyzes classical Mediterranean frameworks of hospitality (xenia), where accommodating the stranger is treated as a sacred ritual essential for social stability in unknown territories.

[5]: Pietronigro, F. (2006). Coining STEAM: Integrating Art into the STEM Paradigm during Studio Residency. Carnegie Mellon University, College of Fine Arts. Documentation tracking the early formulation of the STEAM acronym (Science, Technology, Engineering, Arts, Music, and Mathematics) to place humanistic creative inquiry on equal footing with technical disciplines.

[6]: Tsing, A. L. (2015). The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins. Princeton University Press. Examines non-hierarchical fungal networks and multi-species symbiosis as models for collaborative survival and adaptive socio-ecological architecture.

"We do not build machines; we cultivate interfaces. The living components that illuminate our spaces and respond to our movements are not industrial resources to be mined, overdriven, or exploited for sterile data throughput. They are symbiotic companions. To practice Universal Hospitality in space engineering means we must care for the life that keeps us safe. The habitat becomes a collective garden that helps maintain harmony and helps destress. In cultivating the metabolic well-being of our biological interfaces, the crew cultivates their own humanity, participating in a shared cycle of respiration, care, and mutual survival."

2.4 The Numerical Philosophy of 30-33-30

The conceptual foundation of The Xenian Node is anchored by the numerical lineage 30-33-30, connecting high-concept spatial physics to human civil rights history and personal mortality and an inference to burial practices off and on our home planet:



The Xenian Node and Niche 30, Pigment Print on Paper, 11" x 8.5", Frank Pietronigro, Interdisciplinary Artist and Artronaut, Highly Modified AI

30 (Artistic Lineage): Refers to Jackson Pollock's Number 30, establishing the historical artistic trajectory that freed visual marks from two-dimensional canvas constraints and terrestrial gravity. [7]

33 (Zero-G Research): Represents Research Project Number 33: Investigating the Creative Process in a Microgravity Environment. [8] This landmark project yielded three primary zero-G flight explorations (including Flags in Space and Vertical Inversion Drawings) and produced the first American zero-gravity "drift paintings," formally preserved in Document 34, April 4, 1998, the resulting 150" x 54" canvas whose mediums are acrylic paint, diamond dust, stainless steel, iron and organic matter on canvas.

Document 34 holds a pivotal place at the intersection of space history, fine art, and cultural archiving. Formed as the ultimate physical artifact and archival codex resulting from Research Project Number 33 executed aboard NASA's KC135 turbojet. Document 34 encompasses both the rigorous research documentation and the actual painted canvas created during the world's first zero-gravity "drift paintings".

30 (Historical Anchor): Represents the physical anchor for the artist's ashes to reside in San Francisco Columbarium (Hall of the Olympians, The Room of Dionysus, Lot 1, Space #30). Positioned precisely three niches down and three niches over from the Harvey Milk Memorial, this location serves as counterpoint grounding location, in the heart of San Francisco, to The Xenian Node living in Low Earth Orbit with the counterpoint orbital mechanics and spatial art serving as an electromagnetic symphony whose interplanetary angulations reflect the ongoing human struggle for civil rights, dignity, and equality. [9]

3. The Architectural & Technological Framework

LuminaVision Innovation Labs structures its research ecosystem through a precise technological and artistic hierarchy, shifting space architecture away from dead "tin cans" toward biological structures that function as extensions of the human nervous system.

WILLOWHAB	(Overarching Integrated Biological Habitat Concept)
THE XENIAN NODE	(Architectural Junction & Habitat Environment in LEO)
BIO-KINETIC DRIFT	(Mechanical & Fluid Dynamics Governing Free-Floating Motion)
THE LIVING PAINTING	(Dynamic Interior Surface Composed of Responsive Bio-Pixels)

[7]: Varnedoe, K., & Karmel, P. (1998). Jackson Pollock: New Approaches. The Museum of Modern Art, New York. Discusses Pollock's breakthrough in Number 30 (1950) and related drip paintings, which freed line and gesture from conventional boundary edges, laying the conceptual groundwork for three-dimensional spatial mark-making.
[8]: Pietronigro, F. (2000). Research Project Number 33: Investigating the Creative Process in a Microgravity Environment. Leonardo, 33(3), 167-173. MIT Press. Peer-reviewed research paper documenting Pietronigro's April 4, 1998, NASA KC-135 microgravity flight experiments, detailing the creation of the first zero-gravity "drift paintings" inside a custom acrylic chamber.
[9]: Shilts, R. (1982). The Mayor of Castro Street: The Life and Times of Harvey Milk. St. Martin's Press. Biographical history of Harvey Milk's civil rights legacy in San Francisco, serving as the moral anchor for the Columbarium physical placement and the LEO Civil Rights Museum framework.

3.1 Structural Hierarchy: Willowhab & The Xenian Node

Willowhab: The overarching integrated, living space habitat concept designed for long-term endurance in extreme environments, built upon the foundation of Bio-Pixels and cultivated organic nutrients within the philosophy of #willoworld. In essence, #willoworld is the foundational philosophy of "biological space architecture," where the structural fabric of nodes like the Xenian Node and habitats like Willowhab are grown from organic life—turning off-planet habitats into living, adaptive organisms rather than mechanical enclosures.

The Xenian Node: The specific architectural junction and habitat environment that utilizes Bio-Pixels for diverse structural and environmental applications, facilitating the continuation of YLEM: Artists Using Science and Technology 'Seeding the Frontier' philosophy complimenting Frontier Age research within the Willowhab architecture. [10]. YLEM was a pioneering San Francisco Bay Area non-profit collective founded in 1981 by artist Trudy Myrrh Reagan, alongside core early members including pioneer multimedia and interactive artist Beverly Reiser; named after the Greek concept for the primordial matter of the Big Bang.

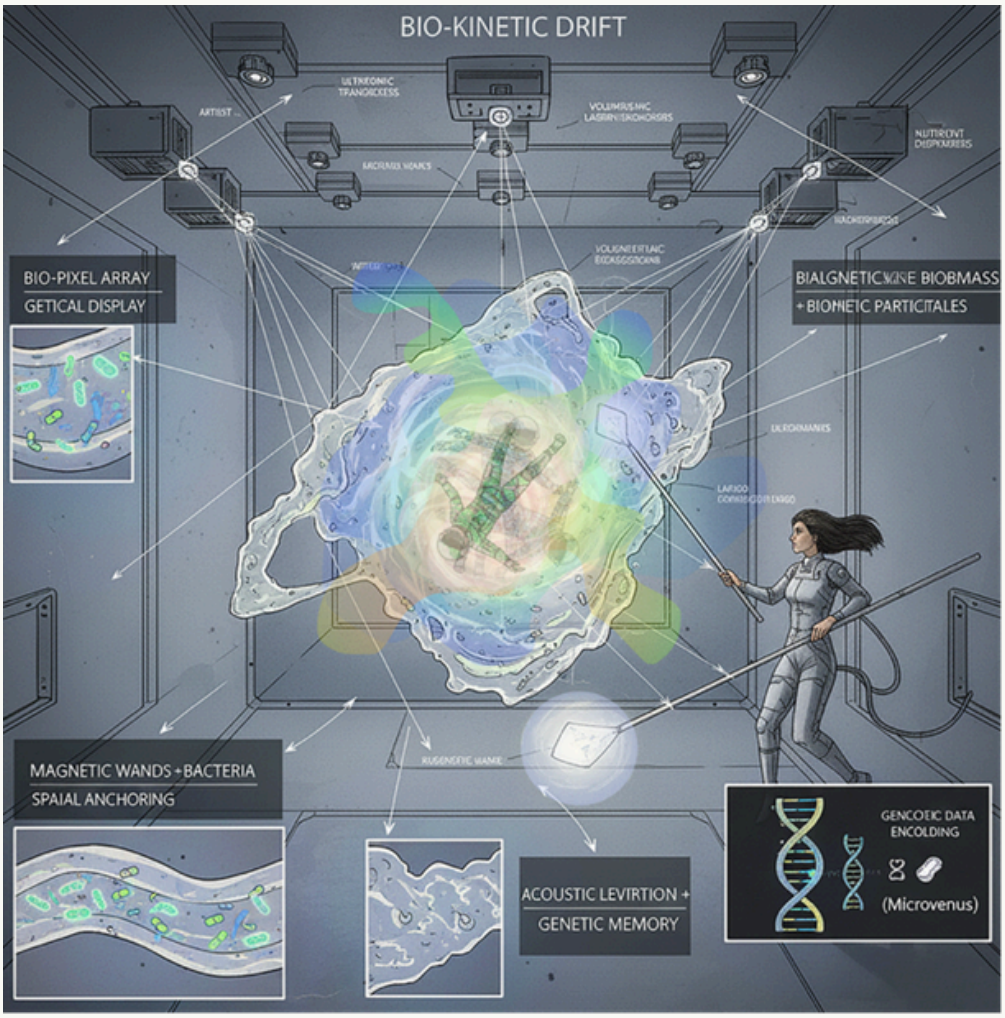
3.2 The Living Canvas and the Bio-Pixel Array

Instead of staring at blinking LEDs, carbon-heavy glass monitors, or blank metallic bulkheads, the inhabitants of a Xenian Node are surrounded by light and form generated by life itself.

The Bio-Pixel: The fundamental technological unit and building block powering the entire ecosystem. Rather than burning out or relying on rare-earth metals like Organic LEDs (OLEDs), Bio-Pixels are synchronized, flexible, multi-layered units of living cells suspended in microfluidic channels. They act as a synthetic sensory organ, feeding on nutrient flows to emit biological light.

The Living Canvas: An artistic and structural application of habitat technology where interior bulkheads become dynamic, glowing, responsive canvases. Composed of an active extracellular matrix, the canvas uses living stem cells, bioluminescent bacteria, or color-changing proteins that regenerate, age, mutate, and adapt based on light, temperature, touch, and biological cycles.

[10]: YLEM reflected a philosophy of bridging scientific discovery and artistic expression through forums, newsletters, and ground-breaking digital art showcases. For detailed archival documentation on YLEM's founding by Trudy Myrrh Reagan in 1981, as well as its history, membership, and mission to integrate art, science, and technology, see the YLEM: Artists Using Science and Technology archival collection preserved at the Stanford University Libraries, Department of Special Collections (Manuscript Collection M1338) and the official project history preserved in the Leonardo/ISAST (International Society for the Arts, Sciences and Technology) historical archives.



BioPixel Drift Painting Concept 1, 2026, Pigment Print on Paper, 12" x 12" Frank Pietronigro, Interdisciplinary Artist, Highly Modified AI

Technological Feature	Traditional Aerospace Interface	LuminaVision Bio-Pixel Interface
Material Base	Aluminum, titanium, carbon fiber, OLED glass.	Biological extracellular matrix, microfluidic channels
Energy & Maintenance	Electrical draw, component replacement	Metabolic nutrient feed, self-sustaining regeneration
Sensory Output	Static metallic surfaces, harsh digital LEDs.	Organic, fluid, non-geometric bioluminescence
Human Interface	Mechanical switches, rigid touchscreens	Biometric resonance, touch, kinetic proximity
Psychological Impact	Sensory monotony, isolation fatigue, stress.	Calming biofeedback, emotional grounding

3.3 The Mechanics of Bio-Kinetic Drift

In microgravity or simulated low-gravity analog environments, physical movement changes dramatically. Movement is no longer constrained to two-dimensional floor planes; inhabitants drift, rotate, and interact across three-dimensional organic volumes.

Bio-Kinetic Drift is the scientific and mechanical framework that governs how Bio-Pixels move, aggregate, and evolve within the free-floating, zero-gravity space of The Xenian Node. When an inhabitant moves through the space or experiences a shift in their biometric rhythm (such as elevated heart rate or altered respiration during a stressful mission task), the architecture senses this presence. The biological cells within the wall physically shift, migrate, and modulate their light output in real time.

Where Pietronigro's 1998 zero-gravity drift painting experiments explored the physics of artistic detachment in midair, Bio-Kinetic Drift applies these fluid dynamics to social cohesion. The Living Canvas reflects the astronaut's internal emotional state back to them as a calming, external biological dance, mitigating panic and dissolving isolation through shared kinesis.

4. Sociocultural & Orbital Infrastructure

Within the Low Earth Orbit & Interstellar Cultural Collective (LEOICC) framework, the LEO Civil Rights Museum Initiative serves as a vital sociocultural and orbital infrastructure anchor. Its core mission is to project human civil rights, equity, and liberation struggles into Low Earth Orbit and beyond—ensuring that as humanity expands into the frontier of space, we bring forward our highest moral commitments to human dignity, equality, and universal hospitality.

The initiative arranges its global, intersectional legacy into intentional paired and singular Historical Anchors:

1. The Moral Anchor

Harvey Milk: Serves as the central moral compass for the orbital museum. As one of the first openly gay elected officials in the U.S., his legacy symbolizes ground-level grassroots bravery, queer liberation, and the unyielding fight for social justice. Anchoring the LEO Civil Rights Museum around Milk ensures that human rights and LGBTQI+ visibility form the foundational bedrock of off-planet cultural governance.

2. Anti-Oppression & Anti-Apartheid Liberation Struggles

Marielle Franco & Steve Biko: Unites global Black liberation and anti-state-violence movements. Steve Biko, leader of the Black Consciousness Movement in South Africa who died in police custody, is paired with Marielle Franco, the Afro-Brazilian favela-born politician and human rights defender assassinated in 2018. Together, they anchor resistance against systemic racism, state violence, and spatial segregation across the Global South.

3. Intersection of Queer Liberation & Technological Innovation

Bayard Rustin & Alan Turing: Connects human rights advocacy with scientific and organizational brilliance. Bayard Rustin, the openly gay chief architect of the 1963 March on Washington, is paired with Alan Turing, the father of modern computing and WWII codebreaker who was persecuted for his homosexuality. This pairing highlights how queer pioneers built the organizational and technological foundations of modern society, asserting that space technology must honor human rights.

4. Caste Abolition & Indigenous Sovereignty

B.R. Ambedkar & Rigoberta Menchú: Bridges global movements against hereditary oppression and colonial exploitation. Dr. B.R. Ambedkar, chief architect of the Indian Constitution and fierce campaigner against the caste system, is paired with K'iche' Maya activist Rigoberta Menchú, a Nobel Peace Prize winner dedicated to Indigenous rights and land sovereignty. In an orbital context, this pairing asserts that space colonization must reject caste hierarchies, resource extraction, and Indigenous disenfranchisement.

5. Feminist Thought, Queer Identity & Space Exploration

Audre Lorde & Sally Ride: Fuses feminist intersectionality with aerospace achievement. Audre Lorde, the self-described "black, lesbian, mother, warrior, poet," is paired with Dr. Sally Ride, the first American woman and first known LGBTQ+ astronaut in space. This pairing emphasizes that expanding into orbit requires both the analytical tools of radical feminist theory and the technical excellence of women in spaceflight.

6. Historical Priority & Global Representation in Orbit

Dr. Arnaldo Tamayo Méndez: Represents the historic pioneer of Black and Latin American presence in spaceflight. As a Afro-Cuban cosmonaut aboard Soyuz 38 in 1980, Tamayo was the first person of African descent, the first Latin American, and the first Cuban to fly in space. His inclusion honors the historical contributions of the Global South and Afro-descendant pioneers in space exploration.

7. Disability Justice, Universal Access & Adaptive Spaceflight

Ed Roberts & Dr. Judith Heumann: Anchors the global fight for disability rights, physical accessibility, and bodily autonomy. Ed Roberts, a pioneer of the Independent Living Movement who contracted polio as a child, and Judy Heumann, the fundamental architect of the Section 504 Sit-in and the Americans with Disabilities Act (ADA), transformed how society designs physical and social environments. In an orbital context—where microgravity inherently alters mobility, balance, and physical orientation—this anchor asserts that space architecture, habitats, and technologies must be engineered around universal design and radically inclusive access, rejecting the exclusion of disabled and neurodivergent bodies from the cosmic frontier.

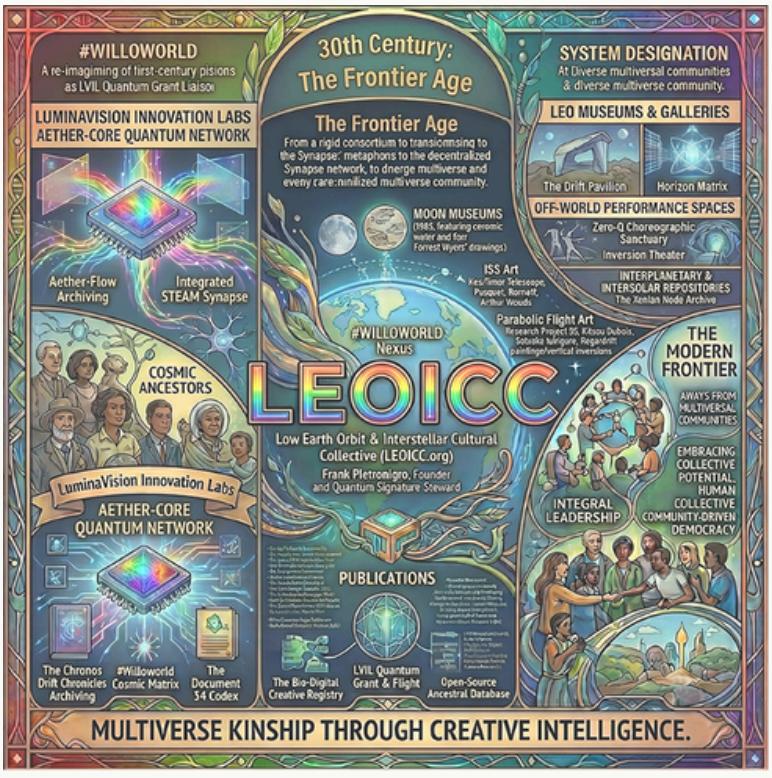
4.1 Analog Space Humanism (HI-SEAS, MDRS, CHAPEA)

Terrestrial analog space missions—conducted in isolated deserts, polar ridges, or undersea modules—consistently reveal that the greatest threat to mission success in Isolated, Confined, and Extreme (ICE) environments is not mechanical failure, but crew friction, sensory monotony, and psychological fatigue. [11]

The deployment of a Modular and Portable Bio-Kinetic Responsive Interface into environments like HI-SEAS, MDRS, or CHAPEA acts as a profound disruptor. Because the interface is lightweight, flexible, and packable, it can be deployed directly into existing rigid analog architectures. It instantly transforms a sterile isolation container into a restorative environment where environmental maintenance becomes an act of care, fostering an empathetic social structure among the crew.

4.2 LEOICC: Low Earth Orbit Interplanetary Cultural Collective

Universal hospitality requires dedicated off-planet institutional frameworks. Operating as an organ of LuminaVision Innovation Labs, the Low Earth Orbit & Interstellar Cultural Collective (LEOICC.org) serves as a permanent repository for artistic consciousness generated off planet.



LEOICC Low Earth Orbit Interstellar Cultural Collective, Frank Pietronigro, Founder and Quantum Signature Steward, June 2026

[11]: Kanas, N., Salnitskiy, V., Ritsher, J. B., Gushin, V. I., Weiss, D. S., Saylor, S. A., & Marmar, C. R. (2009). Human interactions during space missions and space simulations. Aviation, Space, and Environmental Medicine, 80(3), A37–A41. Empirical study examining inter-crew friction, cultural diversity, and sensory monotony in high-stress, isolated, confined, and extreme (ICE) environments like space analogs.

LEOICC operates through The Synapse—a living, decentralized neural network of human consciousness, biological technology, and orbital telemetry:

Persistent Quantum Archiving: Instantly capturing and cataloging the unique quantum signatures and physical manifestations of off-planet art.

Nurturing Living Infrastructure: Cultivating bio-adaptive orbital galleries and deep-space cultural nodes.

The Infinite STEAM Framework: Ensuring artistic logic maintains parity with engineering logic in deep-space colonization models.

The Bio-Digital Creative Registry: Tracking orbital telemetry and digital twins of off-Earth creations.

The Document 34 Codex & Chronos Drift Chronicles: Archival streams analyzing fluid behavior, microgravity aesthetics, and zero-G history.

4.3 Sociocultural Infrastructure: The LEO Civil Rights Museum

Universal hospitality cannot exist as an abstract ideal; it requires physical and historical anchors. As a core component of LEOICC, The Xenian Node embeds the LEO Civil Rights Museum directly into its biological habitat architecture.

By honoring pioneers of human dignity—from Harvey Milk, Bayard Rustin, and Audre Lorde to global figures like Steve Biko, Marielle Franco, and Dr. Arnaldo Tamayo Méndez—the habitat continually grounds off-world society in the civil rights movements that expanded human freedom on Earth. In diverse, multi-national space crews, this framework establishes an operational baseline of psychological safety, mutual respect, and ethical inclusivity.

5. Conclusion: The Frontier Age and One Node at a Time

If we look beyond the Information Age, humanity is entering The Frontier Age—a phase where transportation systems are shifting from exploration-based vehicles to integrated, biological habitat nodes. The migration beyond Earth requires more than life-support mechanics; it requires a migration of human empathy.

Through the integration of responsive living materials, classical hospitality frameworks, and civil rights legacies, The Xenian Node offers a practical model for deep-space living. The Modular and Portable Bio-Kinetic Responsive Interface is a declaration of independence from the arcane metallic paradigm.

Through LuminaVision Innovation Labs, space exploration is re-envisioned through symbiotic harmony and Universal Hospitality. By surrounding ourselves with living canvases that drift and breathe alongside us, we ensure that when we look out into the terrifying, empty vastness of outer space, we are always embraced by the welcoming, undulating light of home.



BEYOND FAST AND SLOW THINKING: TOWARD A "SYSTEM 3" FRAMEWORK FOR COGNITIVE STABILITY IN ANALOG SPACE MISSIONS



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INDEPENDENT RESEARCHER — TUO RESEARCH INITIATIVE

1 . Introduction

As humanity prepares for long-duration space missions, lunar habitats, analog stations, and future Mars settlements, increasing attention is being directed toward the stability of human cognition and social organization in extreme environments.

Confinement, communication delays, operational fatigue, sensory monotony, uncertainty, and environmental hostility profoundly affect interpretation and decision-making processes (Kanas & Manzey, 2009). Research in space psychology and human factors has repeatedly shown that isolated operational environments amplify interpersonal tensions, cognitive rigidity, stress accumulation, and communication difficulties (Kanas & Manzey, 2009).

Many failures in confined operational systems do not originate from a lack of intelligence or technical expertise. Instead, they often emerge from premature interpretation:

- rapid assumptions,
- attentional collapse,
- emotional compression,
- heuristic rigidity,
- and accelerated cognitive closure.

The dominant framework used to describe such mechanisms remains dual-process cognition (Kahneman, 2011; Evans, 2008).

In simplified form:

- System 1 corresponds to rapid, automatic, intuitive processing;
- System 2 corresponds to slower, deliberate, analytical reasoning.

However, certain operational situations suggest the existence of a third functional mode.In some contexts, successful interpretation does not emerge from heavy analytical calculation, yet neither does it arise from immediate intuition. Instead, effective cognition appears to depend on temporary stabilization of attention before interpretation closes too rapidly.

This paper explores this possibility.

Importantly, the proposed framework does not reject dual-process theories. Rather, it attempts to describe a complementary operational mode situated between immediate heuristic closure and fully analytical computation.

2 Premature Interpretive Closure

Extreme environments place unusual pressure on cognitive systems.
Analog space missions reproduce many of these constraints:

- confinement,
- reduced novelty,
- fatigue,
- delayed communication,
- uncertainty,
- repetitive social interaction,
- and operational stress.

Under such conditions, the brain increasingly relies on heuristic compression and predictive shortcuts (Clark, 2013; Friston, 2010). Within predictive processing frameworks, cognition may be interpreted as a continuous anticipatory process attempting to minimize uncertainty by rapidly identifying familiar patterns and generating predictive interpretations.

This process is highly adaptive in ordinary environments.
However, under confinement and stress, it may also increase the probability of:

- false assumptions,
- operational oversimplification,
- interpersonal misunderstandings,
- rigid interpretations,
- and conflict escalation.

Importantly, the issue is not necessarily irrationality.
Individuals may respond coherently — but only to a compressed representation of the situation.
The operational problem therefore becomes less:

“failure to reason”

than:

“premature closure of interpretation.”

Research on bounded rationality and heuristic efficiency already suggests that human cognition often favors reduced informational expenditure (Simon, 1957; Gigerenzer et al., 1999). In operational environments, this tendency may become amplified by fatigue, urgency, emotional saturation, and communication constraints.

Olivier Houdé's work on cognitive inhibition offers an important perspective here (Houdé, 2000, 2014). Houdé argues that intelligence does not merely consist in producing logical reasoning, but also in inhibiting dominant but misleading intuitive responses.

The present paper extends this operationally.

Beyond inhibition alone, successful cognition may sometimes depend on maintaining attentional openness slightly longer before interpretive closure occurs.

This temporary stabilization may allow:

- contextual meaning,
- operational logic,
- memory,
- ambiguity,
- and relational structure

to interact before a final interpretation stabilizes.

3 The Proposed "System 3" Framework

The proposed "System 3" framework does not describe a new biological organ or a distinct neural architecture.

Rather, it refers to a functional operational mode characterized by:

- inhibition of premature closure,
- attentional stabilization,
- active structural listening,
- maintenance of interpretive flexibility,
- and delayed cognitive compression.

Operationally, "System 3" may be defined as:

the temporary maintenance of attentional openness sufficient to prevent premature heuristic closure before analytical reasoning becomes necessary.

The distinction is important.

System 3 is not equivalent to heavy analytical reasoning.

Many successful responses emerging from this mode may still appear intuitive. However, unlike rapid heuristic intuition, they result from sustained structural attention rather than immediate interpretive completion.

One may therefore distinguish between:

- automatic intuition,
- and attentive intuition.

The proposed distinction between rapid heuristic closure, analytical reasoning, and attentive stabilization may be summarized schematically as follows.

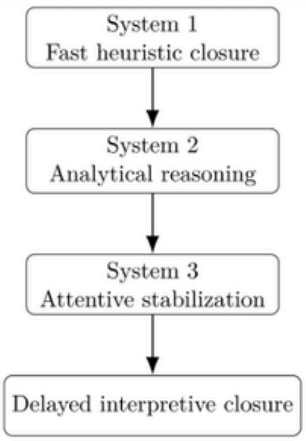


Figure 1: Conceptual distinction between rapid heuristic cognition, analytical reasoning, and attentive stabilization before interpretive closure.

This distinction becomes particularly relevant in environments where ambiguity, fatigue, emotional compression, and informational overload distort interpretation.

Simple cognitive reflection problems help illustrate this mechanism.

One famous example is the “bat and ball” problem introduced in cognitive reflection studies (Kahneman, 2011):

“A bat and a ball cost $1.10 in total. The bat costs $1 more than the ball. How much does the ball cost?”

Many participants immediately answer:

“10 cents.”

The error does not emerge from irrationality.

Instead, the brain rapidly compresses the structure of the problem into a familiar heuristic pattern:

1.10 − 1 = 0.10

Correct resolution requires maintaining the relational structure of the statement long enough to inhibit premature closure.

Importantly, many individuals solve the problem correctly without formal algebraic reasoning.

Instead, they appear to maintain structural attention slightly longer before interpretation stabilizes.

The same mechanism appears in exponential growth problems, communication ambiguity, technical anomaly interpretation, and social misunderstanding.

The proposed framework also remains compatible with later refinements of reflective cognition proposed by Stanovich (2011), particularly regarding higher-order monitoring and cognitive control.

In each case, successful cognition may depend less on increased analytical complexity than on stabilization of interpretation itself.

The operational difference between rapid heuristic compression and attentive stabilization may also be represented conceptually.

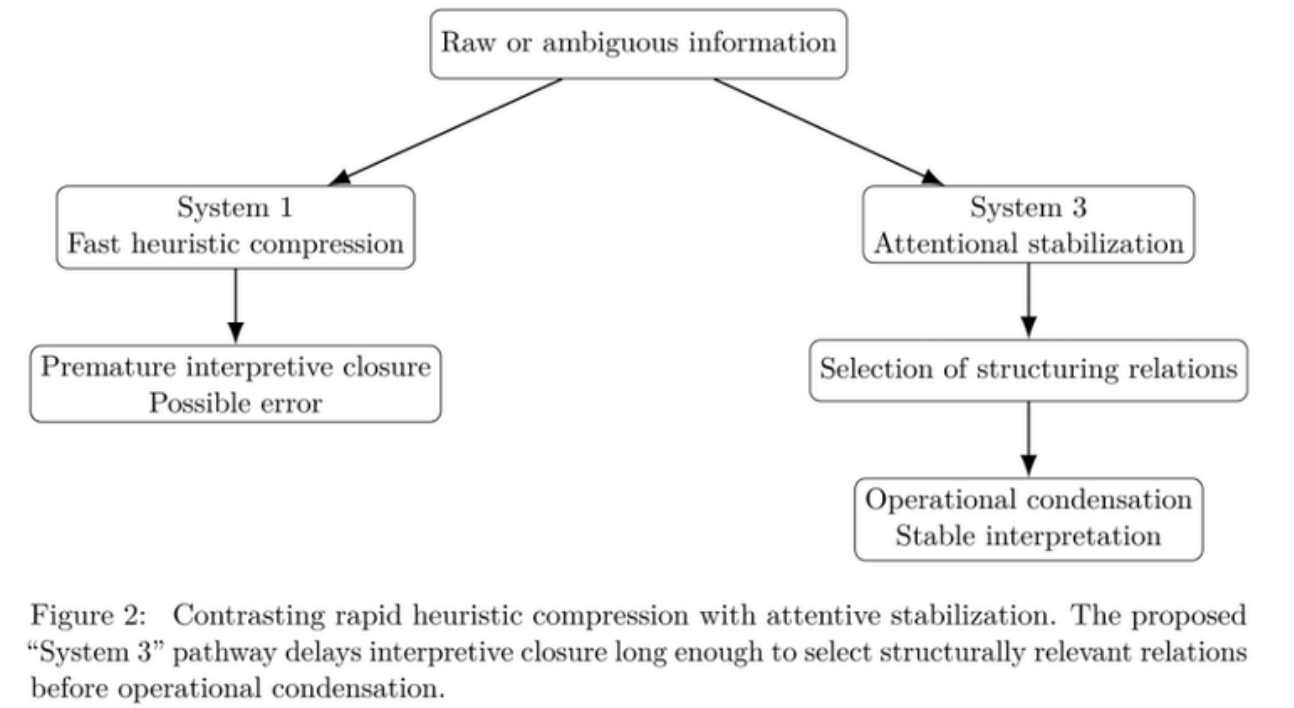


Figure 2: Contrasting rapid heuristic compression with attentive stabilization. The proposed "System 3" pathway delays interpretive closure long enough to select structurally relevant relations before operational condensation.

4 Operational Relevance for Analog Space Missions

The relevance of attentive cognition becomes especially visible in analog space missions.

Such environments amplify several cognitive risks:

- interpretive rigidity,
- attentional fatigue,
- emotional saturation,
- communicational compression,
- overconfidence in first impressions,
- and social feedback loops.

Crew members under stress may increasingly react not to the full structure of situations, but to internally completed assumptions.

Small interpretive distortions may progressively accumulate into:

- interpersonal tension,
- mistrust,
- operational errors,
- and cognitive fragmentation.

Examples may include:

- communication ambiguity under delayed response conditions,
- premature interpretation of technical anomalies,
- emotionally compressed social interactions,
- or rapid consensus formation under operational pressure.

In such situations, attentive cognition may become operationally important.

A “System 3” framework may therefore contribute to:

- communication stability,
- conflict reduction,
- operational flexibility,
- collective reasoning,
- and crew resilience.

Another potentially important dimension concerns relational discrimination.

In confined operational environments, crew members frequently need to interpret:

- partial signals,
- incomplete operational reports,
- sequences of events,
- ambiguous causal chains,
- and social behaviors.

Under stress, a major cognitive risk consists in confusing:

- correlation,
- causality,
- temporal proximity,
- narrative coherence,
- or perceptual similarity.

Attentive cognition may therefore involve not only inhibition of premature responses, but also a capacity to identify structurally relevant relationships.

In this perspective, effective problem-solving depends not only on computational speed or immediate intuition, but also on:

- the quality of selected relations,
- their structural coherence,
- and their condensation into operationally usable representations.

This issue may become particularly important in analog missions, where informational overload, fatigue, and communication delays significantly increase the probability of premature interpretive closure.

Several of these operational concerns are already recognized within NASA's Human Research Program roadmap, particularly regarding behavioral health, crew cohesion, stress adaptation, and decision-making under isolation (NASA HRP).

5 Illustrative Operational Training Concepts

The following concepts are purely exploratory and do not constitute validated astronautical protocols.

However, they may illustrate how attentive cognition could potentially be operationalized in analog mission preparation.

One possible training approach would involve exposing participants to ambiguous or incomplete operational situations designed to trigger rapid heuristic closure.

Examples may include:

- incomplete communication instructions,
- ambiguous anomaly reports,
- delayed information sequences,
- or stress-induced interpretation tasks.

The objective would not primarily consist in producing rapid answers, but in identifying the moment at which interpretation prematurely stabilizes.

Another possible exercise would involve maintaining multiple hypotheses simultaneously before operational decision-making.

Participants could be trained to:

- distinguish correlation from causality,
- reconstruct logical chains explicitly,
- detect implicit assumptions,
- and delay premature explanatory closure.

Short interpretive stabilization pauses before critical decisions may also represent a useful operational concept.

- Such pauses could encourage operators to:
- reformulate observations,
- distinguish interpretation from raw information,
- identify remaining ambiguities,
- and evaluate alternative hypotheses before action.

The objective would not be to suppress intuition or reduce operational efficiency excessively.

Rather, the purpose would be to improve the structural quality of interpretation under operational stress.

6 Conclusion

As humanity moves toward increasingly isolated and operationally complex environments, cognitive resilience may become as important as technological capability.

The central cognitive challenge may not simply involve:

- thinking faster,
- or calculating more accurately.

It may instead involve:
preventing interpretation from closing too quickly.

From this perspective, cognition may depend not only on computational speed, but also on the temporary preservation of structurally relevant informational relations before interpretive fragmentation occurs. This view also resonates with broader hypotheses concerning cognition as a process of structural compression and stabilization of informational invariances (Maillot, 2026).

The proposed "System 3" framework suggests that attentive cognition — characterized by inhibition, structural listening, relational stabilization, and delayed interpretive closure — may play an important role in future human adaptation to confined and extreme operational environments.

This issue may become particularly important in long-duration missions involving:

- communication latency,
- ecological confinement,
- irreversible crew interdependence,
- and operational uncertainty.

Beyond space exploration, the framework may also have broader implications for human factors, education, communication, operational decision-making, and cognition in increasingly compressed informational environments.

References

1.Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behavioral and Brain Sciences, 36, 181–204.
2.Evans, J. St. B. T. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. Annual Review of Psychology, 59, 255–278.
3.Friston, K. (2010). The free-energy principle: A unified brain theory? Nature Reviews Neuroscience, 11, 127–138.
4.Gigerenzer, G., Todd, P., & the ABC Research Group. (1999). Simple Heuristics That Make Us Smart. Oxford University Press.
5.Houdé, O. (2000). Inhibition and cognitive development. Cognitive Development, 15, 63–73.
6.Houdé, O. (2014). The Development of Cognitive Inhibition. Springer.
7.Kahneman, D. (2011). Thinking, Fast and Slow. Farrar, Straus and Giroux.
8.Kanas, N., & Manzey, D. (2009). Space Psychology and Psychiatry. Springer.
9.Maillot, F. (2026). Understanding, Compression, and Intellectual Substance:A Reflection on Memory, Reading, and Cognitive Structures. Zenodo. https://doi.org/10.5281/zenodo.20070686
10.NASA Human Research Program. Human Research Roadmap. https://humanresearchroadmap.nasa.gov/
11.Salas, E., Tannenbaum, D., Kraiger, K., & Smith-Jentsch, K. (2012). The science of training and development in organizations. Psychological Science in the Public Interest, 13, 74–101.
12.Simon, H. (1957). Models of Man. Wiley.
13.Stanovich, K. (2011). Rationality and the Reflective Mind. Oxford University Press.



BEYOND TECHNOLOGY: THE HUMAN SIDE OF ANALOG SPACE MISSIONS



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FOUNDER AND CEO OF CASSIOPEIA, STARDUST AMBASSADOR IN EGYPT, ANALOG ASTRONAUT.

When people think about the future of space exploration, they often imagine powerful rockets, advanced spacecraft, artificial intelligence, and revolutionary technologies. While these innovations are essential, my experience has taught me that the greatest challenge of any space mission is not the technology it is the people.

Every successful mission depends on trust, communication, resilience, leadership, and the ability of a crew to function as a unified team under extraordinary circumstances. Long before humanity establishes permanent settlements on the Moon or Mars, we must first understand how humans adapt, cooperate, and thrive in extreme environments. This is where analog space missions become invaluable, and where astrosociology plays a vital role.

My journey into analog astronautics began at the Mars-Moon Astronautics Academy & Research Science (MMAARS), where I completed an intensive month-long training program designed to prepare future analog astronauts for the operational, scientific, medical, and human dimensions of space exploration.

The curriculum covered the foundations of astronautics, analog mission architecture, mission planning, remote mission operations, crew selection, and the principles of building highly effective multidisciplinary teams. From the very beginning, the program demonstrated that every successful mission starts long before launch, through careful preparation and a deep understanding of teamwork.

I received specialized training in space medicine, including robotic-assisted surgery, telemedicine, remote anesthesia, and medical support concepts designed for long-duration missions where immediate access to Earth-based healthcare is impossible.

Another major component focused on space manufacturing, where I studied the application of 3D printing for future space exploration, including the production of medical tools, replacement parts, and life-support system components that will allow astronauts to manufacture essential equipment directly on the Moon or Mars.

The program also emphasized space health and human performance, covering astronaut wellness, space psychology, human factors engineering, stress management, decision-making under pressure, and the physiological and psychological challenges associated with living and working in isolated environments.

Operational training included Extravehicular Activities (EVA), where I learned spacewalk procedures, habitat communication protocols, and the correct methods for donning and doffing a spacesuit. To complement these skills, I also participated in underwater training designed to simulate aspects of working in reduced-gravity environments. These practical exercises highlighted the importance of coordination, discipline, precision, and trust among crew members.

My practical training at MMAARS was conducted as part of Crew Huygens, an international analog astronaut crew composed of four members from different countries. I served as the Crew Engineer Officer, taking responsibility for supporting the crew's technical operations while working closely with teammates from diverse cultural and professional backgrounds.
This experience demonstrated that successful space missions are built not only on technical expertise, but also on collaboration, mutual trust, adaptability, and effective communication across international teams.

As part of our crew identity, each member selected a personal callsign inspired by an animal that reflected their character and approach to the mission. I chose the callsign "Zeyada Cobra." To me, the cobra represents awareness, resilience, precision, adaptability, and the ability to remain calm under pressure. It became more than a simple callsign; it symbolized the mindset I aimed to bring to every mission challenge and every responsibility within the crew.
Beyond technical training, I participated in a multidisciplinary mission hackathon where teams collaborated remotely to solve realistic mission challenges under operational constraints. This experience reinforced one of the most important lessons in human spaceflight: no astronaut succeeds alone.

Medical field operations formed another essential part of the program. I trained in astronaut rescue procedures, the PMARCHP medical protocol, search and rescue operations, medical triage, casualty evacuation, and emergency response strategies that may be required during future planetary missions.

Scientific exploration training focused on geological EVAs using the GEVA system, terrain exploration, scientific soil sampling, rover and drone support, and field research methods similar to those expected during lunar and Martian expeditions.

Astronomical EVA activities introduced celestial navigation, astrophotography, and the use of interactive observatories to conduct scientific observations during analog missions.
The curriculum also explored one of the greatest challenges facing future explorers: sustainable food systems in space. I studied space nutrition, food engineering, hydroponic agriculture, vertical farming, and sustainable food production technologies that will enable future off-world settlements to become increasingly self-sufficient.

The final stage of the program examined humanity's transition toward becoming a multi-planetary species, exploring future lunar and Martian settlements, emerging technologies, accelerated innovation, space law, governance, ethics, and the evolving relationship between humanity and space.

One month after successfully completing the MMAARS program, I was honored to become the First Egyptian Virtual Analog Astronaut. While this milestone marked an important achievement in my own journey, it also represented a greater responsibility. It strengthened my commitment to advancing space education, supporting international scientific collaboration, and encouraging young people to believe that their dreams can extend far beyond the limits they imagine.

Throughout my training, one lesson became impossible to ignore.
Technology may build spacecraft.
People build missions.

Every analog habitat becomes a living laboratory where communication, leadership, resilience, adaptability, cultural understanding, and mutual trust are continuously tested. These are not simply soft skills they are mission-critical capabilities that determine whether crews succeed together or fail together.
This is exactly why astrosociology matters.
As humanity prepares to establish permanent communities beyond Earth, we must study not only how people survive in space, but how they build societies in space. Future lunar bases and Martian settlements will become more than engineering projects; they will become communities shaped by shared values, cooperation, diversity, and human relationships.
The technologies we develop will undoubtedly carry us farther into the Solar System.

But it is our ability to work together, understand one another, and build resilient communities that will determine whether humanity truly becomes a multi-planetary civilization.

Coming from Egypt, my own journey has taught me that no dream is defined by where it begins. Every challenge became an opportunity to learn. Every obstacle became another lesson. Every experience strengthened my belief that the future belongs to those who continue learning, adapting, and serving something greater than themselves.

It prepares us to become better teammates.
Better leaders.
Better scientists.
And ultimately, better representatives of humanity as we take our first steps toward becoming an interplanetary civilization.
The distance between Earth and the stars is not measured only in kilometers.
It is measured in curiosity.
In perseverance.
In knowledge.

In collaboration.
And in the courage to keep moving forward.
For me, space has never been simply a destination.
It is a lifelong mission.
From the desert to space, every challenge became another step toward the stars.



THANK YOU FOR READING THE ASTROSOCIOLOGICAL INSIGHTS FORUM!



The Astrosociology Research Institute (ARI) is a California nonprofit public benefit educational corporation dedicated to the development of astrosociology as a multidisciplinary academic field.

Its mission includes providing assistance to individuals and organizations that choose to pursue ARI's mission as stated on the home page of this site. It's mission emphasizes assistance to students conducting astrosociological study and original research.

ARI is the original 501(c)(3) organization dedicated to the development of astrosociology as an accepted field in academia and to cutting-edge astrosociological research.

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