The APUS Analog Research Group (AARG): Research and Outreach Initiatives

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The American Public University System (APUS) is comprised of American Public University (APU) and American Military University (AMU); it is a fully online, synchronous educational institution offering a wide variety of programs at both the undergraduate and graduate level. As an online university, APUS actively seeks opportunities to promote student interaction and supplement the virtual classroom experience which will promote student leadership and research opportunities. Among these opportunities, the APUS Analog Research Group (AARG) stands out as a premier research initiative. AARG is a student-run, faculty supported program that offers unique, hands-on research experiences for students and faculty. Established in 2021, the program provides valuable opportunities to perform

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a wide range of space research in terrestrial analog astronaut facilities. Since its inception, AARG has completed five analog missions to The University of North Dakota's Integrated Lunar/Mars Analog Habitat (ILMAH) and one analog mission to The Mars Society's Mars Deseret Research Station (MDRS) facility. A total of 22 students and faculty members have served as crew members on these missions, with many more serving in mission planning, mission control, and research support roles.

As a research group, AARG's primary goal is to support students through the research process, from ideation through development to publication. Two core components of AARG's scope and purpose are to (1) "perform meaningful research which will be relevant in furthering long-term space exploration and settlement initiatives," and (2) "to foster multi-disciplinary, team-based research experiences within the confines of an online environment" (AARG, 2023). AARG's approach to achieving these goals is two-pronged, consisting of a Research Coordination Team (RCT) and Faculty Subject Matter Experts (SMEs). The RCT supports project development and mission readiness by tracking progress as methods and safety protocols are researched and developed, and materials and equipment are procured. They provide guidance through the Internal Review Board (IRB) process, scheduling during the mission, and support post-mission deliverables. Throughout this process, SMEs provide guidance on project content, scientific relevance, and viability.

AARG is a primarily passive research organization (Persaud, 2004), meaning that the program's normal mode of operations is to support student researchers as they work on personal research projects at designated analog facilities. AARG supports a variety of research projects, including both scientific investigation and educational outreach. Selected crew members are expected to propose, develop, and implement their own research projects during the mission. These projects allow students to pursue personal interests, incorporate individual areas of expertise, and gain experience with research directly related to their educational concentrations. These projects span a wide variety of topics ranging from human factors to plant growth to habitat design/efficiency, etc. AARG has completed forty total projects since its inception. The majority fall under botany, habitability, and crew psychology, although other types of research have been supported as well, for a total of 11 distinct subject areas as shown in Figure 1. Many projects are multidisciplinary and can include research submitted to the mission by AARG planning staff members who are not part of the crew.

AARG also supports program-level research projects; in contrast to the passive research described above, these represent active research consisting of established research objectives and methodologies (Persaud, 2004). For these projects, students are recruited to the project rather than creating their own research. These program-level research initiatives allow

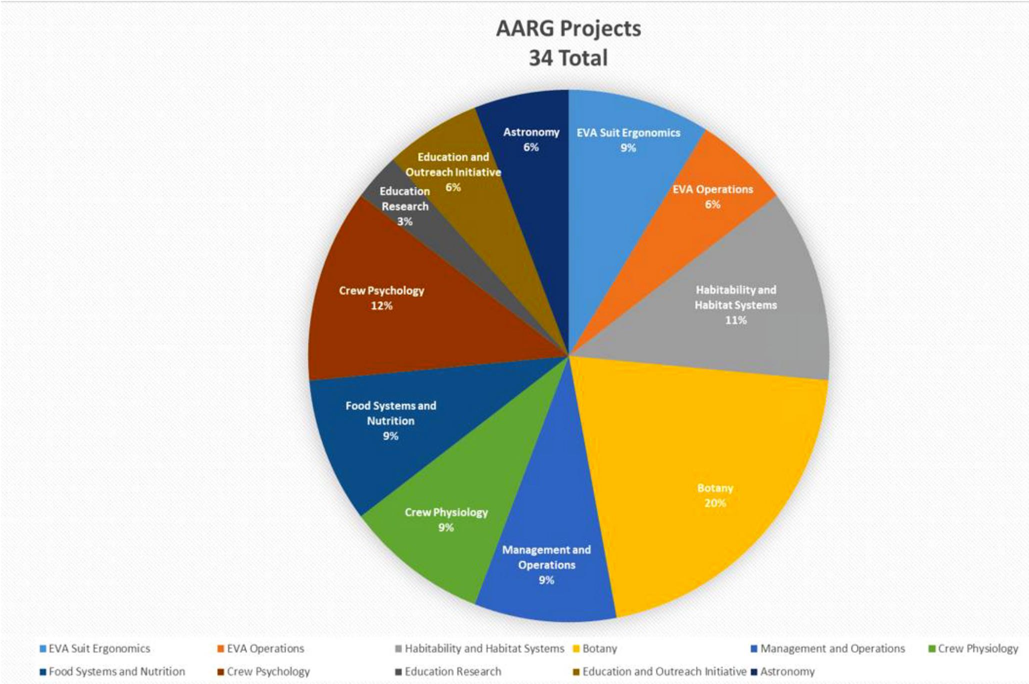

Figure 1. *AARG Research*

Note: This chart depicts the range of AARG research projects during 2022.
Image credit: Scott Van Hoy

less experienced researchers to become familiar with the research process before creating their own projects. They also create opportunities for long-term and more in-depth data collection.

The research described in this panel represents individual (passive) research projects developed and performed by AARG crew members during both ILMAH and MDRS missions in the 2022–2023 field season.

Digitally Assessed Measurement of Stress in an Analog Astronaut Environment: Trends and Potential Mitigations

PI: Alexis Lojek, MS Aerospace Science; AARG Analog Astronaut

This research, performed over the course of three Space Analog Research missions and presented at the SESA conference, supported the principal investigator's Masters' Thesis. The intent of the research focused on the efficacy of digital measurement of stress during space analog simulations with the Garmin Vivosmart 4 devices as a nonintrusive measurement tool that could potentially assist in improving crew health during space exploration. The secondary purpose was to determine the extent to which stress could be reduced through a scheduled regimen of focused-breathing techniques, commonly called meditation. This digital measurement was assessed through the use of multi-role heartrate sensors and a proprietary algorithm developed by a company called *FirstBeat Technologies* and utilized by Garmin.

These experiments ultimately assessed whether this heart rate variability-based digital measurement of stress using wearable devices was helpful in monitoring stress before, during, and after three analog astronaut missions. The measurements were also analyzed to determine if a mitigation technique in the form of scheduled times to "stop, breathe, and focus on the breath" could help reduce stress, and to observe any other trends in the data. Stress data of 14 crewmembers across three different analog astronaut missions were gathered. During these missions, crewmembers performed scheduled "stop and breathe" periods for a predetermined amount of time to assess whether there was an instantaneous decrease in stress during these sessions. Trends relating to longer-term reduction in stress during the mission were also evaluated.

Figure 2. *Average Stress*

Note: This figure shows the average stress of all crewmembers across AARG-2i, AARG-3i, and AARG-1M.

The analysis ultimately revealed that the research crews were not found to have an overall reduction in stress during the days when focused breathing was conducted, but the techniques assessed did lower stress instantly. Surprisingly, the data indicated that the crews experienced lower stress levels when in the analog environment than when not. The study confirmed the use of wearable digital devices provided an easy, noninvasive way to assess crew stress levels. Further research in this area is warranted as it could have possible implications beyond space, including not only the military, but also Arctic and Antarctic expeditions as well as in other extreme environments, everyday employment, and life.

The Role of Science Communication in Space Exploration

PI: Anthony DiBernardo, MS Astronomy; AARG Analog Astronaut

Communication and outreach for space activities is essential to educate, inspire and help the general public understand the importance of working in space and the benefit it has on their daily life. Without effective science communication, people who could potentially grow to make decisions that affect the larger population are often misled in the ways of pseudoscience, conspiracy theories, and the paranormal. This trend can be seen in the rising generation: ask today's teenagers what they want to be when they grow up and the response is overwhelmingly geared towards becoming an influencer rather than a rocket scientist. Scientists often forget that science does not communicate itself; targeted, optimized communications are essential to promote knowledge and inspire. This project was a step in the national efforts to improve science communication for not only future scientists, but citizens as well.

While the venues available to study seem limitless in this regard with the dominance of social media, this project ultimately explored two capabilities by testing types of outreach and communication conducted on an analog astronaut mission for the purpose of instilling exciting scientific research as a positive future for young students and the general public. The mission conducted with this research in mind was the ARG-1M/Crew 274 mission to MDRS from APUS. The first component of this project tested how real outreach can be conducted on an analog mission in real time. The crew spent an entire day talking to over 200 live participants on 11 Zoom calls, answering questions and presenting their research. The target audiences varied from 10-year-olds in a classroom, to full departments at SpaceX. The entire team was engaged; they got a chance to not only explain their research, but field LIVE questions from people inside and outside of the scientific community. The experience gave the crew a new perspective regarding their own research in terms of who could understand it and who may or may not seek it out.

The second effort on this mission was to produce a full-length, professional quality documentary of the experience. With the popularity of documentaries such as *Good Night Oppy* and countless space movies which rank among the most watched in non-scientific circles, analogs seemed like a great opportunity to capture and present real people doing real science that any college student or professional could participate in. The goal here wasn't to inspire everyone to be an analog astronaut, but to lower the barrier to entry for scientific topics in general and make science more approachable.

To complete the documentary, the crew hiked for hours pulling incapacitated astronaut dummies; successfully germinated seeds flown in space; prepared for EVAs, or spacewalks; witnessed daily mission planning in real time as well as the fruits of that planning; collected data on variable stars; and documented when things went wrong. Filming also included interviews with each crew member in which they narrated the documented events and experiments during the mission.

Ultimately, the final product was a 50-min documentary that has over 1,500 views on YouTube, all in 4K and spoken and narrated by the crew. While this is a huge accomplishment, more research is needed. The truth is that target audiences are not watching documentaries all day. Instead, they predominantly use their phones to consume shorter-form content. Further research should document analogs in real time on social media and TikTok, for example. The most important lesson is to not be afraid of the transparency that most agencies shy away from.

Supply Cache Use for Extension of Human Exploration on Mars

PI: Nicholas Pender, APUS Space Studies Masters' student; AARG Analog Astronaut

The prospect of conducting extravehicular activities (EVAs) on the Moon and Mars presents complex logistical challenges which must be addressed. Once a foothold has been established on one of these celestial bodies, research goals and resource gathering may compel crews to traverse beyond walking distances from basecamp, necessitating the use of pressurized and unpressurized rovers. As with all things mechanical, the potential exists for these vehicles to fail. Thus, strategically placed supplies along designated routes will be essential to survive a trek on foot to home base or a pressurized shelter location. This research explores the application of this concept in an analogous environment, with initial testing having been conducted by the APUS/AMU AARG Crew 274 at MDRS in Hanksville, Utah.

To facilitate this experiment, Nicholas Pender, principal investigator, developed a prototype supply cache. The cache is powered by solar panels and an internal battery bank which, when paired with a heating element, ensures required supplies of gel packs and water do not freeze in the extreme winter conditions. A single cache was used for this experiment due to both cost and practicality of the experiment construct, though in practice a network of caches could support a specific route.

The experiment itself was broken up into five phases. Phase 1 had three objectives: test hydration bladder and gel food pack functionality with space suits; conduct a 1-mile EVA to establish a benchmark completion time and plot the simulated objective for a 3-hour hiking distance. This third objective caused Phase 1 to last multiple days as the crew negotiated with MDRS Mission Control on a safe objective location.

Phase 2 comprised of deploying the supply cache in the field at Zubrin's Head, a point 1 hiking hour from base, but allowed for the simulated 3-hour trek required for the research. Phase 3's main purpose was to determine if the supply cache was functioning as designed. Internal and external readings, as well as battery levels and condition assessments were taken and results showed the cache performed well over the first evening, revealing internal temperature of 61F and external temperature of 50F. The battery was at full charge.

Phase 4 was executed by crew members Nicholas Pender and Bill O'Hara embarking from the habitat on foot following the designated route agreed upon by Mission Control. For this scenario, the habitat was designated a simulated break-down location of a rover that Pender and O'Hara were using, and the break-down location was said to be 3 hiking hours from base. The requirement of 3 hiking hours was set to necessitate the use of a supply cache for replenishment of gel packs and water, as each crew member only carried 1 liter of water and 4 gel packs. One liter commonly supports 2 hiking hours, and 1 gel pack sustains 30 minutes of hiking, so with these constraints in place, the supply cache would meet the needs for this experiment, extending the EVA beyond the threshold that initial hand-carried supplies could support. One observation made during this phase of the experiment was that the terrain used for the Phase 1 baseline (rough terrain) was not the same as that traversed during the Phase 4 scenario (over-the-road). Because of this, the pace of travel was quicker during Phase 4, and the two crew members had to artificially modulate their pace to try to meet intended time targets. This effect was not by design but rather forced by Mission Control as more ideal routes were not approved due to safety concerns. Results of this phase are still under review, but preliminary results indicate that each hiker consumed disproportionate amounts of water: 1,140 mL for one and 1,670 mL for the other. Immediate results also revealed that the cache performed as designed, ensuring usable supplies for the two hikers to finish their EVA beyond the 2-hiking hour threshold.

Phase 5 was broken up into two EVAs. First, supplies were brought to the cache site to replenish those consumed during Phase 4. Sensor and condition readings of the cache were also recorded, but this EVA was essentially a proof of concept that caches could be sustained as an operational model. Second, the supply cache was reconstituted back to habitat. This showed that a supply cache network can be a dynamic solution, allowing for repositioning to establish new safety corridors.

Finally, once reconstitution of the cache was completed, recorded data from temperature and power consumption sensors were compiled to gauge performance throughout the experiment. The findings proved the cache to be very effective at regulating internal temperatures, never dropping below 50F in the evening when external low temperatures dropped to an average of 20F. Future research will require testing of the supply cache prototype in harsher, more frigid environments. A number of design changes will be considered, to include better temperature visualizations, more robust solar panels, and GPS tracking. Experiment design should also be improved upon, utilizing similar baseline terrain to that used in experimentation, and leveraging participants independent of the principal investigator's presence.

Advantages of Adaptive Modular Load Distribution Systems for Extravehicular Activities on Surface Operation Mobility

PI: Keith Pierce, MS Aerospace Science; AARG Analog Astronaut

Future EVAs will include extended surface operations with increased metabolic demand on astronauts. Added strain will be placed on the astronauts as well as the mission resources. One possible way to address this challenge is to understand the physiological impact on the astronauts and develop a more effective operator interface with the EVA suit. To address this challenge, researchers from AMU at ILMAH developed a series of experiments that monitored the analogs astronaut's response to various EVA suit configurations.

The four suit configurations studied included: the EVA suit worn and operated as designed; the EVA suit with an internal load distribution harness; the EVA suit as designed with added trekking poles; and the EVA suit using both the internal load distribution harness and the trekking poles. Each of the four suit configurations was tested during a 60-minute period over flat grassy terrain at approximately a 2.5mph walking pace. Data collected included height, weight, age, and gender, along with the duration, distance, pace, temperature, heart rate (HR), perceived exertion, comfort level, and carbon-dioxide (CO_2) levels.

When measuring the aggregate data of all participants over all 18 separate EVAs, the team was able to make some promising observations. The team observed a 4.3 percent lower mean heart rate (HR) while using the internal harness vs the baseline suit configuration. The perceived exertion was found to be 80 percent more positive when comparing the internal harness used in conjunction with the trekking poles to the baseline suit configuration. Finally, the perceived comfort level reports via survey were found to be 74.6 percent more favorable when comparing the internal harness used in conjunction with training poles to the baseline suit configuration.

"*Evaluating Contingency EVAs and Rescue Techniques for Planetary Surface Missions Through the Use of Assistive Devices*"

PI: Sarah Guthrie, APUS Space Studies Masters' student; AARG Analog Astronaut

As part NASA's Artemis Lunar Surface Program planning, Phase 1 (EVA-EXP-0042 and EVA-EXP-0075) discusses the necessity to develop contingency methodologies to support exploration extravehicular activity systems missions. This study aims to support NASA's incapacitated crewmember rescue for partial-gravity surface operations using spaceflight analog facilities and self-developed hardware.

The basis of this study was to explore the pitfalls of a partial gravity rescue, specifically on the lunar surface. Considerations for suit operation and integration as well as environmental factors played a pivotal role in the development of this study. ILMAH provided high fidelity analog spacesuits for evaluating NASA's proper suit-interface requirement. MDRS supported an analogous lunar or Martian surface environment to investigate mobility challenges with staging a rescue. Over the course of a year, this investigation was carried out on two analog missions at ILMAH (ARG-2i, ARG-3i) and one analog mission at MDRS (ARG-1m) supported by 16 participants. Research development was facilitated by AARG's Research Coordination Team and faculty support.

The initial stages of this study were performed at ILMAH utilizing UND's Human Space Flight Laboratory's North Dakota Experimental (NDX-2) Advanced Lunar Suits. Since this study focuses primarily on planetary extra-vehicular activities (EVA), understanding limitations imposed by space suit design was vital to evaluate NASA's concerns for proper suit-interface and self-rescue hardware and techniques. In May 2022, ARG-2i would be the first analog research study operating a series of assistive devices to facilitate an incapacitated member rescue using a Med-Sled®, medical all-terrain transport chair, and telescopic dolly.

Four months later, ARG-3i's analog mission deployed in September 2022 as the second iteration of the study. After the performance of ARG-2i's assistive devices, ARG-3i honed in specifically on suit-interface challenges faced in ARG-2i. In January 2023, ARG-1m became a new stage in the study engaged on transport feasibility in a higher fidelity analog environment without the use of an NDX-2. ARG-1m continued with the use of the Med-Sled® with integration of the Assistive Medical and Incapacitated Extraction (AMIE) vest for surface contingency rescues.

For safety, the Kinetic Utilization Research Tool (KURT) was developed to use as an incapacitated member,

***Figure 3.** Medical Sled Demo*

Note: ARG-2i analog crew performing test of the medical sled. Credit: Keith Pierce (May 2022)

***Figure 4.** The Kinetic Utilization Research Tool*

Note: KURT displayed within medical sled with UND's NDX-2AT "Blueberry" suit during ARG-3i analog mission. Image credit: Alexis Lojek (September 2022) without introducing harm or risk to actual participants. In each analog study, the weight of KURT was increased to simulated partial gravity conditions from 9 kgs, 14.5 kgs, and 18.12 kgs, respectively.

The ARG-2i analog mission revealed complications for participants ability to bend, kneel, lift, and position KURT from the surface to the sled or other device as it was greatly impacted by the suit. While the NDX-2 is a superior tool for EVA testing, its universal fit limited astronaut's (participant) ability to perform. Limitations in mobility from the helmet, hard upper torso (HUT), gloves, and shoes prevented range of motion and impeded vision.

Given the complications revealed in ARG-2i, ARG-3i looked to provide analog astronauts with contact points for lifting. A front clasp construction harness with two large D-clips allowed means for lifting of KURT while accommodating suit design.

Analog testing at the MDRS facility's primary objective was to examine a self-engineered rescue vest to simulate integrated contact points in the HUT, an improvement to the ARG-3i harness. The Assistive Medical and Incapacitated Extraction (AMIE) vest was constructed to support multiple handles in various positions. As participants lifted KURT, combinations of handles and lifting styles were evaluated to determine the best feasibility for handling an incapacitated member on the surface.

Figure 5. *Testing at MDRS*

Note: Image from "ANALOG: A Documentary of the ARG-1M Analog Mars Mission," by Anthony DiBernardo. May 2022.

This study continues to target critical safety concerns for NASA's future lunar and planetary endeavors. It exercises the use of analog facilities and equipment to perform and evaluate proper techniques and develop hardware necessary for planetary surface rescues. Analogs provide means to explore contingency scenarios with reduced risk or introducing unnecessary harm. The study will continue to test variations of the Med-Sled® and an upgraded HUT adapting concepts from the AMIE vest. KURT continues to be an envoy for safe student led spaceflight research. Further exploration with spacesuit design and higher fidelity facilities will be key to providing space-driven agencies with reasonable recommendations for contingency EVA preparedness.

Water Electrolysis Research for Sustainable Space Exploration: Insights from the University of North Dakota's ILMAH

PI: Noah Loy, APUS Space Studies Undergraduate Student; AARG Program Manager; AARG Analog Astronaut

The quest for sustainable space exploration mandates innovative solutions to address resource challenges. ILMAH has been at the forefront of pioneering research in water electrolysis—a technology pivotal in overcoming constraints related to air, water, and fuel supplies. This presentation explores the methods, research objectives, and, notably, the findings of AARG's electrolysis experiments, shedding light on the efficiency, reliability, and integration of this technology into the life support systems of space habitats.

Space missions face the dilemma of resource scarcity, necessitating solutions beyond reliance on Earth-supplied resources. Water electrolysis emerges as a key technology capable of producing oxygen for breathing and hydrogen for rocket propellants. AARG's research objectives encompass efficient resource utilization, ensuring the reliability of electrolysis systems in harsh environments, optimizing gas storage, integrating electrolysis into habitat systems, and decreasing dependence on Earth-supplied resources.

AARG conducted a series of meticulously designed experiments at ILMAH to delve into the intricacies of water electrolysis. The initial experiment utilized graphite electrodes submerged in a solution of 2,500mL distilled water and 20mL sodium hydroxide. Applying a 20V potential difference, the system efficiently generated 50mL of hydrogen and 50mL of oxygen free radicals in 8 minutes and 25 minutes, respectively. This set the stage for more sophisticated experiments.

Subsequent trials involved platinum electrodes, introducing variations in solution concentrations and voltage. Using a 25V potential difference with 750mL distilled water and 20mL sodium hydroxide, the crew collected 500mL of hydrogen and 250mL of oxygen in approximately 1 hour and 6 minutes. This indicated a substantial increase in efficiency compared to the graphite setup.

Further complexity was introduced by incorporating graphite, platinum, and copper conductors in a single experiment. With 225mL distilled water and 50mL sodium hydroxide, and applying a 25V potential difference, AARG observed intriguing outcomes. Graphite conductors exhibited an electric current of 2.07 Amps, isolating 150mL of hydrogen in 20 minutes and 75mL of oxygen in 22 minutes and 40 seconds. Platinum electrodes, despite electrode tip damage affecting efficiency, produced 20mL of hydrogen in 1 hour, 26 minutes, and 40 seconds, and 10mL of oxygen in 1 hour, 40 minutes, and 12 seconds. Copper conductors, with an electric current of 5.75 Amps, outperformed in speed, isolating 140mL of hydrogen in 12 minutes and 70mL of oxygen in 12 minutes and 20 seconds. Corrections for surface area differences were implemented for more accurate results.

An intriguing anomaly surfaced during these experiments. While hydrogen production consistently outpaced oxygen, as expected, the magnitude of the time difference raised questions about the process's efficiency and consistency. It was anticipated that hydrogen and oxygen, integral components of water, would exhibit more synchronous rates of production. The AARG team delved into the anomaly, scrutinizing data sets to identify underlying factors contributing to this temporal disjunction.

These experiments provide valuable insights into the potential of water electrolysis for sustainable space exploration. Graphite conductors demonstrated remarkable efficiency in oxygen production, posing them as a viable option for life support systems in space habitats. Conversely, platinum electrodes exhibited efficiency challenges, necessitating further exploration into electrode materials. The observed time gap between hydrogen and oxygen production beckons further investigations to enhance the overall efficiency and consistency of electrolysis processes, as the relative surface area of the platinum electrodes could have severely stifled the ability of this cathode to produce meaningful results.

AARG's electrolysis research marks a significant stride in advancing technologies crucial for prolonged space missions. The technical results underscore the nuanced dynamics of water electrolysis, offering a foundation for optimizing efficiency and reliability. These findings not only contribute to the scientific understanding of electrolysis but also hold promise for practical applications in ensuring resource autonomy and sustainability in future space exploration endeavors.

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