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RAF–analog space mission: Simulation of a Martian research outpost in a mining environment

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Abstract

The RAF-Analog Space Mission was a ten-day simulation conducted on a post-mining heap in Bytom, Poland, designed to replicate aspects of living and working on Mars. The project, was organized by the Scientific Club of Geophysics at the University of Warsaw and aimed to test principles of habitability, astronaut behavior, and interdisciplinary scientific research in an analog environment. The mission crew, consisting of three students: Natalia Godlewska (astronomy) – co-leader of the project and mission commander, Norbert Nieścior (physics) – geolab officer, and Piotr Lorek (biotechnology and medical chemistry) – biolab officer, lived in a mobile base composed of a camper serving as living quarters and a delivery van adapted as a laboratory, connected by an airlock.

Research activities encompassed geophysical, geological, astrobiological, and psychological studies, simulating the scientific and operational tasks anticipated in futureMars missions. The analog conditions allowed the team to assess logistical challenges, teamwork dynamics, and technical feasibility of field operations in a constrained setting.

Results indicated that the mobile habitat successfully maintained both living and research functions, though psychological aspects and procedural limitations emphasized the necessity of flexibility and compliance with established protocols. The mission demonstrated the value of low-cost terrestrial analogs for preparing methodologies, technologies, and human factors research relevant to future planetary exploration.

Keywords: mining heaps, coal mining, magnetometry, hydroponic garden, spirulina

Introduction

For ten days, a post-mining heap from the coal mine in Bytom was transformed into an analog space base. This place became a hub of scientific activity as young researchers from the Scientific Club of Geophysics at the University of Warsaw embarked on an innovative project to simulate Martian conditions. The mission, named RAF-Analog Space Mission, aimed to replicate space conditions, test behaviors and principles applicable in outer space, and conduct essential scientific research.

The mission team comprised three students: Natalia Godlewska, an astronomy student and co-leader of the project; Norbert Nieścior, a physics student; and Piotr Lorek, a student of biotechnology and medical chemistry. These "astronauts" spent ten days living and working in a specially designed analog space base on the heap. The mission's primary objective was to conduct various scientific studies, including geophysical, geological, psychological, and astrobiological research.

The central phase of the project involved setting up a mobile base composed of a camper (serving as the living quarters) and a delivery van (serving as the scientific laboratory), connected by an airlock. This setup, located on approximately 30 square meters, provided a controlled environment simulating Martian conditions. The participants followed strict protocols, leaving the base only in space suits to maintain the illusion of being on Mars.

Analog space bases are terrestrial simulations of space conditions—in this case, Martian conditions. Analog astronauts strive to live and operate under space-like rules and constraints. The base allowed the team to experience and adapt to the challenges of life on Mars [1].

Historical background

Development of the concept

It was decided to create an analog space base using a camper and a van, connected by a tent. Together, they could form the perfect setup for an analog space base. The camper van would serve as living quarters for three analog astronauts, while the van would function as a scientific laboratory.

The mining heaps in Bytom City (Lower Silesia, Poland) were chosen as the location for the base. There were several reasons for this choice:

• The site has interesting geochemical history. This area is particularly fascinating due to the geochemical processes that have taken place underground, leading to the formation of new types of minerals [2].
• This area resembles the Martian landscape both visually and scientifically. Some of the minerals and geological features present there can be considered analogs of their Martian counterparts.
• The area is deserted, with no ongoing economic activities.
• The club has already performed measurements in this area, which made easier obtaining necessary permissions.
• Additionally, some club members had prior experience working in the specific mining heaps of Bytom.

Grant application

In November 2022, Mikołaj Zawadzki, together with the Scientific Club of Geophysics, submitted a grant application to the Ministry of Education and Science under the program "Student Scientific Clubs Create Innovations" for the implementation of the world's first temporary analog space base on the mining heaps of Bytom. The project, with a budget of 33,210 PLN, received a positive evaluation from the ministry, and its implementation—funded by ministerial resources—began in May 2023.

Team

Analog astronauts

• Natalia Godlewska – a third-year undergraduate student of Astronomy at the Faculty of Physics, University of Warsaw, and the National Point of Contact for Poland in the SGAC organization. During the mission, she served as the crew commander.
• Norbert Nieścior, BSc – a second-year master's student at MISMAP, Faculty of Physics, University of Warsaw. A scientist at the Space Research Center of the Polish Academy of Sciences. During the mission, he served as the officer of the geological laboratory.
• Piotr Lorek – a third-year undergraduate student of Interfaculty Individual Studies in Mathematics and Natural Sciences with a main course in Biotechnology and Medical Chemistry. During the mission, he served as the officer of the biological laboratory.

Figure 1. Analog astronauts on the mining heaps.

Mission control center

• Mikołaj Zawadzki, MSc – a PhD candidate and researcher at the Faculty of Physics, University of Warsaw. He conducts research on water extraction from polar regions of Mars. During the mission, he served as the commander of the ground mission control, coordinating and supervising the entire project.
• Filip Kaczorowski – a third-year undergraduate student of Physics at the Faculty of Physics, University of Warsaw. He is interested in geophysics and nuclear reactor physics and works as a physics teacher. During the mission, he served as the deputy commander of the ground mission control.

Consultants and additional support

• Konrad Kossacki, PhD – a professor at the Faculty of Physics, University of Warsaw. He is a researcher in planetary science. He was the supervisor of the project.
• Urszula Cur, MSc, Junior Police Inspector (retired) – a former police psychologist and profiler, expert in psychological profiling, and educator at her school of psychological profiling "Sie7dem." During the project, she served as a psychological consultant.
• Aleksandra Białek, MSc – specializes in psychological counseling and crisis intervention. During the mission, she served as the chief psychologist.
• Tomasz Mikołajków, MSc – PhD candidate at the University of Warsaw, Faculty of Physics, Institute of Geophysics. Specializes in planetology. He was responsible for design and construction of the diamagnetic frame.
• Łukasz Kruszewski, PhD – a professor at the Institute of Geophysics, Polish Academy of Sciences. Specializes in biogeochemistry, mineralogy, and the hydrogeology of coal mining waste heaps. In the project, he served as a geological consultant.
• Joanna Kargul, PhD – professor at the University of Warsaw, Center for New Technologies, Solar Fuel Laboratory. Specialized in microalgae physiology and artificial-leaf construction. She supervised the experiment involving the cultivation of spirulina.
• Wojciech Kumala, PhD – a scientific and technical specialist at the Institute of Geophysics, Department of Atmospheric Physics. PhD in Physics in the field of solid-state physics. He was responsible for logistical support in the construction of the diamagnetic frame.
• Bartłomiej Brudnowski, BSc – a master's student at the Faculty of Physics, University of Warsaw. He participated in the construction of the hydroponic garden and the frame for the magnetometer.
• Jan Jarzyna – an undergraduate student of Physics. He was responsible for editing and publishing videos on YouTube.

Mission preparation

Pretraining

From April 5-7, 2024, an analog astronaut training took place at the European Centre for Geological Education in Chęciny. Five team members participated in person, while the project consultants joined remotely. The training allowed the astronauts to familiarize themselves with the operation of research equipment and provided an overview of the scientific foundations of the aspects being studied during the mission.

Figure 2. Preparation before the mission in Chęciny.

Setting the base

The mission itself began on April 26, 2024. This day was special not only because it marked the start of the mission but also because in Poland, the period of vacations was beginning, as May 1st and 3rd are public holidays.

The setup of the base lasted from the late evening of April 26, when the team arrived on-site, until April 28, when the actual analog mission began. It is important to note that assembling the base required highly intensive work, as all necessary elements had to be prepared for the experiments conducted during the mission, and the tent connecting the camper with the delivery vehicle had to be set up. This entire process took two days, and only on April 28 were the analog astronauts able to begin their work in a properly prepared research and living environment. The mission ended on May 5, 2024, and within a few hours, the base elements were dismantled. The team then returned to Warsaw, where the research equipment was stored at the Faculty of Physics, University of Warsaw, during the night of May 5-6.

Course of the mission

Daily schedule

The daily schedule followed a strict routine designed to simulate real space mission dynamics. Crew members typically woke up at 4 AM and went to sleep at 8 PM. The schedule was suitable for high temperature conditions during the time of the mission.

Each day began with preparation for outside research and EVA simulation. Afterward, the crew ate breakfast and had a short briefing with Mission Control Center. During the day the whole crew stayed inside the habitat and analyzed data, maintain the habitat, and conducted experiments inside the base.

During the early afternoon, a lunch break was scheduled which allowed the crew to rest and recharge. Post-lunch, activities included second EVA simulation of the day. During those walks the analog astronauts collected geological and biological samples as well as mapped the whole terrain of the heap using magnetometer attached to special diamagnetic frame.

Figure 3. Analog Astronauts during their daily tasks.

Evenings were reserved for dinner and briefings with psychological consultants. After those activities the crew had some personal time before lights went out. When the crew was absent in the habitat, members of mission control center were refilling the water tank in the camper. This task was necessary, due to the small amount of water that can be stored at one time. Notably, despite efforts to conserve water, the supply still required replenishment.

Diet

As the mission aimed to simulate real space missions conditions as closely as possible, the diet was carefully designed to reflect the limitations and challenges of nutrition in isolation. Access to certain food types, mainly meat and dairy products, was restricted. Because of this, the mission took on a plant-based diet more suitable for long-duration space missions. Before the mission, the caloric needs of each crew member were individually calculated based on their age, body type and activity level. These counts served as the foundation for developing a balanced and functional dietary plan [3].

Meals were prepared using limited cooking space and equipment. Despite the dietary restrictions and all the limitations, the crew was satisfied with the food.

Psychological support

Maintaining well-being was a main focus from the start plans of the project. The team collaborated with two psychologists to ensure mental wellness during the entire mission, and pay attention to teamwork, communication and stress resilience.

Throughout the mission, daily psychological briefings were held with the psychological team. These meetings focused on monitoring the mental state of the crew and dealing with problems as they appear. The goal was to create a safe space where crew members could freely express their emotions, group dynamics and any difficulties [4].

Scientific Part

Geophysics

Due to the fact that the magnetometric method is sensitive to the presence of materials with ferromagnetic properties, one of the elements of the project was the design of a special frame made exclusively from diamagnetic materials. Its purpose was to shield the magnetometer from the ferromagnetic components of the astronaut's suit. In an actual space mission, the astronaut's suit would certainly contain ferromagnetic elements, which would interfere with measurements of the magnetic field of a given celestial body (most likely Mars, which possesses a residual magnetic field). The frame was primarily constructed from aluminum components. The wheels consisted of rubber tires, and the bearings used in their construction were made from diamagnetic materials.

The frame was tested in field conditions by the astronauts. However, due to the use of components of insufficient quality, it did not fulfill its intended function, and its parts began to deteriorate rather quickly under the challenging terrain conditions (numerous steep inclines and uneven surfaces).

Figure 4. Conducting measurements with a magnetometer on heaps using a diamagnetic frame. The measurements in the photo are carried out by Natalia Godlewska.

Geology

During the mission, the analog astronauts collected research samples. These included both consolidated (lithified) and unconsolidated (non-lithified) rock samples. The rock samples collected during the mission were analyzed using the XRF (X-ray Fluorescence) method. XRF is a non-destructive analytical technique used to determine the elemental composition of materials.

The data were processed with statistical techniques like Cluster Analysis (CA) and PolyComponent Analysis (PCA) to identify intra-elemental correlations and classify samples into groups.

The analyses confirmed the presence of pyrometamorphic rocks (PMR) such as clinkers, porcellanites, and metacarbonate slags, along with post-smelting slags and non-pyrometamorphosed rocks. CA identified chemically distinct samples and confirmed the common source materials. The PCA biplot shows elements as eigenvectors and samples as datapoints. Elements like Fe, Cu, and Zn have significant variance, indicated by longer vectors, most samples cluster near the center, indicating similar compositions, with outliers displaying unique compositions. The meta carbonate slag—the most interesting from the magnetic point of view.

Figure 5. Geology. Collected rock samples that were tested for ferromagnetic properties.

Astrobiology

The astronauts collected numerous rock samples also for the purpose of astrobiological research. In environments as harsh as mining heaps—particularly due to high temperatures—the existence of living organisms is highly unlikely.

There are exceptions; organisms known as extremophiles are capable of surviving and functioning under such extreme conditions. To ensure the integrity of the biological samples, the astronauts disinfected the sampling tool with ethyl alcohol before collecting each sample. Unfortunately, the analysis did not reveal the presence of any living organisms in the samples.

Spirulina experiment

Arthrospira platensis, commonly known as spirulina, is a cyanobacterium with exceptionally high nutritional value [5]. Its dry mass consists of approximately 65–70% protein, which contains all essential exogenous amino acids and numerous antioxidants. As a unicellular organism, it grows significantly faster than traditional crops. Under Earth conditions, when cultivated out-doors, it can achieve a biomass production rate of 30 g m^{-2} per day in simple raceway open-pond system in Inner Mongolia [6], or up to 60 g m^{-2} per day in Qingdao, China [7]. Given this knowledge, the decision was made to cultivate spirulina inside the habitat.

A 30-liter polypropylene bucket was used for cultivation. At its bottom, a hollow silicone tube ring was installed and connected to an aerator, which provided CO_2 necessary for photosynthesis while also mixing the culture. As a light source, a set of five 72 W LED strips was wrapped around the bucket—an essential setup for Martian conditions, where natural light cannot be used.

This system was used to cultivate 20 liters of spirulina culture in Modified Zarrouck's medium. Experiments conducted after the mission in a laboratory setting confirmed that spirulina growth in this system was as effective as in a standard laboratory phototron [8].

Hydroponic garden

Design, construction, and testing of a hydroponic garden using the NFT (Nutrient Film Technique) system with artificial lighting. The main goal of the project was to create a plant cultivation system that would be an ideal supplement to astronauts' diets. Due to its fast growth and minimal nutrient requirements, a hydroponic system was chosen. To allow for easy scalability, the NFT flow-based hydroponic technique was implemented [9].

To best fulfill the goal of enhancing astronauts' meals, the focus was primarily on herbs—such as basil, marjoram, parsley, and others—that contribute the most flavor, aroma, and culinary richness. Additionally, popular, and palatable crops like tomatoes, strawberries, and wild strawberries were cultivated.

Figure 6. Building a hydroponic garden.

Figure 7. Hydroponic Garden.

Actions after mission

Public visibility

The project attracted a great deal of media attention. Over 20 articles were published across a wide range of online media platforms, offering in-depth coverage of the project's goals, activities, and findings. In addition to written media, the project was featured multiple times on both local and national television as well as in many radio stations. This shows that the interest the project generated went well beyond the academic community.

In addition to media outreach, members of the team actively shared the outcomes of the project at several major scientific conferences. These included the International Conference of Physics Students (ICPS 2024) in Tbilisi, Georgia – the world's largest student-led physics conference; the 2024 Symposium of Young Scientists in Warsaw; the 2024 Earth Science Days in Krakow; the CPSYS 2024 conference in Wroclaw; the prestigious AGU Fall Meeting 2024 in Washington, D.C., United States; as well as at Analog Astronaut Conference 2025 in Tucson, Arizona. These presentations helped bring the project's findings to both national and international scientific audiences.

The project was awarded with the main prize- StRuNa-SCIENCE in 2024. Additionally, Natalia Godlewska received an award for the best presentation at ICPS 2024 in Tbilisi with her talk about RAF Analog Space Mission. Moreover, Natalia Godlewska was a guest speaker at the Women in Tech Summit 2024, which is the biggest conference about science and technology in Europe and Asia.

Educational activities

Educational outreach is important part of whole team's activity. Recognizing the importance of engaging with society and inspiring future generations promote participation in numerous public events and science festivals. These include the Warsaw Science Festival 2024 the Day Explorers at the Ochota Campus 2024 and 2025, the University of Warsaw Student Clubs Fair 2024 and 2025, Physicists Day 2024 and 2025, and World Space Week Wrocław 2024, w Baltic Festival of Science in Gdańsk, "Kapitularz" – Fantasy Festival. These efforts not only broaden the public's understanding of science but also help build a more society passionate about space [10].

Figure 8. Baltic Festival of Science in Gdańsk.

Discussion

Strong points of the project

One of the greatest strengths of RAF project was its interdisciplinary approach. People from various fields worked tirelessly together to design, build, and maintain the analog space base, ensuring the success of the mission. The interdisciplinary collaboration allowed for smooth operation of the analog space base and contributed to expanding current knowledge about post-mining heaps.

Gaining greatly needed practical experience in planning and executing a mission that would be successful while having low budget that must be strictly maintained is another main strength of RAF mission. Managing a research project with strict financial limitation and low budget required from our team to experience and adapt to the financial challenges that would also be a problem while planning and executing an actual space mission, where budgets must be optimized for efficiency.

Another strength of RAF mission is that it lays foundations and creates a blueprint for future mobile analog bases. Thanks to RAF project, pioneering in creation of a mobile space base, it opened a way for designing more advanced mobile research units capable of mimicking the conditions of various types of other worlds. Creating new mobile space bases will be helpful as a testing ground which will long-term support missions of human space exploration.

By creating content for social media as well as promotion of RAF project through traditional media, which brought national attention, surely has brought more awareness to the field of analog space missions and inspired people to pursue scientific career and work on analog space missions.

Weak points of the project

During the RAF project, members of our team encountered some technical challenges, including the failure of the diamagnetic scaffold and magnetometer. These technical problems highlighted the importance of using durable and sturdy equipment as well as more through equipment tests prior to the mission in scientific exploration, particularly where repairs and replacement are not readily available.

The strict budgetary constraints limited the scope and scale of the RAF project, which prohibited the team from purchasing more advanced equipment or expanding the scope of research. Although budgetary constraints encouraged innovation and creativity, they also largely restricted the project from conducting more expansive and possibly more fruitful research. Future missions need access to additional funds to enable the purchase of better equipment and to expand research initiatives.

Extremely interdependent working and living conditions over a period which members of the RAF team experienced created tensions and interpersonal conflicts, which affected the overall success of the mission.

Severe environmental conditions, such as the hot temperatures RAF analog astronauts faced, were a strict test for field work. Environmental limitations were to be overcome at the cost of the research timeline and impacted how much data about post-mining heaps was gathered.

Conclusions for future

For better coping with technical disruptions and enabling the success of future missions, it is crucial to invest in acquiring resilient and reliable equipment. Pre-mission testing and redundancy strategies can help detect potential malfunctions in equipment to be avoided during interference in mission objectives. By stressing technical readiness, future missions can strengthen their capabilities in collecting data and ensuring the reliability of their results.

The realization of secondary funding is crucial in ensuring the success of future analog space missions. Adequate financial resources allow for acquiring sophisticated technologies, widening research programs, and creating new approaches to research methods. By providing access to key resources, future missions will be in a position to carry out more expansive and high-quality research, advancing our knowledge of extraterrestrial settings and innovating in areas of space missions.

The effectiveness of team dynamics and conflict resolution methods is crucial in ensuring the success of analog missions in space. Future missions ought to place high emphasis on the use of team-building programs and conflict resolution programs to ensure team members' welfare and functionality in their work.

It is crucial that future missions design adaptive research strategies that exhibit resilience to changes in the environment and can collect data in hostile situations. By incorporating flexibility in their design of research, future missions can continue collecting data without compromising on the authenticity of their results. Such flexibility is paramount in carrying out effective research in unstable and turbulent settings.

The public engagement programs that came with the RAF–Analog Space Mission highlighted the importance of good science communication and outreach in ensuring that support is secured for scientific studies and technological innovations.

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Conflicts of interest

There are no conflicts of interest in this work.

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