THE ESA CAVES ASTRONAUT TRAINING PROGRAM: SPELEOLOGY AS AN ANALOGUE FOR SPACE MISSIONS

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Introduction: Space agencies are concerned with training of their astronauts for long duration missions, not only for current and future orbital missions but also for future human and robotic planetary surface exploration. Preparing for expeditions to other planets requires a realistic replication of environmental and situational characteristics of the extreme conditions of space in earth analogue platforms, where stressors similar to those encountered in long duration spaceflight are provided [1] . The environments in which such training events are carried out must have realistic perceived risk and must enable the execution of complex technical tasks, as well as requiring group living in isolated and/or confined settings. This requires the identification of suitable terrestrial analogue environments and the design of high-fidelity training courses / mission scenarios with representative operational set-up.

Since 2008 the European Space Agency has started investigating the use of scientific expeditions into caves as a novel platform for astronaut training, taking advantage of the natural analogies of the cave environment and associated technical operations with space missions. In 2011 a new ESA training programme named CAVES (Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills) was launched, with the specific goal to prepare astronauts for long duration space missions.

Environmental and expeditionary analogies: The cave environment naturally shares several of the stressors that are usually found in human spaceflights [1]. From a physiological point of view the absence of natural zeitgebers can cause alteration of the circadian rhythms [2] and the related physiological stress can be avoided only through earth-like work/rest schedules, similar to those developed for the ISS. In the dark environment of a cave there is a decrease in sunlight exposure requiring consequent adaptation to artificial light, similar to conditions on the ISS, due to confinement and the sixteen day/night cycle/day, and for future interplanetary travel, due to external lighting conditions, as well as the need to live in artificial habitats. The three-dimensionality of cave progression, the lack of common references, the use of headlights and the associated presence of shadows and badly illuminated/visible or inaccessible/keep-out zones increase the hostilility of the environment, similarly to what is experienced during Extravehicular Activities (EVA).

Behavioural issues for isolated, confined teams in future planetary missions are one of the least known factors with a very high potential impact on the mission success. From a psychological and psychosocial point of view, much of the spaceflight stressors are present in cave exploration. When inside a cave, days of progression far from the entrance, the isolation is complete. Cave environments are obviously confined, but mainly mobility is constrained, for safety reasons, to specific paths along walls, like in EVA. Communication with the surface is extremely limited and relies only on technologies that are not trustworthy. This sense of isolation is directly correlated with the distance (in time) from the entrance.

Some stress elements are directly related to the rough nature of the cave environment and to the difficulty of creating comfortable habitability settings at the base camp. That is translated in lack of privacy, uncomfortable sleeping, limited hygiene, exposure to cold and humidity, dust and mud, etc. All these stressors, if not managed, in the long term induce irritation, social conflicts within the team, altered decision-making or even physiological discomfort and health issues.

Different cultural approaches to leadership, information sharing, decision making and teamwork are employed during current ISS missions, all while respecting established hierarchies, rules and procedures. Whilst not all cave expeditions have a structured approach to team processes, the CAVES programme builds upon the situational analogies, while imposing a structured approach to the development of the team, while maintaining flexibility, strongly emphasising team growth via thorough analysis of its own activities and decisions.

CAVES concept and training structure: Caves are hostile and dangerous environments that shall be dealt with clear operational safety rules, requiring the mastering of technical progression skills. The environment is however just a "container": analogies should be based on similarities in experiences, not just in environment [3]. During CAVES astronauts are trained in the use of single rope ascension tools and techniques, to negotiate obstacles and long traverses rigged with iron cables. This technical training resembles skills and safety protocols required to move and operate in extra-vehicular activity, with reduced field of view, shadows, tri-dimensional progression through viable paths, confused perception of obstacles and distances, keep-out and no-touch zones.

This preparatory training is propedeutical to an extended caves exploration phase, where the astronauts autonomously perform a scientific expedition as a multicultural and multidisciplinary team. Astronauts are trained to use a buddy system and to maintain team situational awareness through briefings and debriefings in order to maintain control on the safety of the whole group, to allow informed decision making for each member of the team, and to enable team learning through analysis of failures and successes.

Analogue team training needs to be based on the concept of operations [4] , and provide real challenges, stressors and a credible programme. During the CAVES mission, astronauts will explore new branches of the cave, and are required to survey all newly explored areas, as well as provide photographic documentation of all activities performed.

Scientific and technological program: As for space missions, in CAVES astronauts carry out a comprehensive scientific program, according to a flexible operational timeline and space-like procedures. The scientific tasks the astronauts are asked to carry out are numerous: microbiological sampling of air, water, and solid material, monitoring of cave air temperature, relative humidity, CO_2 concentration, and wind speed and direction, sampling of waters and minerals for follow-up laboratory analyses, and monitoring (and, in some cases, sampling) of cave dwelling fauna (mainly troglobites). During the pre-expedition training, crewmembers test the different experiment procedures and methodologies assisted by scientists, in order also to achieve a good understanding of the relevance of observation and sample collection or data analysis acquisition methodology to the achievement of good scientific objectives.

The scientific programme not only offers a set of realistic tasks and objectives, but it also provides really interesting scientific results. Multidisciplinary researches allow a continuative and detailed study on the caves visited during the course. The environmental monitoring and the geological and geochemical studies are giving important information about the cave environment in this karst area of Sardinia. Moreover systematic microbiological and biological researches provide new information on these peculiar ecosystems, even discovering previously unknown species. All these important scientific goals were achieved thanks to the careful astronauts' performance of strict scientific protocols and procedures.

Aside of scientific experiments and research the mission is also the ground for technological testing of new innovative equipment that has the overall goal to improve operations in the cave environment, but also with potential applications in space. In the last three editions much of the efforts have been dedicated to the evaluation of two wireless cave radio systems, called TEDRA and XFERRA. Both of them have provided interesting results, allowing to the crew the set up of an advanced camp, ensuring the communication with the ground team, required for safety reasons. Also, collision resistant drones specifically developed for inspecting confined and dangerous environments have been tested. The tests are used to improve the instruments and their user procedures for the next editions, but also these systems could provide a base from which to develop reliable communication systems from lunar lava tube missions in the future. Other technologies tested are those related to survey and documentation, like new laser measurement tools (Cavesniper, Megaplot SJ), or for equipment and clothing (new concept of cave shoes for slippery surfaces, CUPRON fibres socks and others).

Conclusions: The environment scientific, operational and situational realism, as well as the real, albeit controlled risk of makes this it a highly credible and valuable training venue. Astronauts are directly involved in one of the open human frontiers of exploration on Earth: the underground. Despite various important differences with space stations, that host current space missions, caves are complex alien environments, offering several of the same situations and associated spaceflight stressors and team processes, as well as science opportunities.

Differently to other analogues, communication inside a cave is rather unreliable, forcing the development of very autonomous mission operations, with reduced reliance on control and directions from ground teams. This offers a rather interesting testbed for future planetary exploration scenarios, which will include delayed communication and higher level of autonomy.

Progression tools, safety and emergency procedures that are used in the CAVES training could be in the future used to develop concepts for moonwalks and surface traverse activities on planetary bodies like asteroids, or even for lunar or martian lava tube exploration.

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