Acta Astronautica 89 (2013) 166–178

Contents lists available at SciVerse ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

NEEMO 15: Evaluation of human exploration systems for near-Earth asteroids

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ARTICLE INFO

Article history:
Received 17 October 2012
Received in revised form
28 January 2013
Accepted 4 March 2013
Available online 19 March 2013

Keywords:
Underwater
Analogs
Aquarius
Asteroids
Exploration

ABSTRACT

The NASA Extreme Environment Mission Operations (NEEMO) 15 mission was focused on evaluating techniques for exploring near-Earth asteroids (NEAs). It began with a University of Delaware autonomous underwater vehicle (AUV) systematically mapping the coral reef for hundreds of meters surrounding the *Aquarius* habitat. This activity is akin to the type of "far-field survey" approach that may be used by a robotic precursor in advance of a human mission to a NEA. Data from the far-field survey were then examined by the NEEMO science team and follow-up exploration traverses were planned, which used Deepworker single-person submersibles. Science traverses at NEEMO 15 were planned according to a prioritized list of objectives developed by the science team. These objectives were based on review and discussion of previous related marine science research, including previous marine science saturation missions conducted at the *Aquarius* habitat. AUV data were used to select several areas of scientific interest. The Deepworker science traverses were then executed at these areas of interest during 4 days of the NEEMO 15 mission and provided higher resolution data such as coral species distribution and mortality. These traverses are analogous to the "near-field survey" approach that is expected to be performed by a Multi-Mission Space Exploration Vehicle (MMSEV) during a human mission to a NEA before extravehicular activities (EVAs) are conducted. In addition to the science objectives that were pursued, the NEEMO 15 traverses provided an opportunity to test newly developed software and techniques. Sample collection and instrument deployment on the NEA surface by EVA crew would follow the "near-field survey" in a human NEA mission. Sample collection was not necessary for the purposes of the NEEMO science objectives; however, the engineering and operations objectives during NEEMO 15 were to evaluate different combinations of vehicles, crew members, tools, and equipment that could be used to perform these science objectives on a NEA. Specifically, the productivity and acceptability of simulated NEA exploration activities were systematically quantified and compared when operating with different combinations of crew sizes and exploration systems including MMSEVs, EVA jet packs, and EVA translation devices. Data from NEEMO 15 will be used in conjunction with data from software simulations, parametric analysis, other analog field tests, anchoring models, and integrated testing at Johnson Space Center to inform the evolving architectures and exploration systems being developed by the Human Spaceflight Architecture Team.

Abbreviations: APS, astronaut positioning system; AUV, autonomous underwater vehicle; CG, center of gravity; RATS, Research and Technology Studies; EAMD, Exploration Analogs and Mission Development; EPSP, EVA Physiology, Systems, and Performance; EVA, extravehicular activity; ISS, International Space Station; LSB, Life Support Buoy; MMCC, Mobile Mission Control Center; MMSEV, Multi-Mission Space Exploration Vehicle; NASA, National Aeronautics and Space Administration; NEA, near-Earth asteroid; NURC, National Undersea Research Center; NEEMO, NASA Extreme Environment Mission Operations; ORU, orbital replacement unit; PFR, portable foot restraint; PLRP, Pavilion Lake Research Project; SAFER, Simplified Aid for EVA Rescue.

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http://dx.doi.org/10.1016/j.actaastro.2013.03.002

1. Introduction

1.1. Aquarius habitat

Aquarius is the only operational undersea research habitat in the world (Fig. 1). It is operated for the National Oceanic and Atmospheric Association by the Florida International University. It is highly sophisticated in its logistical infrastructure, and has not required major modifications to support unique NASA needs.

Aquarius was built in the mid-1980s, and was previously located in Saint Croix (U.S. Virgin Islands) before it was moved to the reef line 19.3 km (12 miles) off Key Largo, Florida, in 1990. In these 2 locations, *Aquarius* has supported dozens of missions to study the undersea realm for several hundred marine research scientists from around the world.

Aquarius is similar in size to the U.S. Laboratory module on the International Space Station, or ISS (~15 m long × 4.5 m in diameter). It is firmly secured to a sand patch surrounded by large spur-and-groove coral reefs on 3 sides. It sits in water 18 m (60 ft) deep, but the entrance level is actually closer to 15 m (50 ft), which corresponds to an internal pressure of ~253 kPa (~2.5 atm). At this depth, aquanauts living and working in the habitat become exposed to excessive levels of nitrogen within the first few hours and must commit to staying in the habitat and undergoing a decompression schedule before returning to the surface. This type of diving is called "saturation" diving, referring to the complete saturation of the body tissues by the breathing gas mixture. A diver in this condition will quickly experience decompression sickness if he or she returns to the surface without going through the requisite decompression schedule, and would most likely experience injury and even death if not treated. The danger is real and the environment is truly extreme, which is one of the key reasons it makes such a good analog to living in space. Aquanauts participating in these missions must utilize their training, skills, knowledge, and teamwork to ensure their safety and mission success.

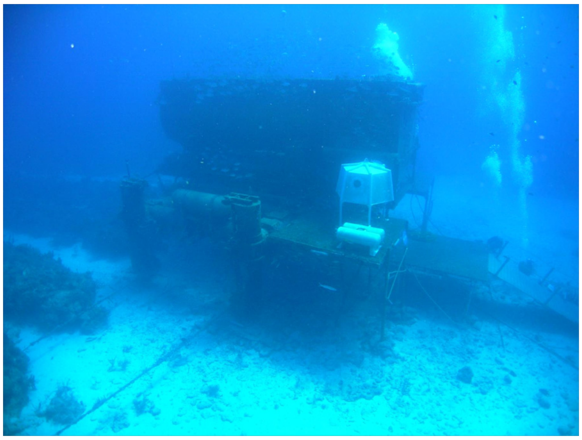

Fig. 1. *Aquarius* is the world's only undersea research habitat, off Key Largo, FL. Photo credit: NASA.

Permanently anchored above *Aquarius* is a 10-m (32.8 ft) "Life Support Buoy", or LSB. On board the LSB are redundant generators and compressors which provide electrical power and fresh air through an umbilical line to the habitat. Separate umbilicals provide communications connectivity. From the LSB the signal is relayed by microwave to the NURC headquarters in Key Largo. This allows *Aquarius* to have real-time voice communication (radio and telephone) and Internet connectivity. It also allows the "watch desk" at NURC to monitor video and systems telemetry in real time, which they do continuously during a mission.

The *Aquarius* facility provides an isolated and confined environment from which realistic EVAs can be performed. With the addition of vehicle and equipment mockups near the habitat, EVAs can be performed to assess operations concepts in a way that will inform suit, vehicle, and tool requirements to maximize crew performance. Because crew members on EVA can be out for extended periods and their environment can be configured to simulate near-zero or partial gravity, the *Aquarius* site is the most effective way to accurately test these operations concepts.

1.2. NASA Extreme Environment Mission Operations (NEEMO) project

The combination of isolation in a confined and extreme environment along with the ability to simulate weightlessness or reduced gravity during EVA excursions makes *Aquarius* an excellent analog for spaceflight. NASA's NEEMO (NASA Extreme Environment Mission Operations) project began in 2001 with the primary goal of astronaut training. Over time, the project has evolved to include many science and engineering studies during the missions. Previous NEEMO missions have included evaluations of the effects of communications time delay on mission operations, demonstration of telemedicine techniques, and testing of methods for measuring behavioral health, team cohesion, fatigue, and other physiological and psychological adaptations that occur during NEEMO missions. Other objectives take advantage of buoyancy while crew members are diving on scuba or umbilical-supplied diving helmets outside the *Aquarius* habitat; by attaching the appropriate amount of weight or flotation to EVA crew members, the effects of different gravity environments and spacesuits of different weights can be simulated. In some cases, custom-built backpacks have been used to simulate the backpacks on EVA suits except that they are reconfigurable so that the center of gravity (CG) can be moved to simulate the CG of different spacesuit designs [1]. Crew members have then performed predefined tasks in the simulated partial-gravity environment to provide valuable data on, for example, the design of tasks, EVA interfaces, and hardware, and the effect of spacesuit weight and CG on EVA performance (Fig. 2).

1.3. Near-Earth asteroids

Near-Earth asteroids (NEAs) have been identified as potential destinations for future human missions and