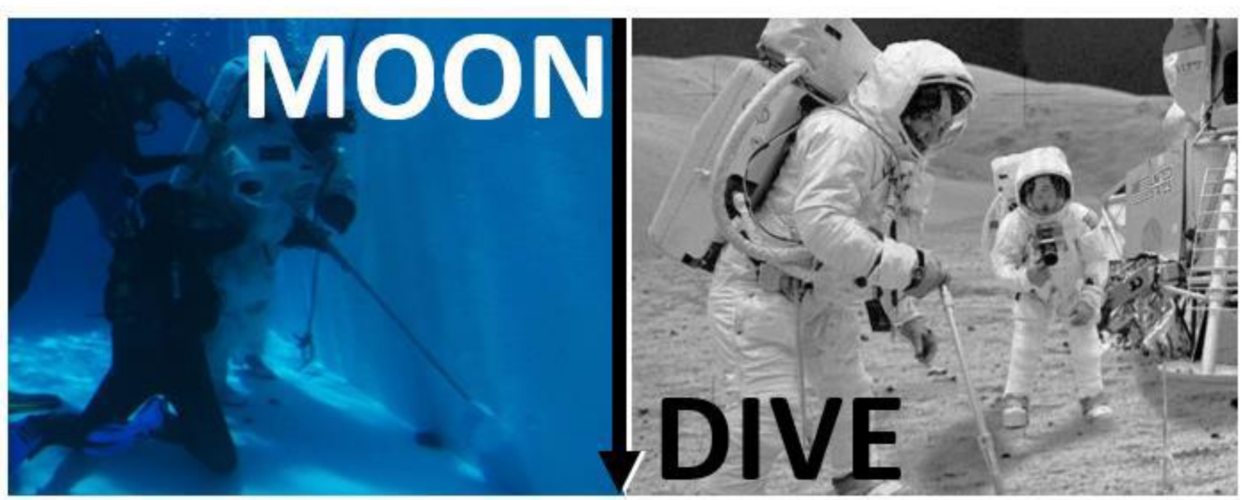
MOONDIVE

ESA GSP Study: Concept Development of EVA Operations
in EAC Neutral Buoyancy Facility for Extra-terrestrial Surface Explorations. Contract 4000113852.
Executive Summary



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ABSTRACT

The International Space Station (ISS) is slowly approaching the end of its mission. The European Space Agency (ESA) and its international partners are considering new mission targets for the future of human space exploration in the post-ISS era. Highest ranked on the list of potential targets are a return to the Moon, Near-Earth Objects or asteroids, the moons of Mars (Phobos, Deimos) and, as the ultimate target the surface of Mars. The Neutral Buoyancy Facility (NBF) at the European Astronaut Centre (EAC), Cologne, serves as a Training Facility for Extravehicular Activity (EVA) Training of European Astronauts in simulated microgravity. Recently, simulations of lunar partial gravity were successfully implemented. Within Europe the NBF provides a unique environment for such simulations.

Enhancements of the Facility towards lunar and asteroid mission simulation would fulfill the need of research, test operations and astronaut training for future mission destinations and would allow Europe to make contributions of significant value to the international effort to make such missions become a reality in the future.

The MOONDIVE consortium first analyzed the exploration objectives of various past, present and future space mission and also the analogue missions to identify the EVA tasks needed on the lunar surface and on asteroids. The identified tasks were then logged into the Surface Operations Task Catalogue (SOTC). The tasks directly extracted from the sources are referred to as Specific Tasks. They were further classified into groups, which have been named Generic Tasks. A Specific Task would therefore be a particular manner of executing a Generic Task, with difference in mission context, tools used, contingency level, or others. Each specific task has a series of fields that provide necessary information to characterize it. At the end of the analysis, a total of 379 specific tasks clustered under 30 generic tasks were catalogued into the SOTC.

The study team then compiled a list of requirements needed for each of the identified EVA task. The requirements were classified into three categories 1) Environmental requirements describe the natural conditions at the target body (Moon or Asteroid) such as partial gravity, vacuum, micrometeoroids, terrain, dust, illumination, temperature, radiation, and which are applicable to the tasks. 2) Hardware requirements: describe the necessary design, function and operational characteristics of tools, payloads, spacecraft, habitats and spacesuits (a related catalogue of hardware was produced in the scope of the activity). 3) Operational requirements: include the rules of engagement or guidelines for the EVA tasks, requirements related to Human-Machine Interaction and to Communications. In the end more than *500 requirements were identified for the Moon and Asteroids*

Based on the previous results, in the next step of the study simulation requirements were developed for EVA operations in the EAC NBF. The study provides simulation requirements for each lunar and asteroid Generic EVA Task relevant for implementation in the NBF. In addition, overall simulation requirements for environmental conditions, human-robot interaction, crew and spacesuits are presented. General requirements specific to NBF operations were also considered.

In the final step of the study, a catalogue of various hardware's such as simulator spacesuit, lunar terrain model, habitat with suitport, payloads, tools, communication infrastructure and robots were proposed either by modifying the existing NBF hardware or by designing new hardware. The proposed hardware list was then cross-checked with the simulation requirements and further iterated to comply with the simulation requirements.

INTRODUCTION

Concept Development of EVA Operations in EAC Neutral Buoyancy Facility for Extra-terrestrial Surface Explorations in the frame of ESA's General Studies Programme (GSP).

The main objectives of this GSP activity is to study the adaptation of the Neutral Buoyancy Facility of ESA-EAC in Cologne for lunar and asteroid mission simulations. The work is separated in the following four Work Packages (WP):

- Analysis of exploration objectives requiring EVA operations and identification of typical EVA exploration tasks on the Moon´s Surface and around an asteroid
- Identification of EVA operational requirements for the identified EVA tasks
- Definition of EVA simulation requirements inside the NBF for Extra-terrestrial Surface Explorations
- Analysis of NBF infrastructure evolution required for Moon surface EVA and asteroid EVA simulations.

The outcome of this study was defined to be a precise implementation plan for operations and modifications of the existing NBF at ESA that will allow follow-up development of typical EVA simulations.

Background of the study

The International Space Station (ISS) is approaching the end of its mission. European Space Agency and its international partners are considering new mission targets for the future of human space exploration in the coming post-ISS era. Highest ranked on the list of potential targets are a return to the Moon (surface or orbital outpost, potentially at the Lagrange Points in Lunar Distant Retrograde Orbit), Near-Earth Objects or asteroids , the moons of Mars (Phobos, Deimos) and, as the ultimate target, the surface of Mars.

The exploration by astronauts of the surface of these targets will go hand in hand together with robotic exploration; robots will not only be precursors to prepare human exploration but may also be companions of humans during field exploration and surface operations.

This novel élan in human space exploration bears challenges and great opportunities for ESA: challenges, since EVA on such surfaces must take into account the lessons learned during the APOLLO Programme, while also integrating ne operations and exploration concepts under surface conditions only partly unknown today (e.g. asteroid field exploration in microgravity).

There are opportunities for ESA to maintain its position as a valuable partner in the international effort of human space exploration. The adaptation of EAC's Neutral Buoyancy Facility in Cologne to fulfill the need of research and astronaut training for new mission destinations such as the Moon and asteroids is unique, and would allow Europe to make contributions of significant value to the international effort to make such missions become a reality in the future.

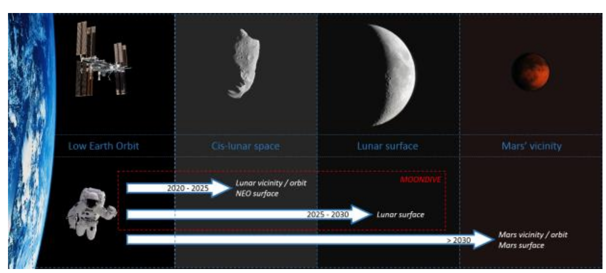

Figure 1: Timeline of human space exploration of targets beyond ISS.

Figure 1 depicts exploring targets beyond ISS in the future and gives a high-level timeline for these missions based on the ISECG Global

Exploration Roadmap. The MOONDIVE project will be focused on research, development, and training activities for the lunar vicinity and surface as well as NEO/asteroid EVA. The study conceived and developed EVA training methods in neutral buoyancy for those mission targets based at the EAC Neutral Buoyancy Facility capacities in Cologne.

Analysis of EVA Exploration Objectives

Past space missions have been examined in order to retrieve EVA activities that are still relevant for future missions. As input to this study Mission Reports from the Apollo Programme have been used. In addition to mission reports, there is a wealth of research since the Apollo program that has been consulted to determine how EVA systems and operations concepts have evolved, through reports of studies and reports of Analogue tests performed since the era.

Figure 2: Apollo Mission Insignia

NASA Human Research Roadmap where Risks and Gaps for future human space missions are identified where studied. While these items are not directly linked to any specific mission, the NASA Human Research Roadmap and Evidence Books offers the possibility to address identified Human Research Program (HRP) gaps and risks and aid in mitigating them through future NBF simulations at EAC. The outcome of the analysis is a general list of missions and objectives, including EVA that are to be considered for preparatory activities at ESA's NBF, a database of EVA operations that are likely to be performed on the Moon or asteroids in the future, and an analysis of the findings.

Analysis of Activities Requiring EVA Operations

The exploration of the Moon started with robotic activities in the 1950s and achieved a major peak in the period between 1969 and 1972 with the APOLLO missions which contributed greatly to our understanding of this planetary body.

The Moon and the asteroids are seen as locations, close to our home planet, on which practicing and perfecting the needed operations and technology that ought to be mastered before embarking in farther missions can be exercised.

Study assumptions and baseline status of space exploration

1. APOLLO Missions as a good indicator of the nature of future tasks on the Moon
2. CONSTELLATION program EVA task preparation (through NEEMO and DRATS analogues) as an approach to EVA tasks on the Moon based on modern architecture
3. Private-Public partnership, and non-NASA exploration of the Moon and Asteroids likely but not publicly detailed to the level required by this effort, at the time of the study.
4. Asteroid Missions as a NASA-led initiative, both for deep space and lunar orbit asteroid exploration were considered as an option at the start of the study.

Activities on the Moon

While APOLLO Missions concentrated on science that could be performed on the Moon during relatively short stays, and relied on the scientific data and technology available at the time, future missions will be focused on similar activities, but also on an additional number of new activities enabled by recent discoveries and technology developments.

Figure 3: Lunar activities of interest

1. Scientific exploration; Field investigation and Operation of geophysical apparatuses
2. Support to Astronomy: i) Operation of instruments to characterize the environment ii) Operational demonstration of Lunar observatories and iii) Demonstration of large telescope technology
3. Support to Technology tests:
    i. Test EVA suit hardware
    ii. Demonstration of tools and capabilities
    iii. Demonstration of EVA operations concepts
    iv. Monitoring of health and performance of crew during EVA
    v. Support to regolith excavation and movement technology tests
    vi. Demonstration of surface mobility systems
    vii. Demonstration of construction
    viii. Launch and landing facilities
    ix. Maintenance, repair and operations
    x. Demonstration of spacecraft fueling
    xi. Demonstration of power transmission
4. Resource prospecting and utilization: Solar wind implanted volatiles, He3, H2O, O2, metals and silicon

Identification of tasks

Sources of Specific Tasks

i. NASA Lunar Surface Reference Mission document
ii. Lunar and Mars Exploration Project Office (LMEPO) Catalogue of Lunar and Mars Science Payloads
iii. NEEMO 14 / Constellation reports
iv. ASTEROID REDIRECT MISSION preliminary documentation, analogue tests at the NBL and updates (includes analogues)
v. NEEMO 15, 16 reports
vi. APOLLO Missions Surface Journals, Surface Operations Plans, and Post-Mission Reports

Sources of additional crosscutting considerations

i. DRATS 2009 report
ii. MOONWALK reports

The Surface Operations Task Catalogue

The Surface Operations Task Catalogue (SOTC) is a compilation of tasks retrieved from the various sources indicated in the previous section, and divided into Moon and asteroid tasks.

The tasks directly extracted from the sources are referred to as Specific Tasks. They were further classified into groups, which have been named Generic Tasks. A Specific Task would therefore be a particular manner of executing a Generic Task, with difference in mission context, tools used, contingency level, or others. And each specific task has a series of fields that provide necessary information to characterize it.

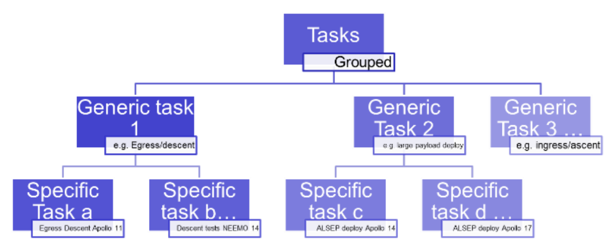

Figure 4: Task classification

The classification into Generic Tasks was made in an iterative manner, associating tasks that are similar in a way that at the end the Generic Tasks would be representative of the Specific Tasks that compose it.

At the end of the analysis a total of 379 specific tasks clustered under 30 generic tasks were catalogued into the SOTC.
The SOTC catalogue was stored in MySQL 6.0 workbench database, and a front-end was developed for easily navigating through the catalogue.

Identification of operational requirements for EVA tasks

Operational requirements were identified for Moon and asteroid EVAs. The following is a summary of the requirements identified for the Moon.

The Moon is a celestial body significantly different from Earth. It has a lower mass, which results in a smaller gravity force, and it lacks an atmosphere similar to that on Earth. Due to this lack of atmosphere, there is a constant flux of micrometeoroids that has contributed to shaping the landscape for a long time. The Moon regolith, result of this persistent impact, is composed by particles of different sizes, with a pervasive presence of dust (small sized particles).
At a larger scale, the landscape has features that are the result of internal geological mechanisms, as well as the falling of larger asteroids on the surface over millions of years.

The rotation of the Moon is tied to the rotation of the Earth, days and nights on the Moon last significantly longer than those on Earth. Moreover, certain regions on the Moon, depending on latitude and topography, have very particular periods of exposure to the Sun.

The thermal environment is dominated by the presence or absence of sun light, which due to the absence of atmosphere, results in extreme temperature changes. The lack of a magnetic field and atmosphere also makes so that radiation constantly impinges the surface of this planetary body.

The above-mentioned environmental factors influence the performance of extravehicular activities on the Moon from a hardware and operational point of view. Due to some of them, humans must utilize pressurized vessels in order to land, take off, and as a home base to operate from.

All the aforementioned parameters were then elaborated in deriving in requirements that can be the object of simulations at the NBF.

Partial gravity: One of the main driving factors of the lunar environment is the reduced gravity field of the Moon. The gravity is around $1/6^{th}$ that of the Earth (0.165G), or 1.62 m/s2 gravitational acceleration at the equator, compared to 9.78 m/s2 on Earth. This environment has an effect on the kinesthetic and proprioceptive perception, and it causes things to fall to the ground at different rates than those on Earth. Contrary to microgravity, the gravity field still provides humans with a visceral sense of up and down and can be used to keep tools and equipment in place.

Vacuum: The Moon lacks a substantial atmosphere, however molecules of gas have been measured at densities that reach 2x10^5 molecules/cm3 (10-12 Torr). The main effect of this low atmospheric content is the need to provide breathing and air pressure to an EV crew, through the use of a spacesuit.

Micrometeoroids: Estimates of the micrometeoroid flux on the Moon state that on a surface of about 150 m2 located on the Moon, is impacted on average by one micrometeoroid larger than 0.5 mm diameter meteoroid per year, with an average velocity of 13 km/s. “Actual risk to critical structures is difficult to estimate”. But the flux of meteoroids is a hazard requiring proper protection of infrastructure

Terrain: The geology of the Moon is quite different from that of Earth. The Moon lacks a significant atmosphere, which eliminates erosion due to weather; it does not have any form of plate tectonics, it has a lower gravity, and because of its small size, it cooled more rapidly. The complex geomorphology of the lunar surface has been formed by a combination of processes, especially impact cratering and volcanism. The Lunar landscape is characterized by **regolith, slopes, impact craters and boulders.**

Sunlight: The lunar day/night cycle in non-polar areas is of approximately 28 days. The sidereal period (time to complete a revolution with respect to the celestial reference frame) is slightly longer than 27 days and the synodic period (time between conjunctions) is slightly longer than 29 days. Day/night periods offer certain cycle protection from solar non-ionizing radiation although not full protection. They also make artificial lightning a requirement for EVA.

Temperature: The Moon has the most extreme surface temperature profile of any planetary body in the Solar system (except Mercury). At the equator the mean surface temperatures reach 400K (126 degrees Celsius) and then drop to 100K (-173 degrees Celsius)

Radiation: In comparison to current ISS missions, the expeditions to the Moon will place crews at a greater risk of hazardous radiation exposure. The radiation environment in the Earth's satellite is known to be harsh. The surface of the moon is exposed to the steady flux of Galactic Cosmic Radiation (GCR) and to non-frequent periods of intense solar energetic activity. Particle fluxes on the surface of the Moon are half of their equivalent of free space, as the Moon itself below the crew blocks them [RD56]. However it must be noted that due to plasma wake behind the Moon, "hiding behind" the Moon does not provide shielding from high-energy particle events

Lunar Dust: Lunar dust has been described as one of the most critical issues to be faced when performing lunar surface operations. Reports from the Apollo missions are useful in identifying all of the issues that the dust creates during an EVA. The effects of the dust can be Vision obscuration (not directly applicable to EVA), false instrument readings (not directly applicable to EVA), Dust coating and contamination, Loss of traction, clogging of mechanisms, Abrasion, Thermal control problems, Seal failures, and Inhalation and irritation.

Requirements derived from hardware

The MOONDIVE project studied the hardware requirements for Moon and asteroid EVAs. These include environment conditions, spacecraft interfaces, spacesuits, sample equipment and tools, and payloads and science equipment.

Spacecraft interfaces: Performing EVA requires some specific interfaces to be installed on the spacecraft for a safe and easy access to the lunar extra-vehicular environment. Access facilities will be needed to get in and out the Spacecraft. Such spacecraft interfaces should have at least one hatch to allow the crew ingress/egress. It has to be usable both from inside and outside the spacecraft, and large enough for an astronaut equipped with a spacesuit to go through. The spacecraft interfaces should handgrips to help astronaut's movements and to provide him/her with support for standing on his feet and at least one ladder has to be affixed to the spacecraft if the hatch is not at the ground level for safe landing of astronauts on the lunar surface.

Equipment storage and tools interfaces: Astronauts will need some room for the stowing of the scientific and mission equipment.

Spacesuits: An EVA spacesuit must isolate and protect the astronaut from the space environment. It is typically composed of the space suit assembly and a Portable Life Support System (PLSS). EVA spacesuits are designed to fulfil precise basic requirements: a stable internal pressure, a supply of oxygen, a temperature and humidity regulation as well as ventilation. They have to provide the astronaut with dexterity, mobility and visibility for performing EVA tasks. The EVA suit design must take into account the airlock system.

One of the main constraints for EVA suit is to have a sufficient mobility to accomplish defined tasks. Several suits already exist and can be differentiated from their range of motion that conditions the tasks they are able to handle.

Sample Equipment and Tools: Given that tools and sample containers to be used on the Moon are to be handled by crew inside a spacesuit, all tools and sample equipment shall be compatible with EVA glove and must meet particular requirements: Weight and volume of these tools is to be carefully controlled, therefore the tools and containers are made of the lightest material possible. All mechanisms ought to be designed to account for the abrasive and fine lunar dust. The materials need to be designed to tolerate the lunar thermal range. Long extension handles are required to pick up samples since astronauts cannot bend down with the spacesuit.

Payloads and Science Equipment: Handling and operation of payloads and science equipment largely depends on the experiments and measurements to be performed during future missions on the lunar surface. Irrespective to the objective of the payload, most payloads need human intervention such as stowing/ unloading from s/c, deploying procedure, interconnections with cables, connectors or wireless communications devices, the operation of the payload, which might include the switching of buttons or similar MMI, the reading of values and the communication of data to Mission Control. This could be achieved directly on the payload, or through a common Human-Machine Interface.

Rules of Engagement: Rules of engagement define the envelope of the lunar surface operational capabilities. The guidelines include: Lunar surface stay guidelines, EVA guidelines – EVA crew participate jointly in all excursions away from the immediate vicinity of the lunar module and remain within sight of each other at all times, lunar surface mission plans and EVA operations. For a return to the Moon, similar categories of guidelines will no doubt be established, based on Apollo and ISS.

Robots: Robots can operate in various modes, which include: Tele-operated (direct control) mode by IV crew (on Moon or cis-lunar station), by Earth and by EV crew. Tele-operated (shared control) mode, which combines automatic control of the robot and the operator’s direct control (IV, EV or Earth). Fully autonomous mode.

Robots can carry tools and hand them to EV crew, keep eyes for IV crew, act as an emergency / back-up communications station/ additional / mobile communications relay station, mobile computer / reference manual, additional or emergency lighting and provide construction assistance. Such robotic performances for an EVA are of major interest in this study.

At the end of the analysis more than 500 requirements for lunar and asteroid simulation were identified respectively.

Definition of EVA simulation requirements for NBF operations

The crucial point for conducting underwater (UW) simulations of extravehicular activities is that crew as well as any transportable hardware and surface object (e.g. rock samples) can be adapted to simulate partial gravity or microgravity.

The main objectives for the implementation of UW simulations of lunar or asteroid EVAs are accordingly:

- Testing of the performance of potential tools/hardware for EVA tasks in 1/6th G or microgravity
- Testing of potential procedures/sequences to conduct EVA tasks in 1/6th G or microgravity
- Testing of operational concepts

The simulation requirements defined for such EVA operations in the NBF were divided into three groups:

- General NBF Simulation Requirements
- Simulation Requirements for Lunar EVAs
- Simulation Requirements for Asteroid EVAs

General NBF Simulation Requirements were derived from safety and operational regulations that are standard for every NBF operation and are specific to the Facility.

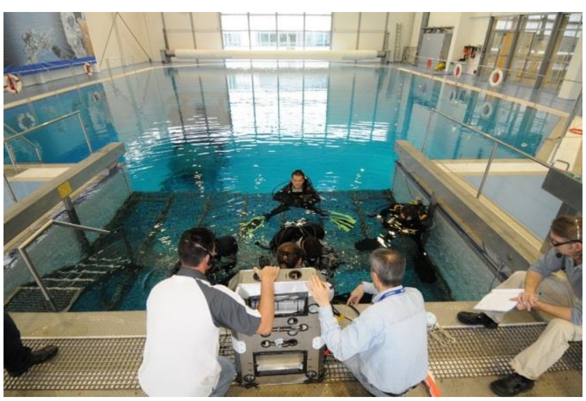

Figure 5: NBF diving tank (Photo: ESA)

They include regulations and restrictions for NBF installations (Crane, Lifting Platform etc.) and electrical devices (Cameras, Lights, etc.). Mandatory safety monitoring and communication capabilities as well as Safety and First Aid facilities were also considered and reflected in the general simulation requirements. Furthermore, the requirements cover the training status and safety regulations related to personnel involved in operations.

In total, approximately 100 General NBF Simulation Requirements were defined.

The **Simulation Requirements for Lunar and Asteroid EVAs** each cover the following aspects:

- Environmental Conditions
- Generic EVA Tasks (Requirements for Hardware, Infrastructure, Worksite, etc. specific to Tasks)
- Human-Robot Interaction
- EVA crew and suit/configuration

More than 500 simulation requirements for Lunar EVAs and more than 500 for Asteroid EVAs were defined and presented in this part of the study. In the following some examples are given.

Simulation Requirements for Environmental Conditions

As simulation of Partial/Micro-Gravity presents a key element of UW simulations the related requirements are of high relevance. Different gravity underwater shall be established by the adjustment of buoyancy. In case of lunar EVAs, a negative buoyancy representing 1/6 G is required for all portable hardware/tools, lunar surface objects (stones etc.) and crew as well as spacesuit simulant. While EVAs in microgravity shall be performed with all objects, crew and spacesuit simulants in a neutral buoyant condition. The simulation requirements further specify applicable means and limits for buoyancy adjustments. For example, the use of ballast or floating devices without constraining the functionality of hardware.

The effects of vacuum are covered mainly by simulation requirements related to spacesuit simulants (see below). The further aspect of air provision and environmental conditions like temperature and radiation can only be simulated indirectly through different communication interfaces. For those simulation requirements were defined. Simulation requirements for terrain features were connected to Generic Tasks (see below).

Simulation Requirements for Generic Tasks

Most Generic Tasks defined in the first part of the study are of high relevance for UW simulations in the NBF. They involve physical movement, handling of and interfacing with items whereby the effects of partial- and micro-gravity are highly significant. Furthermore, many Generic Tasks can be implemented in a limited worksite which complies well with the confined environment that the NBF water tank provides.

For each relevant Generic Task, a short description was provided including its position in a sequence of tasks or its link to other tasks. In addition, the applicable UW set-up for each task was defined.

The simulation requirements for a task consist mainly of requirements for infrastructure, hardware and worksite. They list all infrastructure and/or hardware items necessary to implement the task. For example, the simulation of a sampling task requires among others:

- a tool representing the interface and functionality of a tool for the sampling
- sample storage devices for single samples
- storage facilities for several samples

In addition, the required features of the hardware items are contained in the simulation requirements. Those were mainly derived from the operational requirements.

Depending on the task however different requirements for similar hardware items apply: For example, storage or item transfer tasks do not necessary require tools to be functional.

Especially sampling tasks need to be conducted at worksites representing lunar Terrain. Accordingly, simulation requirements for locally confined worksites were defined as shown in the following examples:

- the worksite shall be a local representation of the lunar surface covered with loose material
- the worksite shall be big enough to allow crew the retrieval of several rock samples
- in case, a robot is involved the worksite shall be accessible for a robot

All simulation requirements for hardware items, infrastructure and worksite were further supplemented to cover compatibility with the UW environment, NBF regulations and if necessary means for buoyancy adjustments.

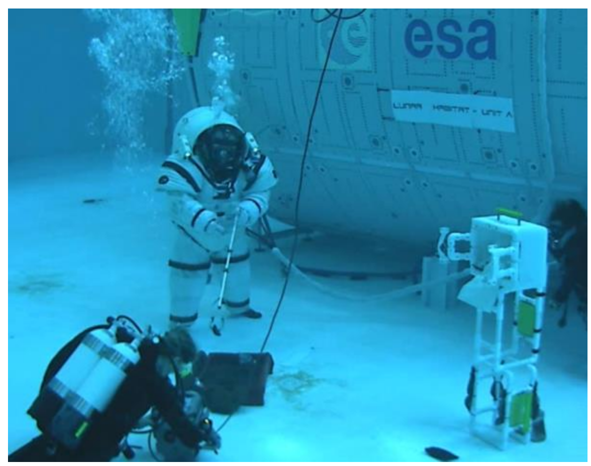

Figure 6: UW Simulation of Lunar Sampling Task in the NBF (photo: COMEX – ESA)

Further Simulation Requirements

Human-Robotic Interaction was considered being of high interest for most of the Generic Tasks. Many Operational Requirements for robotic assistance could be directly utilized for UW operations as simulation requirements. They had to be supplemented by mandatory requirements covering water compatibility and safety.

Simulation Requirements for **EVA crew and suit/configuration** are relevant to all Generic

Tasks. The application of an EVA suit/configuration simulating aspects of an EVA spacesuit would be an asset to UW simulations. Whereby some operational requirements could be again used as simulation requirements for such a suit/envelop, several others are discarded as no actual protection from extra-terrestrial environment is required. However, for example, the necessary pressurization of a real spacesuit due to **vacuum** effects its mobility. Such an effect was converted into simulation requirements: Movement limitations and suit resistance shall be perceived by crew. In addition, simulation requirements related to the compatibility of any suit simulants with NBF diving systems, safety and the UW environment were defined.

Hardware Concept Development

The goal of concept development was not to provide a detailed concept per item; the purpose is rather to illustrate different options to achieve the simulation of specific elements, and to give a ROM cost estimation for such future development.

Each concept that were developed where cross-checked to ensure that the developed concept meets the simulation requirements

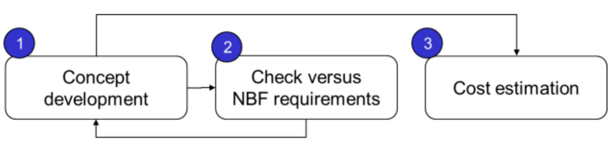

Figure 7: Concept development methodology

Some of the concept that were developed part of the study are presented here

Terrain Concept

Modular multi-terrain sampling workbench (MoMuT)

Similar to the currently used COLUMBUS mock-up at NBF, future lunar or asteroid EVA simulations will require a main workbench to simulate activities on the surface. The developed concept is versatile structure that can be adapted to a large variety of operations such to simulate translation, climbing a crater or hills, sample collection, drilling, anchoring, payload interface interactions etc.

The concept is to develop a system can serve both simulation purposes: Moon and asteroids. It is proposed to develop a terrain workbench that can be configured for lunar 1/6th G simulations and for asteroid 0G simulations. In the first case the EVs are walking on the structure (therefore lateral railing should be foreseen to avoid accidental falling down from the MoMuT). In the second case, asteroid EVA simulations, those would not be necessary anymore and the EV can evolve (in 0G) around the complete structure.

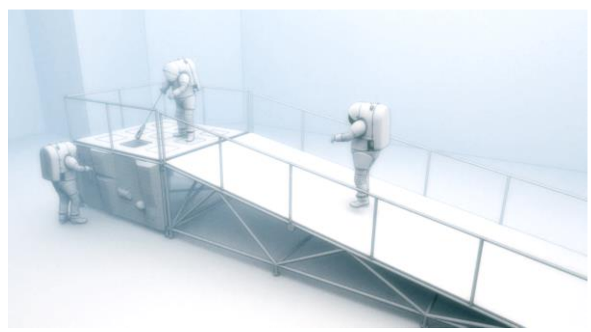

Figure 8: Concept of the MoMuT Terrain simulator based on the EAC NBF requirements (image: COMEX LIQUIFER)

EAC TRAINING SUIT

The developed EAC Training Suit kinematics is similar to the NASA Z1, Z2 and xEMU spacesuit induced by an exoskeleton. Compatible with the existing NBF diving systems, high-fidelity gloves at EAC, and standard NBF EVA boots. The simulator suit has interfaces for camera and flashlight in the shoulder. For mini-workstation and tethers the interfaces are available in the torso.

SOL Infrastructure

A single “plug-and-play” type infrastructure model that can be configured to simulate EVs interaction with airlocks, hatches, suitports, pressurized rover, donning stand and descender/ascender platform with the help of a simple lock mechanism.

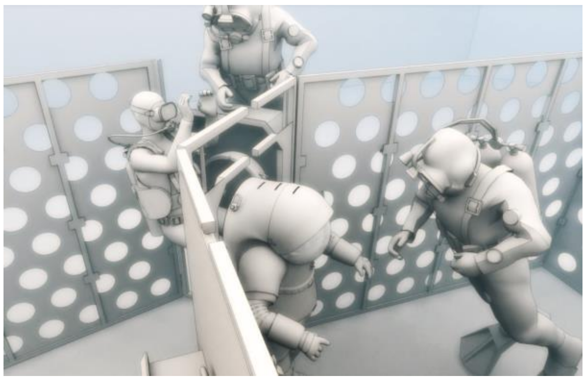

Figure 9: SOL infrastructure used for ingress simulations (image: COMEX LIQUIFER)

Multi-Payload Simulation Set (Mupss)

For EVA simulation training, the human-machine interfaces (HMI) are more of interest than the functionality of the payload. Keeping that in mind Mupss was developed to simulate different payload HMIs.

Mupss is made up of multiple PVC beams, joints and other components. These components can be connected to the PVC structure to create different payload scenarios such us but not limited to

1. Simulating opening and closing procedure of a payload.
2. Lever operation simulation
3. Connectors
4. HMI
5. Bigger payload assembly

Tools

In the frame of the study over 15 tools were developed. These tools were either a replica of the Apollo tools or complete new tools from the lessons learned from the various simulation in the NBF. Some of the tools were manufactured by COMEX and tested inside the NBF.

Figure 10: Lunar sampling simulation in NBF with the COMEX EVA simulation suit

EVA Information System (EVIS)

A tablet-format touch screen which can be attached to the Suit simulator. That can perform various functions including but not limited to:

1. Displays telemetry and biometric data
2. Can run on android and it can run on different hardware from tablets to mobile phones, including desktop PC
3. Has an architecture that allows for different screen sizes and resolutions.
4. Has a procedure viewer (ODF compatible) allows current user to follow simplified procedures
5. Allows remote users (MCC or IV) to monitor and track with comms delay.
6. Has a dedicated text communications tab allows for EV, IV and MCC to send and receive text.
7. Can remotely control robot and payload

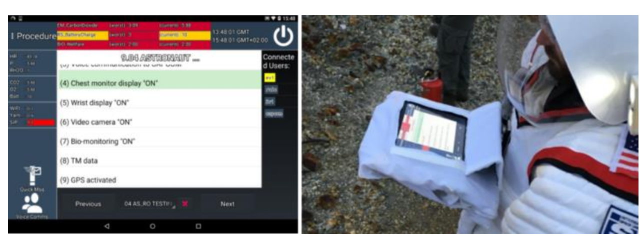

Figure 11: COMEX EVA simulation suit with EVIS system

Robots

Three different types were identified in the study that could be great interest for the NBF simulation.

1. Dexterous robotic system: Submersible robotically operable dexterous robotic system to the support various EVA tasks such as Carry and transfer tools to EV, Situational awareness enhancement for IV, Sample handling, to deploy different payloads from KOZ and to provide construction assistance.
2. Sea Walker robotic system: A six-wheeled surface crawler robot with a pan and tilt camera system that can be used as Situational awareness system for IV and to carry out survey action.
3. Mini Observation ROV: A miniaturized situational awareness and collision avoidance ROV with a 360 degrees or wide angle or 3D cameras with video feeds through umbilical's.

Figure 12: Three different concepts of the UW robots (DEXROV, SEA WALKER and mini-ROV Observer of SUBSEATECH)

Conclusion

The MOONDIVE study demonstrated that the EAC-NBF can be adapted for future lunar and asteroid gravity simulation operations.

Based on the Simulation Requirements for the Generic Tasks new hardware can be developed and introduced into the NBF

By implementing the hardware concept suggested in the study along with the planned LUNA DOME in EAC will make ESA a world leader in preparation for future Moon mission.