Executive Study

MOONWALK

a step further into the future of human space exploration

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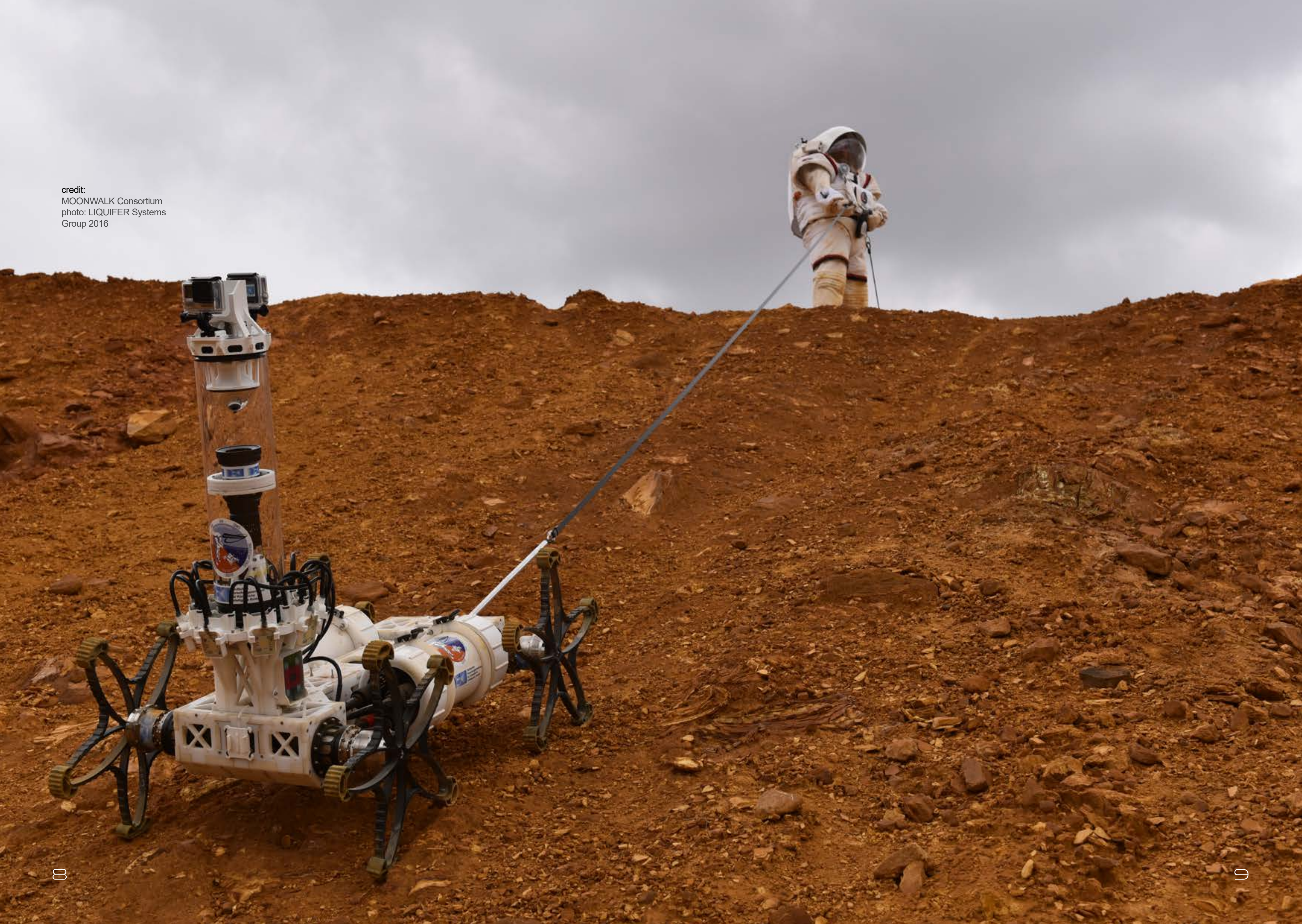
a step further into the future of human space exploration

where humankind pairs with technology to transcend known boundaries

credit:
MOONWALK Consortium
photo: COMEX 2016

credit:
MOONWALK Consortium
photo: Bruno Stubenrauch
2016



credit:
MOONWALK Consortium
photo: LIQUIFER Systems
Group 2016

credit:
MOONWALK Consortium
photo: COMEX 2016

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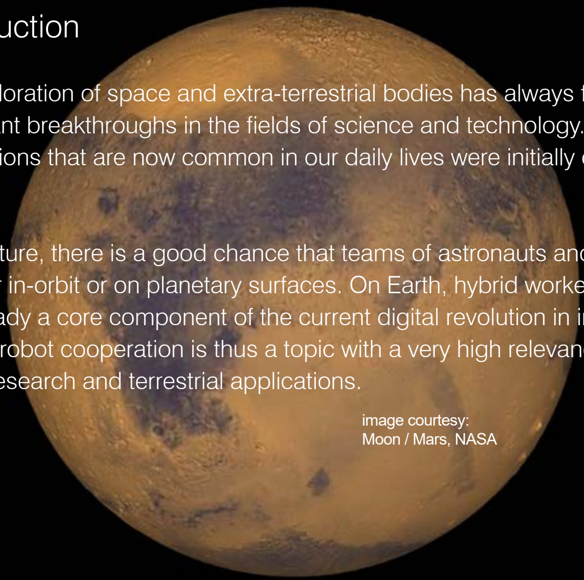
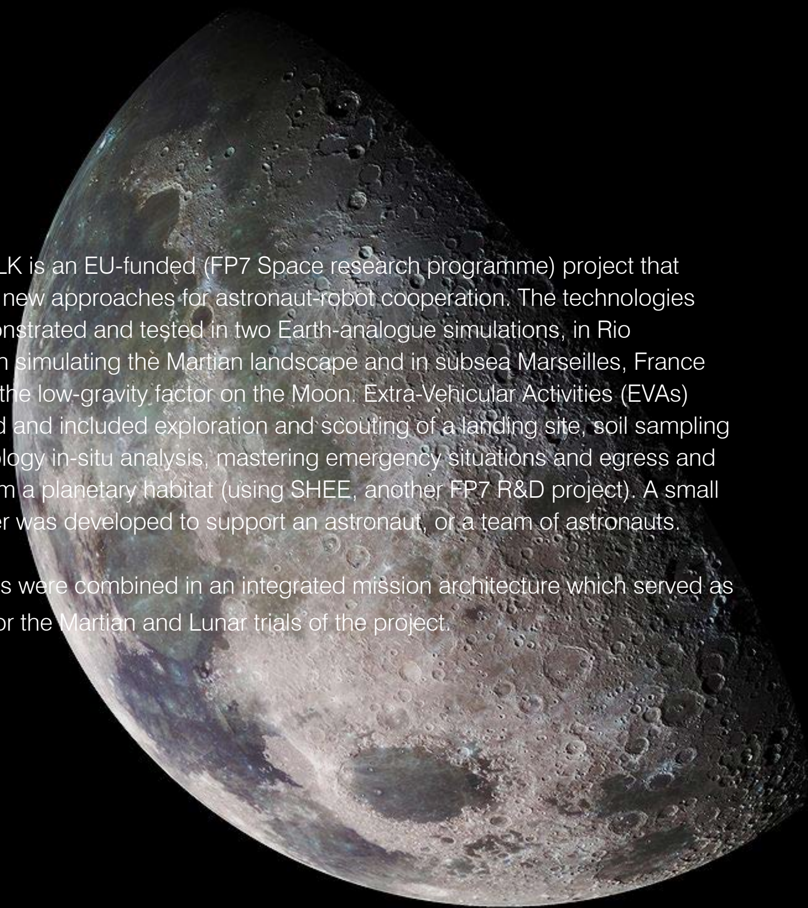


The exploration of space and extra-terrestrial bodies has always fostered significant breakthroughs in the fields of science and technology. Many applications that are now common in our daily lives were initially designed for space.

In the future, there is a good chance that teams of astronauts and robots will work together in-orbit or on planetary surfaces. On Earth, hybrid worker-robot teams are already a core component of the current digital revolution in industry. Human-robot cooperation is thus a topic with a very high relevance both for space research and terrestrial applications.

image courtesy:
Moon / Mars, NASA



MOONWALK is an EU-funded (FP7 Space research programme) project that developed new approaches for astronaut-robot cooperation. The technologies were demonstrated and tested in two Earth-analogue simulations, in Rio Tinto, Spain simulating the Martian landscape and in subsea Marseilles, France simulating the low-gravity factor on the Moon. Extra-Vehicular Activities (EVAs) were tested and included exploration and scouting of a landing site, soil sampling and exobiology in-situ analysis, mastering emergency situations and egress and ingress from a planetary habitat (using SHEE, another FP7 R&D project). A small helper rover was developed to support an astronaut, or a team of astronauts.

All elements were combined in an integrated mission architecture which served as the basis for the Martian and Lunar trials of the project.

credit:
MOONWALK Consortium
photo: COMEX 2016

Project Objective

The general objective of MOONWALK was to enhance European capabilities for future human space exploration, especially surface Extra-Vehicular Activity (EVA) on the Moon and Mars. This was targeted through research, development and evaluation of operations concepts and technologies for exploration and exobiology related EVA tasks focusing on human-robot collaboration and the development of earth-analogue simulation equipment. Specific MOONWALK objectives were:

- To enable human-robot and human-human cooperation in extreme environments with shared robot control between Control Centre and on-site astronaut(s).
- To adapt an earlier, existing autonomous operating rover-type robot platform for the purpose of human-controlled interaction.
- To design the setup of communications, mission planning & operations infrastructure which can be adapted to various mission scenarios (such as Moon or Mars with variable communication delays).
- To develop an EVA simulation suit that can be utilized under water and in various levels of gravity (reflecting conditions on Moon and Mars).
- To evaluate human performance in extreme environments (in function of gravity level variations and temperature) and the effect of human-robot cooperation for the purpose of establishing lessons learned for the design of future exploration missions.
- To establish the physiological correlations between crew activity, suit performance, crew health and the subjective well-being of astronauts in extreme environments, using a protection garment (EVA simulation suit) fit with a portable life support system, including a biomonitoring system.
- To define search methodologies and strategies for the detection of extremophile life forms and bio-signatures in terrestrial analogues by integrating existing hardware in the mission scenarios.
- To develop sampling tools and field exploration procedures that can be utilized in extreme environments and in different application fields.

Mission Scenarios

Technologies developed by the MOONWALK consortium for human-robot collaboration in the exploration of extra-planetary surfaces, such as Moon and Mars, were tested through specifically developed mission scenarios for two analogue sites.

Analogue sites provide researchers with an environment to observe, test and analyse their developments before they are utilised in actual missions beyond earth. Two analogue sites were selected by the MOONWALK consortium based on their physical characteristics similar to that of Moon and Mars. Rio Tinto, Spain, an ancient mine crossed by the Rio Tinto river, is a renouned Mars analogue site and was selected for its high level of microbial diversity. The subsea environment off the coast of Marseilles was selected as the Moon analogue site to simulate the 1/6th gravity found on the Moon.

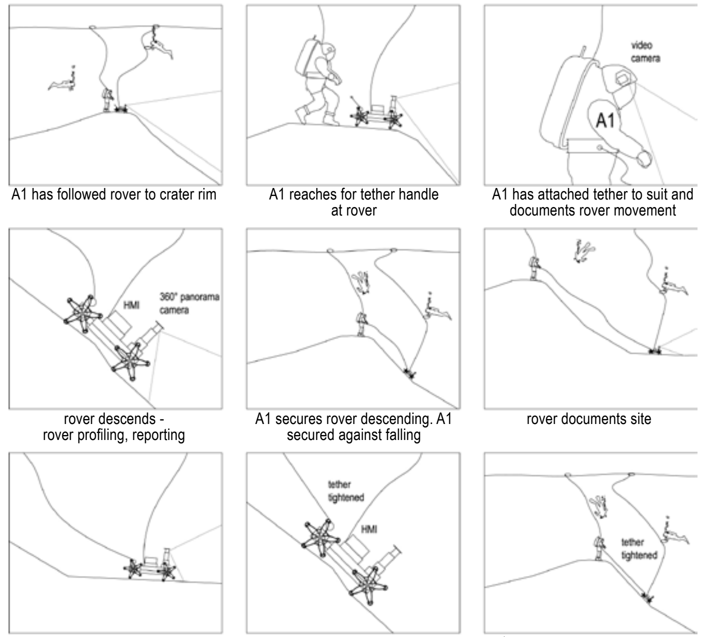
Mission ‘scenarios’ were developed by the MOONWALK team, which outlined specific tasks that were to be performed at each site. These scenarios served as per se ‘scripts’ where the ‘actors’ were able to rehearse a series of actions, inside a relevant environment. The repetitive conduct of these tasks by both astronaut and rover, in the case of project MOONWALK, allowed its team members to analyse the developed concepts and technologies. Data was collected during the MOONWALK simulations, conducted in Rio Tinto and Marseilles in the spring of 2016 and measured the performance of both astronaut(s) and rover while conducting mission scenario tasks.

The tasks, referred to as Extra-Vehicular Activities (EVAs), included scouting of the site, collection of soil samples, exploration of a cave, exploration of a canyon, exploration of a steep slope.

Description of images:
early renditions for MOONWALK Storyboards / Mission Scenarios

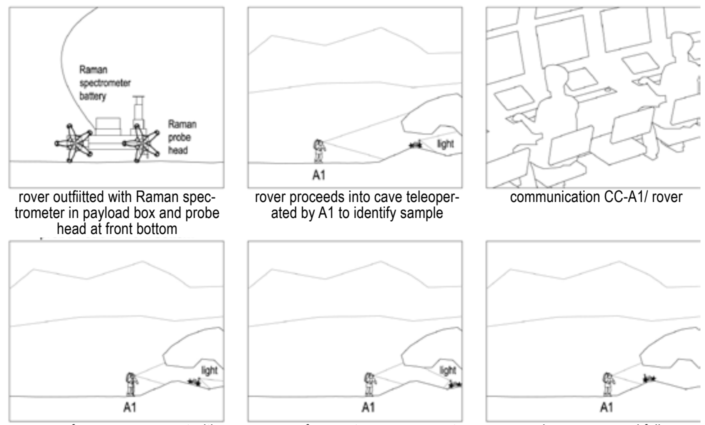
credit:
MOONWALK Consortium
Drawings: LIQUIFER Systems Group 2014

MARSEILLES - STAGE 2 / TYPE I: rover - 1 astronaut
Exploration 01 - cRT: scouting activity - crater ROVER + TETHER



A1 has followed rover to crater rim | A1 reaches for tether handle at rover | A1 has attached tether to suit and documents rover movement
rover descends - rover profiling, reporting | A1 secures rover descending. A1 secured against falling | rover documents site
rover goes into reverse | rover ascents in reverse gear - tether tightened | A1 secures ascent in reverse gear

RIO TINTO - STAGE 2 / TYPE I: rover - 1 astronaut
Sampling 03 - raR: portable RAMAN spectrometer ON ROVER



rover outfiitted with Raman spectrometer in payload box and probe head at front bottom | rover proceeds into cave teleoperated by A1 to identify sample | communication CC-A1/ rover
rover performs measurement with Raman probe head positioned on target | rover performs u-turn or reverses to cave entrance | rover leaves cave and follows A1 back to base or next point of interest

Mars Analogue
Rio Tinto

The Rio Tinto analogue test site is situated in the Huelva province of southern Spain, near the city of Seville. The site is part of a large opencast metal mining district that has been exploited at least since Roman times and probably earlier for iron, copper, and other metals. Iron sulphide has interacted with ground water to produce a very acidic environment with pH 0 – 3 and a mineral assemblage including jarosite, Fe-sulphates and oxides, as found on Mars. Particularly interesting is the presence of microbes living in the extremely acidic and metal rich waters at Rio Tinto. For these reasons and for the astonishing resemblance to martian landscapes, including small canyons, trenches, slopes, caves, or dune-like fields, the site was chosen by the MOONWALK team to simulate a Mars field exploration.

Description of images:
Earth-analogue site at Rio Tinto, Spain

credit:
MOONWALK Consortium
photo 1: LIQUIFER Systems Group 2016
photo 2: INTA-CSIC
photos 3 & 4: LIQUIFER Systems Group 2016

Moon Analogue
subsea Marseilles

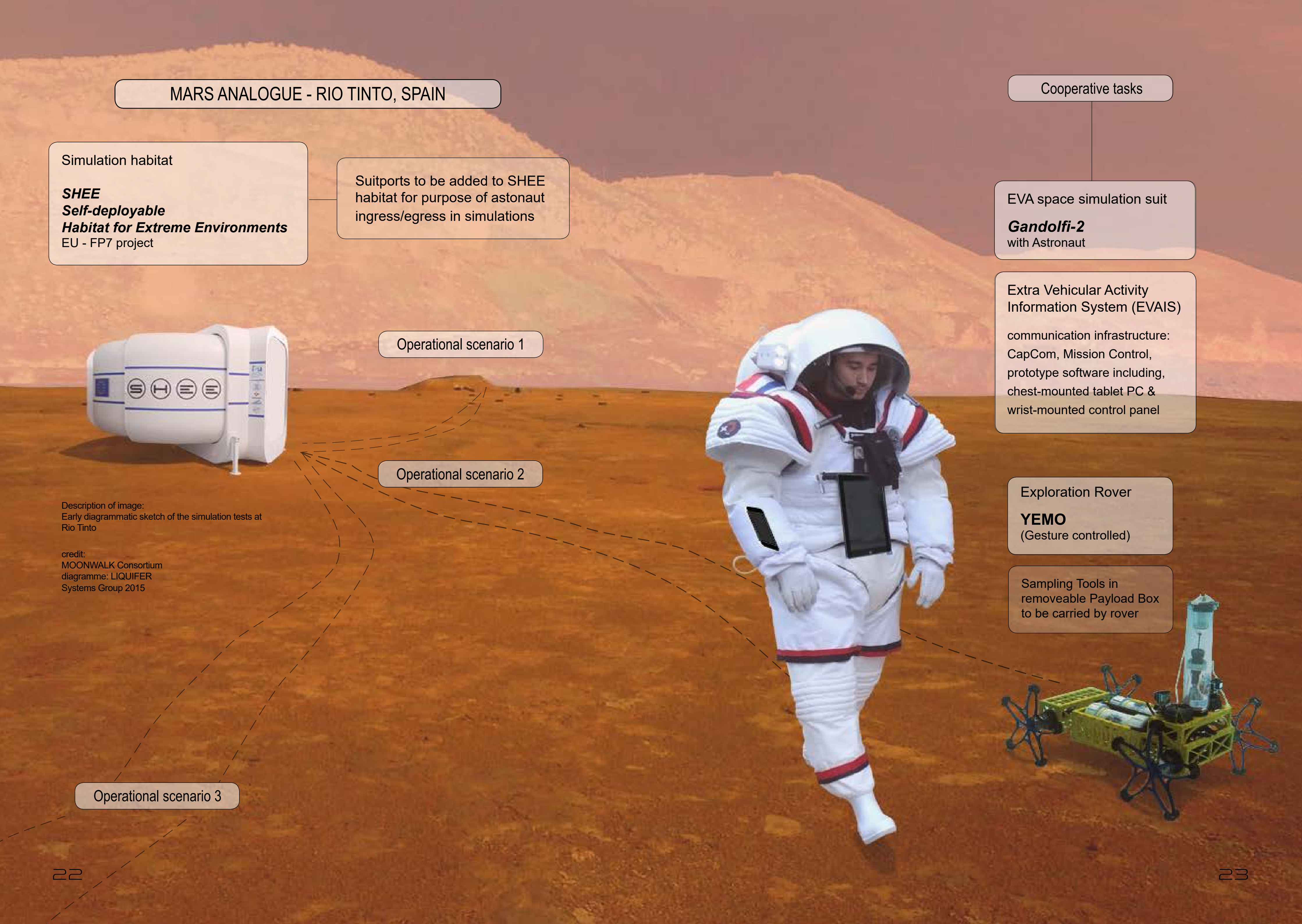
The analogue test site Port Pomègue is located near the city of Marseilles on the southern coast of France and can be reached by offshore deployment, but also offers access through a dock on the island. Port Pomègue has furthermore a historic significance: it was host to the experimental underwater habitat “Precontinent” developed by the team of Jacques-Yves Cousteau. The site is perfectly protected against Northwest and West winds.

Seven potential subsea sites were identified and reserved during the testing period, each rich with particular geological features similar to those found on the Moon. Underwater sites at the same time offer the possibility to test and train human and robotic operations in simulated reduced gravity.

Wind conditions were an extreme factor in determining the exact location of the Marseilles analogue test; the site was based on real-time weather forecasting and the directionality of the prevailing winds. The seafloor depth for test sites ranged from -8m to -10m.

Description of images:
Earth-analogue site at subsea Marseilles, France

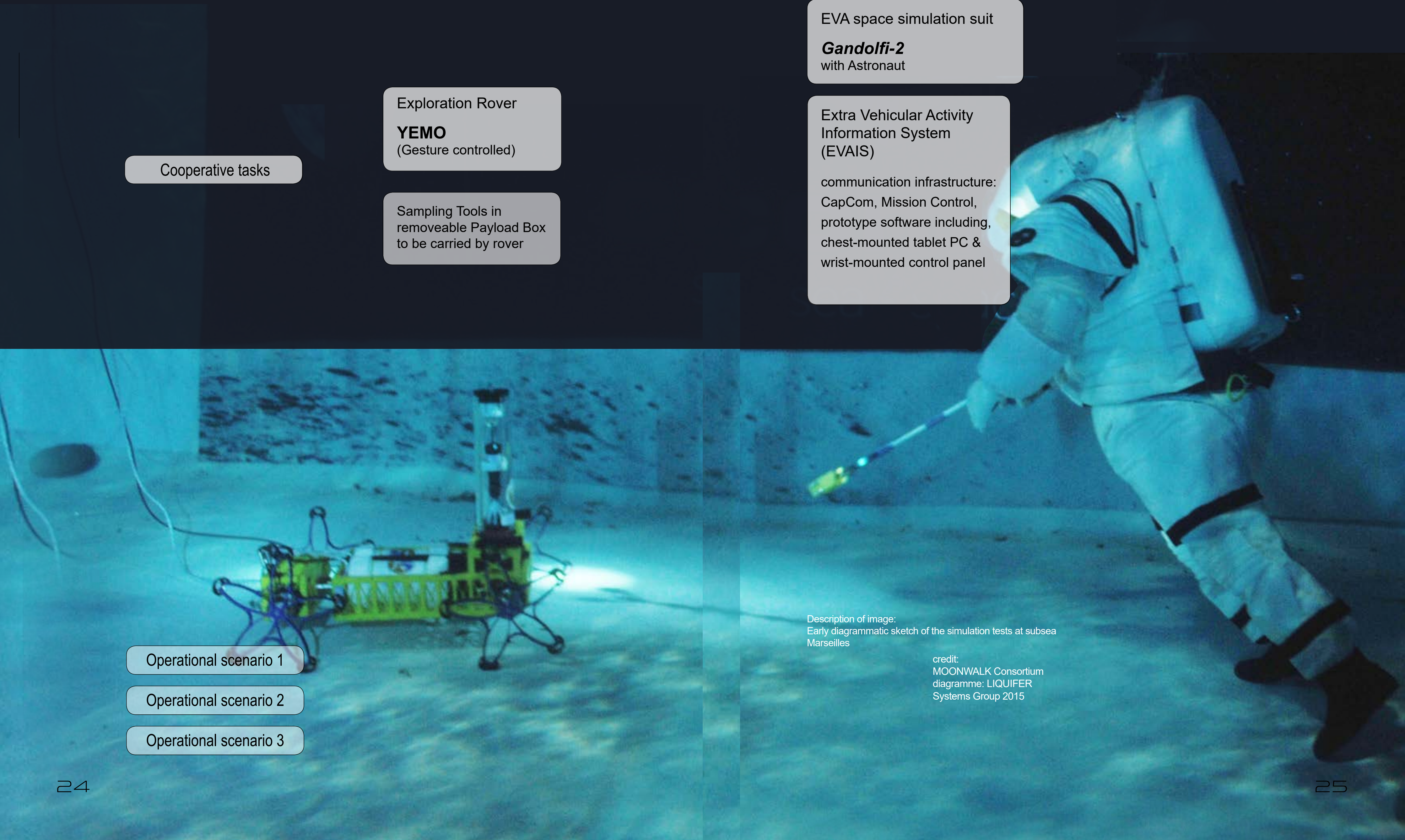
credit:
MOONWALK Consortium
photo 1: LIQUIFER Systems Group 2016
photo 2: COMEX 2016
photos 3 & 4: LIQUIFER Systems Group 2016



Description of image:
Early diagrammatic sketch of the simulation tests at Rio Tinto

credit:
MOONWALK Consortium
diagramme: LIQUIFER Systems Group 2015

MOON SIMULATION - MARSEILLES, FRANCE (pre-analogue pool tests)



Description of image:
Early diagrammatic sketch of the simulation tests at subsea Marseilles

credit:
MOONWALK Consortium
diagramme: LIQUIFER Systems Group 2015

MOONWALK Components

The aim of the MOONWALK project was to show how human-robot collaboration could be useful and vital in exploring unknown planetary surfaces such as the Moon and Mars. For this purpose, the MOONWALK project developed a number of new tools and technologies. Individual technical components were developed by the seven MOONWALK partners. These elements were combined in an integrated mission architecture which served as the basis for the Martian and Lunar trials of the project. Components are described in greater detail in the following pages and include:

Small assistant-robot (helper rover)
YEMO
Assists astronaut in EVA

EVA simulation space suit
Gandolfi -2
Designed to be utilized in both wet and dry environments

credit:
MOONWALK Consortium
images top to bottom:
photos 1: COMEX 2016
photo 2: INTA-CSIC 2016
photo 3 & 4: COMEX 2016

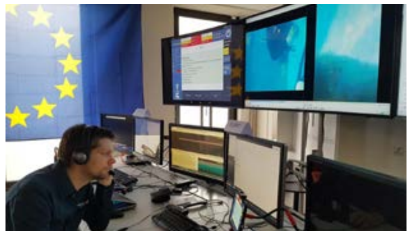
Human Machine Interface (HMI)
One of the objectives of MOONWALK was to enable the control of a helper rover by an astronaut in a heavy space suit. Two solutions were developed to meet this target:

Gesture Control
An intuitive robot-control-subsystem based on the movements of an astronaut

EVA Information System (EVAIS)
A communication infrastructure allowing an astronaut to visualize procedures, and Mission Control to monitor their progress using a tablet integrated in the EVA suit

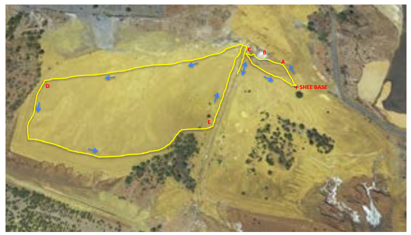
Biomonitoring
The astronaut's stress levels are monitored through observing their heartbeat; sensors are used to determine if the astronaut is getting into a potentially dangerous position

Manual tools for EVA
Manual sampling tools and a sampling box. All items are transported by the helper rover in the specifically developed Payload Box. Manual tools include, Astronaut Rescue Tool, Astronaut Tether Control, Pantograph Sampling Tool, Foldable pick-up Claw



Mission Control Centre
All communications and bio-feedback data go to MOONWALK Mission Control Centre near Brussels (in subsea simulations information is simultaneously transmitted locally to the Minibex boat)

credit:
MOONWALK Consortium
images top to bottom:
Airbus 2016
COMEX 2016
Space Applications 2016
GoogleEarth 2015



ISS-type Procedures
Were reflected in the MOONWALK scenarios and adapted to the specific test sites

Component:
Small assistant-robot YEMO

For use in the earth analogue simulations, YEMO was developed by the DFKI Robotics Innovation Centre in Bremen, Germany; a modified version of their ASGUARD design. As both a terrestrial (Mars) and an underwater (Moon) simulation were planned, a new amphibious robot was conceived.

The robot is equipped with an Omnicam, which is able to image a complete 360 degrees without the need for moving parts. Both on-site astronaut and experts at Mission Control Centre are able to select viewing angles on the Omnicam as well as work on the same video-stream enabled by the image processing software. Additionally, YEMO carries a set of newly developed manual sampling tools (LSG), a sample storage unit (LSG), payload box (LSG) and a portable RAMAN spectroscope (INTA-CSIC).

The decisional autonomy of YEMO is limited to a follow-me function.

YEMO
Fast Facts

Highly mobile, amphibious, small scouting rover

Control through HMI and gestures

Payload includes sampling box and tools plus RAMAN spectrometer

Follow me function

credit:
MOONWALK Consortium
clockwise left to right:
photo: COMEX 2016
rendering: Mathias Höckelmann (DFKI GmbH)
photo: COMEX 2016

Component:
EVA simulation space suit Gandolfi-2

To be able to exist in the hostile environment of space, astronauts have to carry heavy and bulky space suits. Even under zero gravity conditions, these suits significantly restrain natural human manoeuvrability and dexterity. Procedures and technical systems enabling future human, or human-robot, space missions must be tested on earth using realistic space suit mock-ups.

In MOONWALK, the Marseilles-based company COMEX developed a space suit mock-up that can simulate the constraints of a real space suit (such as the Z-1 series by NASA). The Gandolfi-2 can be used both on land (to simulate the gravity conditions on Mars) and underwater (to simulate the reduced or zero gravity conditions on the Moon or in-Orbit). Thus the suit is a valuable asset for earth analogue simulations of a wide range of space missions.

Gandolfi-2
Fast Facts

Reproduces movement constraints induced by pressure in EVA space suits

Adds stress in the EVA simulation with a physical effort

Adjustable size depending on the subject

Approximately 35kg – simulating the weight of the NASA Z-1 suit in Martian gravity

Height ranging from 175cm to 205cm

Independent joints for each of the main articulation

credit:
MOONWALK Consortium
left to right: photo: COMEX 2016
rendering: LIQUIFER Systems Group 2015
photo: COMEX 2016

Component: Human-Machine Interface:
Gesture Control

Gesture Control
Fast Facts

Control of robot based on IMU data

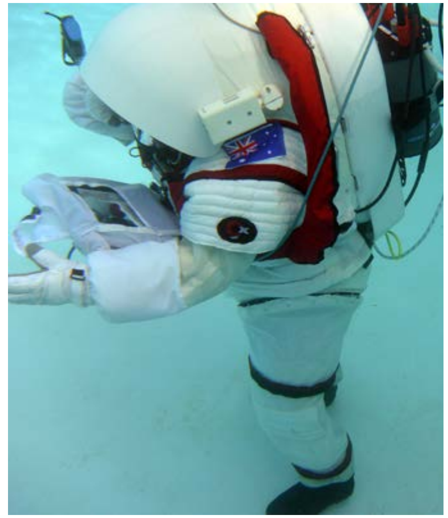
“Hands-free” command of robot

Astronauts can easily enable and disable gesture recognition through “attention” and “pause” gestures

Gesture Control is a novel, yet intuitive, way to control and interact with robots. In contrast to most other control approaches, MOONWALK gesture control enables the user to perform true, hands-free control of the robot. It does not require the handling of any additional input devices, thus allowing for the simultaneous execution of different tasks (e.g. sampling), while controlling the robot.

The Gesture Control system in MOONWALK senses the movement of limbs in the upper-body of an astronaut using inertial measurement units (IMUs) attached to the subject’s arm. These movements, or gestures, are translated into commands for the robot; enabling the human operator to control the robot without the need to be in it’s direct line-of-sight. In return, the robot is able to read the movements of the operator without full visual contact.

Component: Human-Machine Interface:
EVA Information System (EVAIS)



The Human Machine Interface also supports an advanced EVA Information System (EVAIS); a communication infrastructure involving CapCom, Mission Control in Brussels, external science centres, and prototype software allowing the astronaut to visualize procedures and communicate with Mission Control through either the chest-mounted tablet PC or the wrist-mounted control panel. Furthermore, Mission Control used the EVAIS to monitor the progress of the EVA (Extra-Vehicular Activity).

The EVAIS permits the exchange of voice, text, live video, annotated imagery, telemetry, and offered a means to operate the robot. It proved to be very useful and user friendly.

EVAIS
Fast Facts

Allows exchange of images, text, voice, video with MCC, with and without comms delay

Adds realism to the simulation by allowing data exchange with scientific teams

Allows interaction with robots and payloads

credit (opposite page):
MOONWALK Consortium
photos: Bruno Stubenrauch 2016

credit (this page):
MOONWALK Consortium
photo left: Bruno Stubenrauch 2016
photo right: COMEX 2016

Component:
Manual tools for EVA

MOONWALK tools were designed for single-handed application of an astronaut in cooperation with a small rover. They are intuitive to use and prevent the astronaut from having to make bending movements while using or retrieving the instruments. All the manual tools can be folded for storage in the small rover.







The **Pantograph Sampling Tool** is designed to facilitate easy collection of sample material. It allows the single-handed extension and contraction of a tool arm. The head of the tool serves as a shovel and at the same time, a sampling container with a closable lid. With a simple mechanism the container can be released and a new sample box can be affixed to the tool head. Samples are stored independently from one another to avoid cross-contamination.

The other sampling tool is the **Foldable Pick-up Claw,** based on the lazy-tong concept, with which one can collect smaller rocks and debris. The special feature of the Foldable Pick-up Claw is its flexibility allowing astronauts to inspect small, collected samples directly in front of their visor in order to check the quality of the sample.

The **Astronaut Tether Control** allows astronauts to support a rover as it descends a steep slope or maneuvers around other topological features that require additional security.

The **Astronaut Rescue Stick** can be used in cases where the astronaut has fallen over and cannot stand up on his/her own. It takes the form of a foldable walking stick and can be erected by a single-handed flick.

The rover is equipped with a 'layered' mock-up **Payload Box (PB)**, a container designed to carry the manual sampling tools, a sample storage unit, and a portable RAMAN spectroscope.




credit (opposite page):
MOONWALK Consortium
photos: LIQUIFER Systems Group 2015

LIQUIFER SYSTEMS GROUP

credit (this page above):
MOONWALK Consortium
(clockwise from top left):
FH - Würzburg - Schweinfurt 2016, LIQUIFER Systems Group 2016, Alistair Nottle 2016, LIQUIFER Systems Group 2016

credit (this page right):
MOONWALK Consortium
underwater photos: COMEX 2016, Rio Tinto: LIQUIFER Systems Group 2016



Sampling Tools

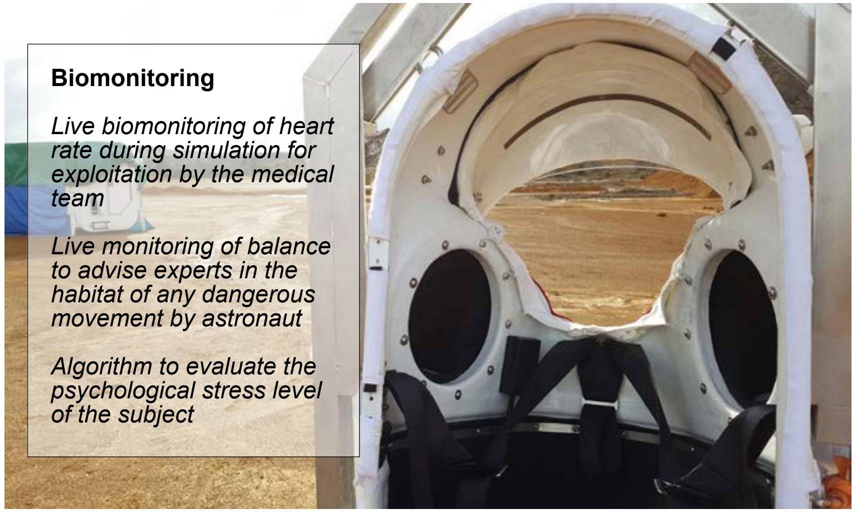
Pantograph Sampling Tool

Astronaut Rescue Stick

Foldable Pick-Up Claw

Astronaut Tether Control

Component:
Biomonitoring



Biomonitoring

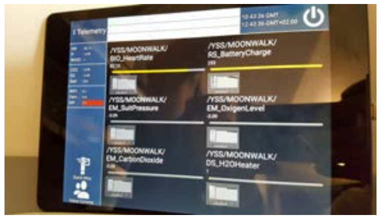
Live biomonitoring of heart rate during simulation for exploitation by the medical team

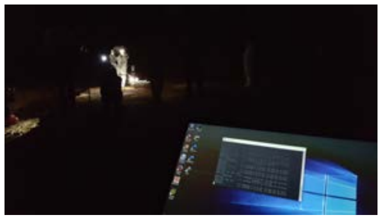
Live monitoring of balance to advise experts in the habitat of any dangerous movement by astronaut

Algorithm to evaluate the psychological stress level of the subject

In human space operations it is vital for mission control to biomonitor the physiological state of the astronaut(s) during EVAs. It is a warning and caution system and can be considered safety critical. In MOONWALK, astronaut stress levels are monitored by observing the heartbeat. Through the utilization of a biomonitoring system, different grades and types of stress can be measured as a function of heart rate variability. The sensor measuring the heart rate is worn by the astronaut placed directly on the skin similar to a pulse meter one would wear for running. This data is communicated to Local Control and Mission Control Centre.

The biomonitoring system, designed by Airbus, can determine if the astronaut is getting into a potentially dangerous position, for instance losing footing in an unstable terrain or losing balance in a reduced-gravity environment.

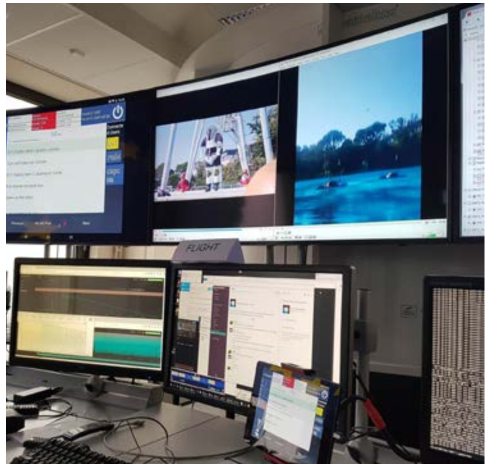


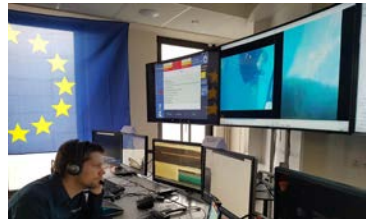


Description of images:
top: integrated Biomonitoring system in Gandolfi-2
bottom two images: biomonitoring software

credit:
MOONWALK Consortium
photos: Airbus 2016

Component:
Mission Control Centre (MCC)





The International Analogue Mission Control Centre is located in Zaventem, near to Brussels, Belgium. The state-of-the-art Control Centre has been designed to interact with the advanced space suit computer prototype and EVA Information System designed for MOONWALK by Space Applications. A team composed of experienced flight controllers from the International Space Station and experts from the field of planetary science performed
real-time operations and provided support for the simulations.

Mission Control Centre and Local Control Centre Communication Loops

Live and delayed communications with Astronaut 1 – Astronaut 2 – Habitat crew

Real-time monitoring of components deployed in the field via video and telemetry/telecommand

Manned by experienced ISS flight controllers

Description of images:
top: Mission Control Centre, Zaventem, Belgium
bottom left: Local Control Centre, established inside SHEE habitat, Rio Tinto

credit:
MOONWALK Consortium
top photos: Space Applications 2016
bottom left: Bruno Stubenrauch 2016

Component:
ISS-type Procedures

Mission scenario 'scripts' are translated into Procedures; simplified versions of the Procedures astronauts use on the ISS. They were utilized in MOONWALK simulations, giving explicit directions to the astronaut(s) performing EVAs. An example of a Procedure for simulations at Rio Tinto:

Scenario: ASTRONAUT ROBOT SAMPLING Itinerary A (ITA)

The objective was to perform sampling at site ITA (Itinerary A) with one astronaut and robot assistant.

The procedure execution time was limited to 2-3 hours including 2 crew exchanges due to a 30-minute maximum EVA time in the MOONWALK suit.

Scenario demonstrated astronaut's use of a robot assistant to:

(1) Access a location forbidden to astronauts for safety reasons
(2) Carry tools and store collected samples
(3) Perform remote science with video imagery and RAMAN
(4) Demonstrate working with time delay between Mission Control Center (MCC), science team and astronaut

+00:00

2.1	EV1	Egress from SHEE suitport Confirm Walk to left and then face north in direction of low hills at site (A) Check/image slope, obstructions and roughness in: (1) Local terrain (2) Terrain in direction of hill site (A) Check wrist gesture control of robot confirm Check chest monitor control of robot confirm Check robot video imagery displayed on chest monitor confirm
2.2	EV1	Drive robot using gesture control and follow to base of hill site (A) Confirm on arrival
2.3	EV1	Visually identify pre-selected sampling location Drive robot to pre-selected sampling location and record by robot video imagery Open PB (Payload Box) lid Identify rock sample #1 to be collected and image Extract foldable gripper from robot PB tool holster and deploy Use foldable gripper to collect rock sample #1 Place rock sample in PB stowage container using foldable gripper Use EVA suit video camera to image position of rock sample in PB Re-place foldable gripper in robot PB tool holster Close PB lid

credit:
underlying image:
Rio Tinto, GoogleEarth 2015
right: Port Pomègue,
GoogleEarth 2016

2.4	EV1	Sampling site (A) completed Confirm
2.5	EV1	Drive robot using gesture control to grey "fluvial deposit" site (B) Confirm on arrival
2.6	EV1	Visually identify pre-selected sampling location Drive robot to pre-selected sampling location and record by robot video imagery Extract foldable gripper from robot PB tool holster Use foldable gripper to make a shallow trench in surface Replace foldable gripper in robot tool holder Record sub-surface characteristics in trench using robot video imagery Identify rock sample #2 to be collected and image Extract foldable gripper from robot PB tool holster and deploy Use foldable gripper to collect rock sample #2 Place rock sample in PB stowage container using foldable gripper Use EVA suit video camera to image position of rock sample #2 in PB Re-place foldable gripper in robot PB tool holster Close PB lid
2.7	EV1	Extract extensible scoop from robot PB tool holster Extend scoop to full length Use scoop to extract sampling box from robot PB Lock sampling box on end of scoop Extract soil sample from shallow trench with the sample box Manually close lid on sample box Use extensible scoop to store sealed sample box in PB
2.8	EV1	Sampling site (B) completed Confirm

Astronaut 1 continues sampling at site C. Operations continue and end with:

2.30	EV1	Drive robot using gesture control and follow to SHEE base Confirm
2.31	EV1	Ingress SHEE suitport Confirm

A B C D E
SHEE BASE

Component:
Mobile suitport and Lunar Excursion Module (LEM)

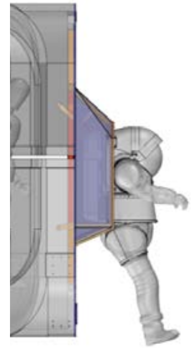

Mobile suitport: Steel frame for astronaut change in the field. Used to dock astronaut and release him/her from the weight of the suit at any time in case of emergency

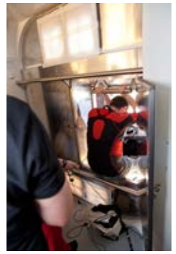
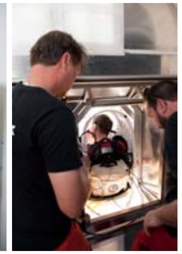
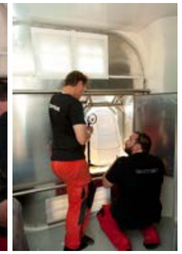
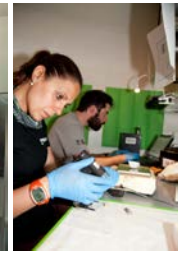
Lunar Excursion Module (LEM): Representation of a lunar-surface landing module, used for underwater egress/ ingress into the astronaut suit. Permits ascent and descent via stairs

Description of images:
Mobile suitport used in simulations at Rio Tinto and LEM in Marseilles

credit:
MOONWALK Consortium
top photos Rio Tinto: Bruno Stubenrauch 2016
middle photo: LIQUIFER Systems Group 2016
bottom photos: COMEX 2016


Component:
SHEE - Self-Deployable Habitat for Extreme Environments


SHEE, the Self-Deployable Habitat for Extreme Environments, was utilized in the simulations at Rio Tinto serving a number of functions. It served as the beginning and end point of all EVAs at Rio Tinto, provided shelter for a number of services and offered a suitport, designed by LSG, for the astronauts ingress/egress to and from the astronaut suit.

Hosted in the habitat was the CAPCOM system used for exchanging scientific data and instructions between astronauts and Mission Control (in Zaventem, Belgium) with a time delay of 7 minutes each way. Additionally, the habitat served as an astrobiology laboratory where samples collected during the simulation's exobiological procedures were analysed for life detection with the SOLID instrument.

SHEE was completed in 2015, through an EU-FP 7 grant independent from project MOONWALK, (co-funded by the European Commission under the Space theme of the 7th Framework Programme) and was concluded Dec. 2016. www.shee.eu

Autonomous habitat for a crew of two

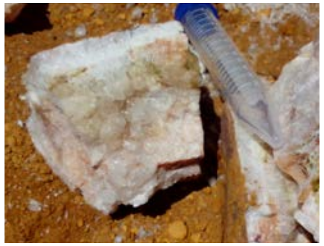
Suitport interface for EVA training suit

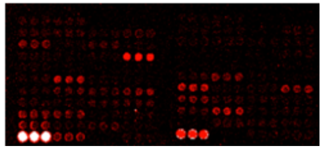
Hosted the CAPCOM and the Biomonitoring (Local control centre)

Description of images:
Habitat SHEE with integrated suitport and internal facilities including CAPCOM and astrobiology laboratory

credit:
MOONWALK Consortium
photos: Bruno Stubenrauch 2016 rendering: LIQUIFER Systems Group 2015

Component:
Signs of Life Detector-Life Detector Chip



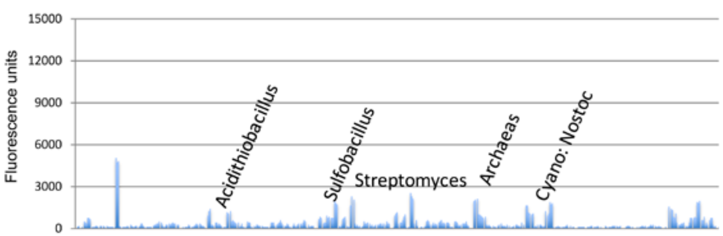


INTA-CSIC validated the astronaut and robot EVA performance by conducting a Mars astrobiology mission simulation at Rio Tinto. Samples collected by the simulation astronaut and robot were analysed with the life detector instrument SOLID-LDChip (Signs of Life Detector Chip), an antibody microarray-based biosensor for detecting microbial markers and biochemical evidences of life. Samples from soil, rocks and salt crusts from a cave wall were brought to the astrobiology laboratory installed in SHEE and analysed.

SOLID detected microbial life in rock samples collected by the astronaut-robot team. Several positive immunoreactions (bright red spots) were detected which corresponded to microbes usually found in the Rio Tinto (Immunogram).

Description of images:
astronaut loads soil / ground rock samples to SOLID
sample preparation unit to search for biomarkers
bottom: Biomarker analyses

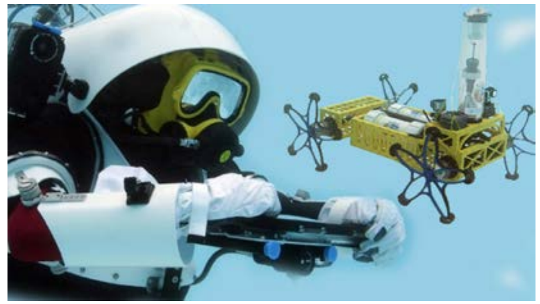
credit:
MOONWALK Consortium
photos / graph: INTA-CSIC



PRESS RELEASE

MOONWALK - Spring Simulations
Rio Tinto / Marseilles - April / May 2016

Announcement of Rio Tinto / Marseilles Spring Simulations 2016
MOONWALK will conduct earth-analogue simulations to test new hardware and various spacewalk scenarios at the Subsea Marseilles Lunar Analogue site in France and Rio Tinto Mars Analogue site in Spain in preparation for future human and robotic mission to Moon and to Mars. Project MOONWALK, is a 3-year cooperative Research & Development project funded by the European Commission under the Space theme of the 7th Framework Programme and aims to compare the performance of different compositions of astronaut-robot teams over multiple tasks and operational scenarios, in two analogue environments.



First evers!

new for the first time in the European Union, the MOONWALK simulations at Marseilles and Rio Tinto will exhibit:

- First-time demonstration of collaboration between an astronaut and a gesture controlled rover (YEMO)
- First European demonstration of the new, specially designed, underwater EVA space simulation suit, Gandolfi-2, for exploration of Lunar and Martian terrain
- First EVA simulation suit, Gandolfi-2 - suitable for testing in two environments, both on ground and immersed in water
- First use of an advanced Extra-Vehicular Activity Information System (EVAIS) in a water immersion, partial gravity simulation
- First integration of a self-deployable simulation habitat into an analogue test (SHEE- Self-deployable Habitat for Extreme Environments

Tests, Technology Demonstration, Simulations

General programme of simulations
Rio Tinto/ subsea Marseilles

- Arrival, set up of all equipment at the ‘Landing Site’ including all logistical items

- Safety procedures and instructions for on-site researchers and astronauts are communicated (for Marseilles: Safety procedures and instructions for divers)

- General testing of all MOONWALK equipment/ systems/ procedures/ including YEMO Robot, Gandolfi-2 Suit, Astronauts, Payload, Scenarios, Outreach, Biomonitoring systems and Science Instruments (RAMAN spectrometer), Communications, Control Centre (Brussels), Mission Coordinator and Logistics; only Rio Tinto: Science Team and Simulation habitat SHEE*

- Operational scenarios conducted by both astronaut and scout rover are carried out in actual Rio Tinto sites (a trench, crater, cave and rocky outcrop) and in actual subsea Marseilles sites

- Mapping of the ‘Landing Site’ by MOONWALK scout rover YEMO; autonomous measuring capabilities in marking sites, imaging, presence of any obstacle that may impede the mobility of the astronaut or rover, or inhibit communications; only Rio Tinto: environmental parameters (temperature, wind speed, humidity), consistency of soil, topographic map

- Time slots throughout the research period are reserved for meetings with the press and/or public

*For further EU exposure, the habitat, SHEE (Self-deployable Habitat for Extreme Environments) will be incorporated into the simulation campaign of MOONWALK at Rio Tinto. The habitat, completed in 2015 through an EU-FP 7 grant, will provide shelter and suitport ingress/egress for the simulation astronauts.

Description of images:
MOONWALK team conducting earth-analogue simulations.
above: Rio Tinto, below: Marseilles

credit:
MOONWALK Consortium
top photo: Bruno
Stubenrauch 2016
bottom: COMEX 2016

Tests, technology demonstration, simulations

Rio Tinto,
Mars Analogue

Objective:
To perform EVA simulations of a planetary exploration on Mars, in both astronaut-astronaut and astronaut-robot configurations, for the evaluation of their respective ability to perform a set of predetermined tasks in a predetermined number of scenarios.

For the first time in Europe, a Mars analogue mission was successful in integrating the following elements:

an EVA that started and ended with egress/ingress from/to a space habitat

exploration and sampling with direct communications to a local control centre (CapCom or HabCom)

inclusion of both astronaut/astronaut and astronaut/robot teams

time-delayed communications to Mission Control and external science centres

The Mars analogue simulation in Rio Tinto took place between 16. April and 01. May 2016. The first week was used to set-up the equipment and to test the EVAs. The actual MOONWALK EVA simulations were performed during the second week.

During five days in the second week of the simulations in Rio Tinto, a total of 18 EVAs were performed and approximately 7 km were covered by the astronauts. Ten of the EVAs were astronaut-astronaut and 8 were astronaut-rover. Simulation astronauts came from France, Austria, Belgium, Italy/Colombia, Spain, United States of America and Germany.

The EVAs at Rio Tinto covered scenarios that included, scouting of the site, collection of soil samples, exploration of a cave, exploration of a canyon and exploration of a steep slope. During the campaign, two main activities and related scenarios have been tested: “Sampling” and “Scouting.”

Description of images (opposite page):
left: astronaut-astronaut team, exploration Mars analogue
right: mock-up Payload Box on YEMO

Description of images (this page):
left: astronaut-robot team, exploration of a cave, middle: astronaut sampling, right: astronaut-robot use of a tether

credit (this page):
MOONWALK Consortium,
photo left/middle: LIQUIFER Systems Group 2016
right: Bruno Stubenrauch 2016

credit (opposite page):
MOONWALK Consortium,
photos: Bruno Stubenrauch
2016


X-01

Tests, technology demonstration, simulations

Subsea Marseilles,
Moon Analogue

Objective:
To perform EVA simulations of a planetary exploration on the Moon, in both astronaut-astronaut and astronaut-robot configurations, for the evaluation of their respective ability to perform a set of predetermined tasks in a predetermined number of scenarios.

The simulations in Marseilles implemented a Lunar scenario and involved a lander mock-up (LEM) equipped with a suitport for the donning and doffing of the astronauts, two simulation space suits (Gandolfi-I and Gandolf-2), the MOONWALK amphibious helper rover, manual sampling tools and the EVA Information System and communication infrastructure (including CapCom on-site, aboard the MINIBEX research vessel and at Mission Control in Brussels.)

Three EVAs related to scouting and soil sampling on the sea-bed, at a depth of 8m, were completed by the astronaut-astronaut team and six by the astronaut-robot team. In the simulations, the astronauts demonstrated the usability of the gesture control which, even under simulated low-gravity conditions, proved to be a practical and efficient way to control the robot. Additionally, the usability of the manual sampling tools, the Gandolfi-2 simulation space suit and the MOONWALK communication infrastructure was demonstrated. During all EVAs, astronauts utilized the biomonitoring equipment.

Description of images:
left: simulation astronaut views procedures,
middle: handling of tools in preparation of sampling,
right: astronaut-astronaut sampling scenario

credit:
MOONWALK Consortium
all photos: COMEX 2016

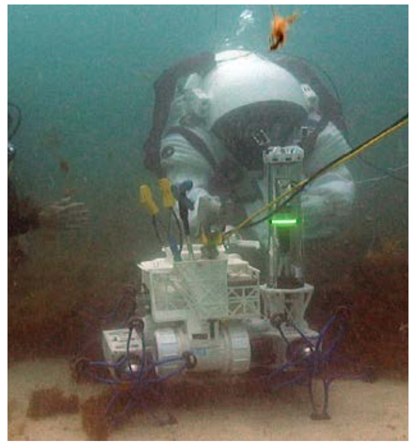
Due to the significantly large logistical overhead, including up to five security divers and several sea-going vessels, the number of EVAs that could be realized was lower than in Rio Tinto. Nevertheless, a total of five test EVAs in the pool and another four EVAs (plus one security exercise) off the coast were achieved.

The Lunar analogue simulations in Marseilles took place in the two weeks between 28. May and 10. June 2016. The simulations were split into five days of equipment set-up and pool trials on the premises of COMEX and five days of subsea trials off the coast of Marseilles (including preparation and wrap-up).

This was the first use of an advanced EVA Information System in a water immersion, partial gravity simulation. It allowed interaction with a robot and communication between remote parties.

The EVAs at Marseilles covered scenarios that included, descent from Lunar Excursion Module (LEM), installation of instruments, astronaut-rover collaboration and sampling.

Description of images:
left: simulation astronaut decends from LEM, right: astronaut-robot collaboration scenario




comex

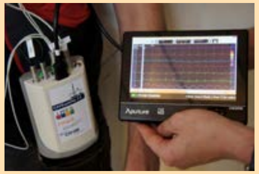
External Experiments

Preceding MOONWALK simulations, consortium members issued a call for proposals, inviting external researchers to conduct experiments alongside simulations in Rio Tinto and Marseilles. In Rio Tinto, four external experiments were selected and conducted successfully. For the Marseilles simulation, two selected experiments from external investigators were included.

Rio Tinto

ADAPA 360 - 360-Degree VR Video Camera System for Space Suit and Helmet
Team: Ali Zareiee, ADAPA, Norway

Documented Rio Tinto using ADAPA 360-Degree Camera. Provided excellent footage of site and MOONWALK project.



credit:
top: Video Still from Adapa 360 Rio Tinto, credit: Adapa Trino

middle: CAVExplorer 2.0, photo credit: Walter Kullmann 2016

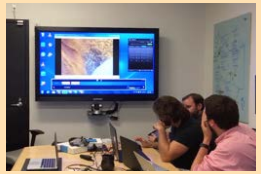
Cave Explorer - Assessment of performance for the wearable electro-optical diagnostic health assistant system
Team: Human Spaceflight Department, OHB System AG; Medical Engineering Department, IMES University of Applied Sciences Würzburg-Schweinfurt

Tests were conducted for a new, mobile, digital diagnostic system for medical monitoring astronauts during manned space missions called the CAVExplorer 2.0. Comprised of electrodes worn on the body of an astronaut and sensor detectors on the earlobe, the CAVExplorer 2.0 measures electrical signals and monitors the health of the heart and circulatory system.

Psychobot: Human Psychological Relationship with a Planetary Exploration Robot
Team: Yvett Mikola, PhD student, Complutense University of Madrid (UCM). Madrid, Spain

The experiment tried to prove the possibility that humans develop an emotional attachment to their robotic "working partners" when interacting with them on a daily basis.

To measure the qualitative and quantitative changes in the human-robot teams, four questionnaires were developed to be used with a pre-post method for each simulation astronaut.



credit:
SCALE, Georgia Tech Mission Control Centre, photo: Georgia Tech 2016

SCALE: Shared Cognitive Architecture for Long-term Exploration
Team: Leslie DeChurch (Georgia Tech), Noshir Contractor (Northwestern), Jeff Johnson (U. of Florida); United States (NASA Behavioural Health & Performance)

Communications by EVA crew, habitat crew and MCC were logged for analysis by the SCALE team in order to develop new methodologies and technologies to improve shared cognition during space missions.

In addition, Mission Control was handed over for the afternoon of the 28th of April 2016 to Georgia Tech during the Rio Tinto simulations, demonstrating the capability of involving international teams into the modular MOONWALK simulation architecture.

Subsea Marseilles

Artist Astronaut Performance
Team: Sarah Jane Pell

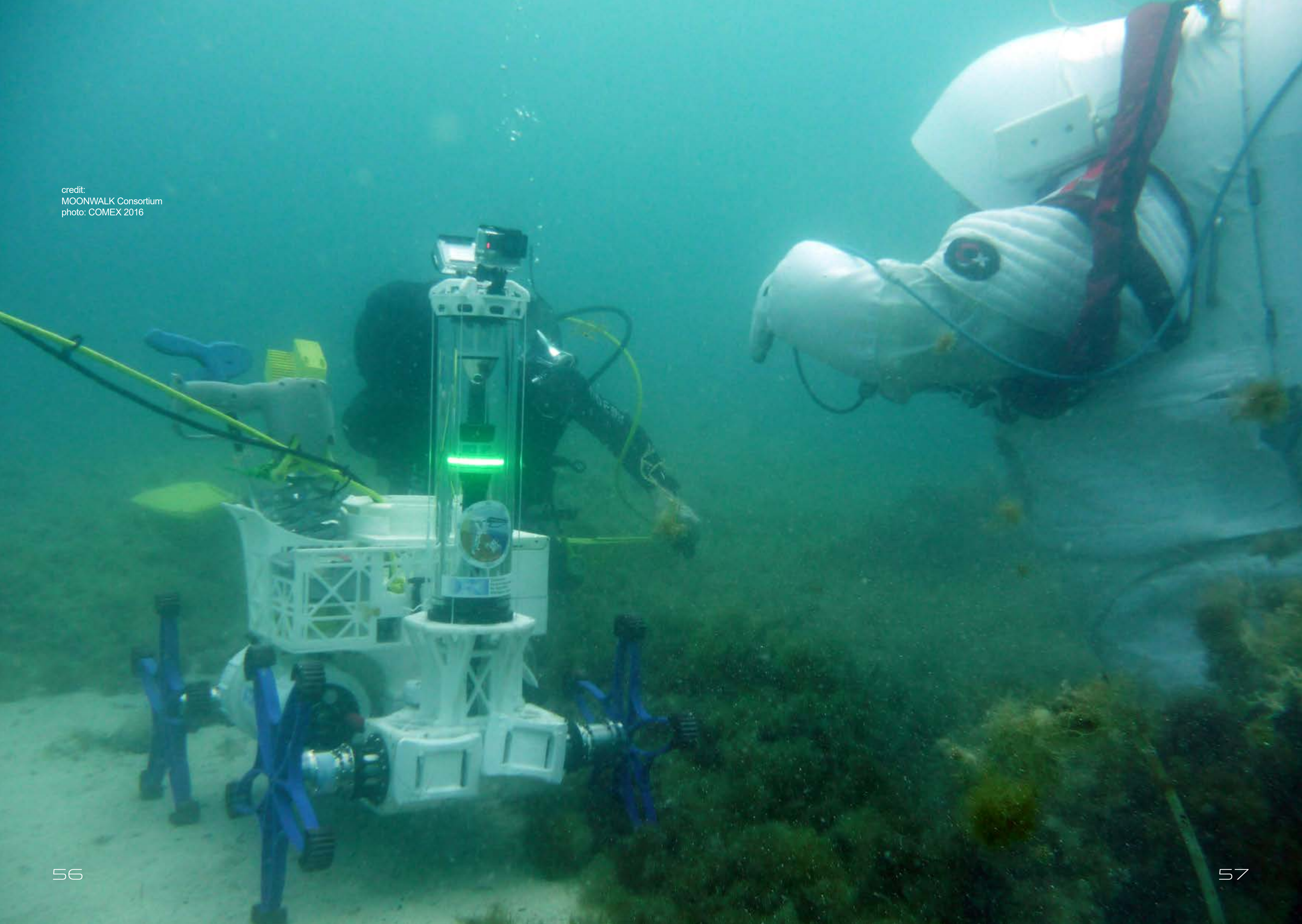
Dr. Sarah Jane Pell, Simulation Astronaut and Professional Diver researching human performance and interactions of the Artist-Astronaut

credit:
top: Sarah Jane Pell, photo credit: COMEX 2016
below: Lunar Pivot Beam in subsea Marseilles, photo credit: COMEX 2016

Lunar Lander Pivot Beam Support System
Team: Aedel Aerospace Unipessoal, Portugal

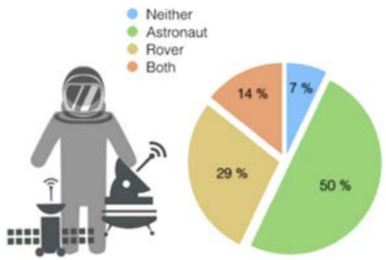
A mock-up of a structure with a pivoting arm showing one activity as part of construction operations was tested in subsea Marseilles.

credit:
MOONWALK Consortium
photo: LIQUIFER Systems
Group 2016

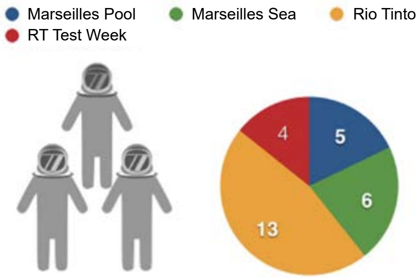


credit:
MOONWALK Consortium
photo: COMEX 2016

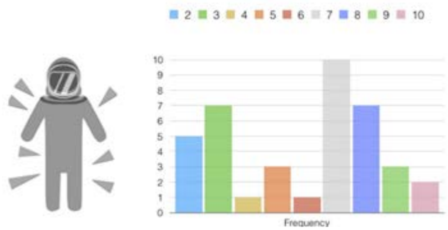
Interaction



EVAs



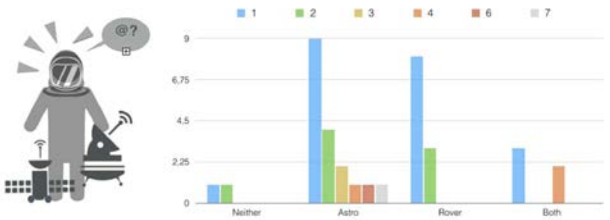
From 1 to 10, how would you rate the physical discomfort of wearing the suit?



Description of images:
Items from the MOONWALK evaluation survey

credit:
MOONWALK Consortium,
survey content / graphics:
NTNU 2016

From 1 to 10, how would you rate the psychological discomfort of wearing the suit?

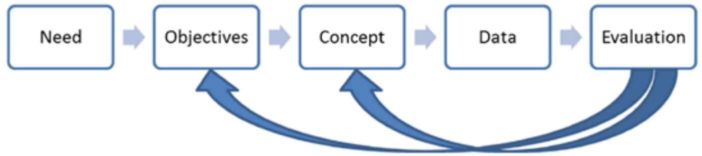


Analysis and Validation

A core objective in the analysis of project MOONWALK is to evaluate the performed analogue missions with respect to human factors and to evaluate and compare the astronaut-astronaut team versus the astronaut-robot team in terms of performance and psychological impact.

Dependent variables were measured by the use of a survey and interviews presented to the astronauts directly after each EVA. The 101 question-survey presented to the astronauts included background-, descriptive-, and statements variables. Some questions were provided by consortium partners asking for feed-back of their specific component, other questions aimed to evaluate the simulations and the different effects that the components had on the subjects.

In total the dataset consist of 120 variables (of which 101 are questions), 75 responses and 14 respondents. From the open questions the survey collected 52 lessons learned, 33 comments about the different simulations, 55 comments about the tools, 63 comments about the HMI and 39 comments about the suit. Data was gathered from 28 different EVAs, 17 performed in Rio Tinto and 11 in Marseilles.



Description:
The diagram shows the scope of the evaluation in the MOONWALK project

Variables: Components / Sites / Teams

The variables that were considered when evaluating the simulations were the different components, sites and core sim teams.

Components

Suit
HMI
Tools
Robot

Sites

Rio Tinto tests
Rio Tinto simulations
Marseilles Pool tests
Marseilles Subsea simulations

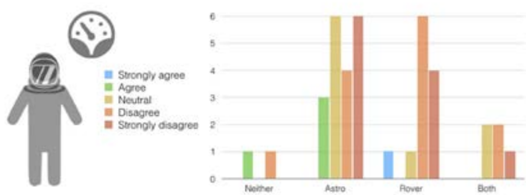
Teams

EV1 and EV2
CAPCOM/BASE
Robot team
Mission Control Centre and Science Centre Brussels

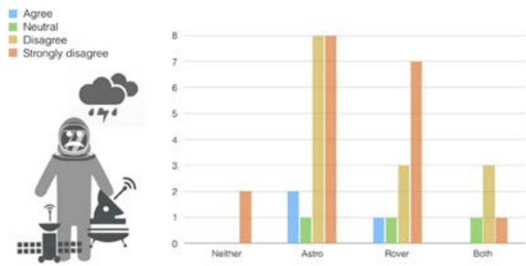
Description of images:
Items from the MOONWALK evaluation survey

credit:
MOONWALK Consortium
survey content / graphics:
NTNU 2016

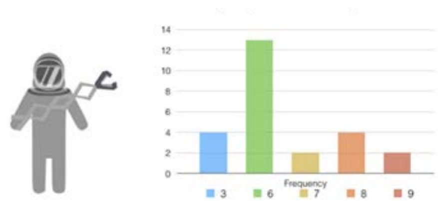
The simulation lasted too long for wearing the suit



I felt oppressed in the suit during the simulation



From 1-10, How was the Pantograph Sampling Tool (PST) in its handling and usability



The NASA RTLX method (Task Load Index without weighing procedure) was utilised for analysis purposes and is a subjective mental workload assessment tool that is used to measure participant mental workload (MWL) during task performance. The procedure was developed by NASA with recognition that excessive demands on resources both mental and physical, imposed by a task, will typically result in performance degradation.

The questions were rated on a scale ranging from low (1) to high (20) and were formulated as follows:

1. How much mental and perceptual activity was required?
2. How much physical activity was required?
3. How much time pressure did you feel due to the pace at which the tasks or task elements occurred?
4. How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?
5. How hard did you have to work (mentally and physically) to accomplish your level of performance?
6. How successful were you in performing the task?

The score from the six subscales were added to compute a total workload score. The findings indicate that the different sites lead to differences in how the astronauts evaluate the system components and their experience of the simulations.

There is little indication that the interaction with the rover/robot resulted in different responses from the simulation astronauts compared to interaction with another astronaut.

The main suppositions we draw from this evaluation is that simulations in analogue sites provide a good tool for learning about the complex socio-technical systems that exists in a human exploration mission that utilises human-robot cooperation.

TRL 9 — Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

TRL 8 — System complete and qualified

TRL 7 — System prototype demonstration in operational environment

TRL 6 — Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 5 — Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 4 — Technology validated in lab

TRL 3 — Experimental proof-of-concept

TRL 2 — Technology concept formulated

TRL 1 — Basic principles observed

credit:
EU - Horizon 2020

Technology Readiness Level (TRL)

In MOONWALK, a number of technologies and technical systems that are relevant for planetary EVAs were modified and raised to a higher TRL level. Many of them, but not all, are also relevant enabling technologies for terrestrial applications.

ELEMENT	TLR 2013*	TLR 2016*	EXPLANATION
Amphibious Scout Rover	4	6	Based on a proven rover design, a light weight scout rover with exeptional all-terrain capabilities was developed. The scout rover is able to operate on land and under water.
Gesture Control	1	3	A novel method human-robot interaction was developed. The method is based on gesture control, where gestures are not tracked optically, but with integrated IMU sensors. The gesture control was successfully operated by multiple (5) astronauts during the simulations.
Tablet for Human-Robot Control	5	6	Alternative methods for human-robot interaction based on user-friendly interfaces on breast- and wrist-mounted touch-screens were developed and tested.
360 Degree Omnicam	5	6	A 360 deg camera was used to produce a constant 360 deg video stream of the robots environment.
Follow-me function	2	5	A function that allows the robot to follow the astronaut autonomously was developed. The method is based on image analysis and machine learning, which makes it very generic, independent of markers and other helping devices.
Gandolfi-2 space suit Mock-Up	2	6	A space suit mock-up that simulates all relevant constraints to astronaut movement was developed. The suit can be used on land and under water.
Manual Soil Sampling Tool - PST	1	5	Pantograph Sampling Tool (PST) is designed to facilitate single-handed extension and contraction of a tool arm. It has a multifunctional, exchangeable toolhead, including a shovel and sampling container with closeable lid.
Biomonitoring System	2	5	prior in-house project done by Airbus (called hornbee), with the aim of human-state monitoring for emergency purposes (TRL 2); laboratory experiments conducted with university partner, data and algorithms carried forward and were used in the relevant environment, critical functions were tested in MOONWALK environments – underwater and old mining site (TRL 5)

TRL 2013* start of project
TRL 2016* project completion

Future of MOONWALK Concepts and Technologies

Many technologies that are now common in our daily lives were initially designed for space. Prominent examples are flexible solar cells, temper foam (for helmets), or aircraft de-icing systems. Space medicine has provided new insights in the functioning of the human organism and supported a number of inventions, such as programmable pacemakers or tools for cataract surgery. Human spaceflight oriented projects do not only inspire but also produce new knowledge and enable new achievements right here on earth.

The MOONWALK project has developed a number of technologies that can be used both in space and terrestrial applications. Potential terrestrial utilisation of MOONWALK technologies when further developed can include:

Amphibious Assistant Robot
Search & Rescue, emergency response, consumer market
The light-weight Amphibious Assistant Robot, with good all-terrain capabilities can be used for the exploration of inaccessible areas such as slopes, caves, trenches, underwater environments, etc.

Gesture Control
Remotely Operated Vehicles (ROVs), divers, emergency response, industrial robots, motion-tracking of workers (e.g. for health & safety)
Novel method for human-robot interaction – human controls robot through gesture. Gestures (i.e. movement and pose) are tracked with IMU sensors attached to the human. Sensors are wearable and no device has to be actively handled, enabling hands-free interaction with the robot, allowing for simultaneous execution of tasks.

Interactive displays
ROV control by diver, emergency response, industrial robots
Methods for human-robot interaction based on user-friendly interfaces on a chest display. Operations concepts involving synchronized multi-party procedure viewing during EVA.

360 Degree Omnicam
Surveillance of assets, subsea scientific observations
Camera used to produce a constant 360-degree video stream.

Generic follow-me function
Hybrid human-robot teams (Search & Rescue, emergency response, consumer market, industrial production)
Function that allows the robot to follow the astronaut autonomously, based on image analysis and machine learning.

Gandolfi-2 space suit mock-up
Future analogue tests of equipment and crew training
A space suit mock-up that simulates all relevant constraints to astronaut movement. The suit can be used on land and underwater for astronaut training.

Manual Soil Sampling tools
Sampling and object manipulation in contaminated areas (chemical, radioactive)
Sampling tools – foldable, extendable, adaptable for sample collection.

Biomonitoring System
Human operators of safety-critical systems, sports, health & elderly care
Easy-to-deploy biomonitoring tool to assess stress level of astronaut.

EVA Information System (EVAIS)
All terrestrial applications where efficiency and safety of human operators depends on close interaction with a central control centre (e.g. emergency response)
User-friendly system to enable efficient communication and exchange of data between astronaut and ground control centre.

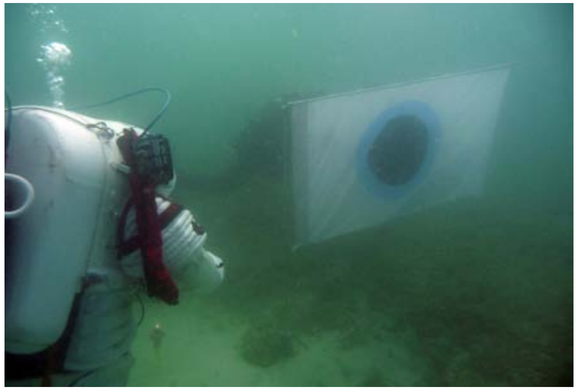
MOONWALK Outreach and Dissemination

The outreach and dissemination campaign that accompanied the Rio Tinto simulations was very successful. Overall, more than estimated 300 external visitors were counted on-site, with 250 visitors on the public day during the first week alone. The simulations were covered extensively by regional and national TV stations and by regional, national and international press.

The MOONWALK Consortium hosted the next generation of space explorers through the MOONWALK Children Competition, its goal to inspire and educate children about past, current, and future human and robotic exploration of the Moon and Mars. A comic book was created telling the story of four children travelling to Mars via the International Space Station and Moon. The fictional cartoon offered both educational in-sight into what a real outer space missions could look like and asked children, in the context of the story, to design a new ‘flag' for the Moon and the first ‘phrase' that will be spoken on Mars by humankind.

Guadalupe Maíz López, from Spain, won the Mars competition with the phrase, ‘Today Mars, tomorrow the stars,' and Leo Leoste, from Estonia, was the winner of the Moon contest.

Each child was awarded a trip to the respective simulation site and was able to have a first-hand look at a real earth-analogue and watch their winning proposal be executed during simulations.



Description of images (opposite page):
top row: press at simulations in Rio Tinto
bottom row: Children Competition winners, left: Leo Leoste, right: Guadalupe Maíz López

credit (opposite page):
MOONWALK Consortium
photos, clockwise from top left: photos 1-3: INTA-CSIC 2016 photo 4: Leo Leoste

Description of image (this page):
top row: Guadalupe on-site at simulations
bottom centre: Moon flag by Leo

credit (this page):
MOONWALK Consortium
photos, top row: INTA-CSIC 2016, bottom: COMEX 2016

CONCLUSION

The results of the MOONWALK project show that the exploitation of space is an enabler of new achievements and new technologies. The extreme environmental conditions that are characteristic for space ask for robust solutions with advanced capabilities that go beyond what is needed for average terrestrial applications. Human spaceflight is an important catalyst not only to initiate the conceptualisation of such solutions, but also to provide the inspiration to go the extra mile to actually achieve them.

With respect to the objective of building up European capacities and infrastructure for future analogue simulations, the MOONWALK simulations created a significant know-how boost within the participating organizations, institutions and companies. This includes an improved understanding of challenges related to logistics, legal aspects, on-site organization and team-building as well as an in-depth knowledge of the test sites, their advantages and limitations. The extensive outreach (also to the space agencies ESA and NASA) and dissemination measures of MOONWALK created high visibility of the project and sparked new interest in space exploration and in earth analogue simulations.

Description of image:
MOONWALK consortium in Rio Tinto, in front of the SHEE habitat with Gandolfi-2 docked on the suitport and helper robot YEMO

credit:
MOONWALK Consortium
2016

credit:
MOONWALK Consortium
photo: LIQUIFER Systems
Group 2016

German Research Centre for Artificial Intelligence (DFKI) Robotics Innovation Centre (RIC)

The DFKI Robotics Innovation Centre (RIC) in Bremen is one of four offices of the German Research Centre for Artificial Intelligence (DFKI), a private non-profit research organization dedicated to application-oriented research and development with a focus on artificial intelligence.

COMPAGNIE MARITIME D'EXPERTISES SA (COMEX)

COMEX provides expertise and innovation in the maritime, submarine, medical, industrial, and space sectors. COMEX develops hyperbaric chambers, diving systems and equipment for human interventions in extreme environments.

AIRBUS GROUP (AG-I)

Airbus Group Innovations offers a network of research facilities, scientists, engineers and partnerships, sharing competences and means between three divisions of the Airbus Group including: Airbus (aeronautics), Airbus Defence and Space and Airbus Helicopters. Airbus Group Innovations fosters technological excellence and business orientation and is at the forefront of research and technology.

LIQUIFER SYSTEMS GROUP GMBH (LSG)

LIQUIFER Systems Group (LSG) is a trans-disciplinary platform engaged in the design of future systems for Earth and (Outer) Space. The LSG team comprises of experts in Architecture, Design, Systems Engineering, Human Factors, Robotics and Satellite Technologies for Terrestrial and Space Applications. LSG excels in designing advanced concepts for habitation, transportation and exploration system for outer space.

SPACE APPLICATIONS SERVICES N.V. (SPACE)

The aim of Space Applications is to research and develop innovative systems, solutions and products for the aerospace and security markets and related industries. The company is experienced in developing and evaluating various Human-Machine Interfaces (HMI), including augmented and virtual reality systems for training purposes, procedural assistance and medical support, haptic exoskeletons and control platforms for manipulation, as well as mobile robots.

NTNU SAMFUNNSFORSKING AS (NTNU) CENTRE FOR INTERDISCIPLINARY RESEARCH IN SPACE (CIRIS)

NTNU Samfunnsforskning AS (NTNU) is a non-profit research company owned 100% by Norwegian University of Science and Technology (NTNU). CIRiS is a department of NTNU Samfunnsforskning AS with a mandate to promote and perform research and development relevant to the exploration and exploitation of space.
Research on safety and efficient communication in "virtual teams" working with large geographical and cultural distance, in "Man-Technology-Organization" (MTO) context, is of special interest.

INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL CENTRO DE ASTROBIOLOGIA (INTA-CSIC)

The Instituto Nacional de Técnica Aeroespacial (INTA) is the Spanish reference in aerospace research. With its more than 70 years of existence, INTA has developed multiple projects in the aeronautic field as well as space and since 1998 bears the name Centro de Astrobiología, the first international partner associated with the NASA Astrobiology Institute.
Researchers have extensive expertise in the exploration of terrestrial analogue environments of Mars and particularly in the Rio Tinto system.

This booklet was prepared as a part of the dissemination activities in the MOONWALK project.

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photo back cover:
COMEX 2016

photo front cover:
Bruno Stubenrauch 2016

www.projectmoonwalk.net

Project MOONWALK has received funding from the European Union’s Seventh Framework Programme for research, technoloical development and demonstration under grant agreement no.607346