National Aeronautics and
Space Administration

Operational Field Testing for Human Space Exploration

NASA “Analog” Projects

Exploration Integration

Extravehicular Activity & Science Operations

Extreme Environment Evaluations & Experiments

What Are Operational Field Tests?

Background

- Future Exploration missions will potentially take humans to destinations where Extravehicular Activity (EVA) work will be done on non-engineered natural bodies
- These missions will also be at distance that precludes instantaneous real-time communication with the crew, hinders fast resupply, and precludes quick help
- There are numerous technology and operations gaps associated with EVA tools, science sampling tools, experiments, and operational techniques for dealing with comm latency

Operational Field Testing

An “analog” mission is an integrated multi-disciplinary operational field test that allows for early end-to-end testing of concepts of operations and hardware in a true operational scenario

- Evaluates objectives mapped to specific needs and knowledge/technology gaps
- Has the crew in-situ and a ground team separated from them in a mission-like manner
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Drives out results not found in standalone testing, including things that do and do not work in a mission environment
- Benefits programs from ISS to Exploration

Integrated Evaluations of Operations Concepts

The objective for an operational field test is to explore the combined aspects of Science, Operations, and Equipment in a mission-like environment in order to evaluate:

- Concepts of operations on a natural surface
- Hardware and tools for pioneering and science tasks
- Tools and techniques that enable effective and efficient communication between the ground (MCC and Science Team) and the crew (IV and EVA) over an appropriate communication latency utilizing a flexible execution methodology

Alignment with NASA's Journey to Mars

NASA JSC PROGRAMS

EARTH RELIANT	PROVING GROUND	MARS READY
MISSION: 6 TO 12 MONTHS RETURN TO EARTH: HOURS	MISSION: 1 TO 12 MONTHS RETURN TO EARTH: DAYS	MISSION: 2 TO 3 YEARS RETURN TO EARTH: MONTHS
Earth Reliant exploration is focused on research aboard ISS testing new technologies and advancing human health and performance research that will enable deep-space, long-duration missions.	Proving Grounds will let NASA learn how to conduct complex operations in a deep space environment. Primarily operating in cislunar space, NASA will advance and validate capabilities required for human exploration of Mars.	Mars Ready endeavors will build on what we learn on ISS and in cislunar space to enable human missions near Mars, including the moons of Mars, and eventually to the Martian surface.
✓ **International Space Station** ✓ Commercial Crew and Resupply ✓ **Astronauts** ✓ **Flight Operations**	✓ **Orion** ✓ **Asteroid Retrieval Crewed Mission** ✓ **Human System Research** ✓ **Suits** ✓ Environmental Control & Life Support ✓ **Robotics and Autonomous Systems** ✓ Space Radiation Protection	✓ **Mars Surface Systems** ✓ Entry, Descent, and Landing ✓ **Science and Planetary Destinations** ✓ In-situ Resource Utilization (ISRU) ✓ **Mission Environments, Integration, and Testing**

Operational field testing contributes to all Journey to Mars phases

Partnerships and Collaborations

- NASA
  - Multiple centers and groups
  - Exploration
  - Extravehicular Activity (EVA)
  - Science
  - Operations
  - Engineering
  - Astronauts
- International Partners
- Academia
- Institutions
- Military
- Industry

And many others…

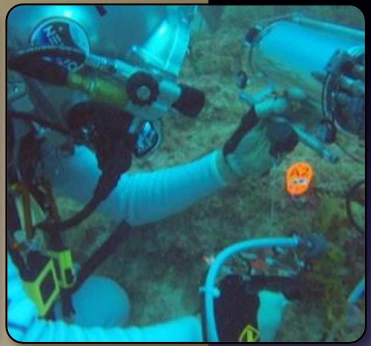
EVA Goals for Operational Field Tests

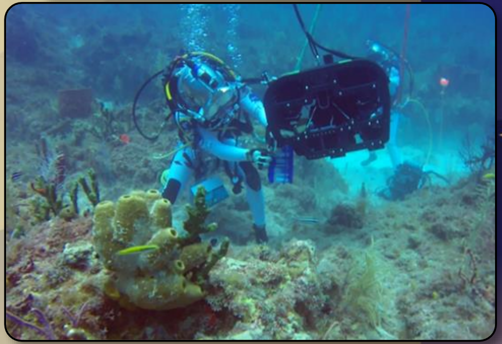
Extravehicular Activity Goals

- Advance the future of the EVA system and operations
- Understand EVA gaps and concepts of operations for a wide range of Exploration destinations being considered by NASA
- Determine and document closures to gaps in EVA capabilities for Exploration missions and inform the EVA Systems Maturation Team (SMT)
- Develop and document concepts of operations for EVA at the Exploration destinations
- Realize the needs of EVA tools and hardware and enable the development of requirements and designs

Benefits of Operational Field Testing

- Concepts of operations can be accurately tested to determine their viability and changes
- Utilization of real science allows for investigation of end-to-end concepts of operations, from both an Earth-based Science Team and the in-situ EVA crew
- Purpose-built prototype hardware can be evaluated in a field test to provide data for design maturation
- Communication latencies can be simulated in an operational environment in order to assess the con ops and needs associated with EVAs
- A range of destinations can be evaluated





Environments for Operational Field Testing

AQUATIC

Neutral Buoyancy Laboratory (NBL)

Aquarius Reef Base (NEEMO)

Neutral Buoyancy Facility

Others …

TERRESTRIAL

Geo-Science Field Exercises & Sites

Field Training Areas

Extreme Environments (ex. Antarctica)

Others …

LABORATORY

Active Response Gravity Offload System (ARGOS)

Virtual Reality & Hybrid Reality Laboratories

International Space Station

Others …

[redacted]

Heritage & Background

Apollo Surface Operations

Low communication latency (~1.25 sec OWLT)

- Exploration traverses were planned in advance using imagery gathered from precursor satellites
- Crews had significant training in geology and science tasks
- An Earth-based science team (ST) supported EVAs (Precursor plans, Feedback during EVA, and changes between EVAs)

Mars Robotic Missions

High communication latency for Mars (~4-22 min OWLT)

- Remote science operations
- Instrumentation / sample selection

MER A - Spirit

MER B - Opportunity

MSL - Curiosity

1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

NASA Extreme Environment Mission Operations

Tested-bed for a variety of communication latency for detailed EVA/Science evaluations

- Utilizes unique facility & environment; rapid prototyping; Evaluations of both IVA and EVA objectives

Science

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Research and Technology Studies

Tested a variety of communication latencies for geo-science operations

- Utilizes terrain appropriate for geo-science tasks; Suit and robotic test-bed

Science

1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

Other NASA Analog Programs

Test a variety of communication latencies

- Each exploring various aspects of exploration
- Funded though grant programs
- Science focused

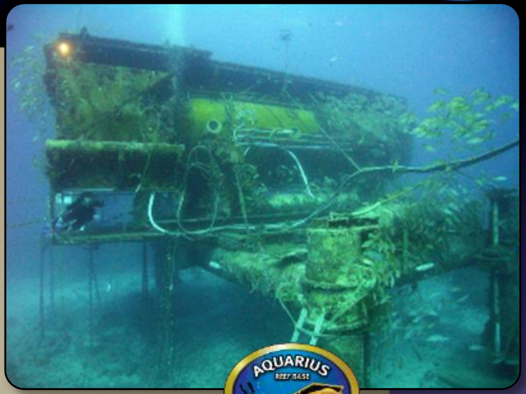
ISRU HI-SEAS BASALT PAVILION LAKE RISE

Exploration Integration & EVA Field Tests: NEEMO

(NASA Extreme Environment Mission Operations)

NEEMO is a project that utilizes Aquarius, the only operational undersea research facility in the world, as a setting for accomplishing a host of NASA and synergistic partner objectives

- Funded by partners and collaborators from across NASA centers, DoD, universities, and industry
- 1-2 missions/year, 10 – 20 days in length
- Shore side Mission Control, staffed by experienced operators
- Crew largely consists of astronauts from CB and IPs, along with PIs and engineers
- Missions have high operational rigor by design (timelines, procedures, etc.)
- Enables evaluation of both IVA and EVA objectives
- Allows for evaluations of end-to-end concepts of operations with crew that are in-situ in a true extreme environment
- Provides for flight-like interactions between the crew and an MCC Science Team, including over comm latencies
- Enables a testing ground for hardware and tool concepts on the start of the road to flight
- Currently the primary field test for EVA & integrated science operations
- Analog Testing Details:
    - Previous mission: July 21- Aug 5, 2016
    - Next mission: TBD (Summer 2017)



Planetary Science Proxies & Relevance

SCIENCE

PLANETARY SCIENCE RELEVANCE OF MISSIONS

- EVA science activities include deployment of handheld instrumentation, context descriptions, imaging, and sampling
- Operational field testing allows for evaluations of sample collection tools, deployable instruments, and EVA concepts of operations
- Geoscience activities at analogs such as RATS and RISE directly correlate to planetary exploration
- The marine science activities and associated research objectives at NEEMO serve as a appropriate proxy for planetary surface exploration activities

- **Integration, coordination, and education from diverse disciplines and organizations**

Astromaterials

Curation

- Sampling Procedures
- Sampling Techniques
- Collection Tools
- Contamination
- Storage & Transport

Research

- Remote Sensing
- In-situ Instrumentation
- High-grading Samples
- Context Descriptions
- Documentation

Exploration

- Science Operations
- Operational Flexibility
- Human-Robot Ops
- Crew Science Training

Concepts of Operations Evaluations

OPERATIONS

OPERATIONS CONCEPTS AT NEEMO

INTEGRATED EVA SCIENCE OPERATIONS

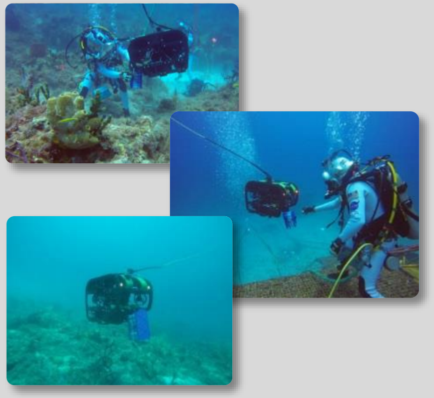
- Examine con ops that enable interaction between the MCC & the crew over a long comm latency including:
  - Interaction with an integrated Science Team
  - Authentic scientific objectives and hypothesis
  - "Flexecution" methodology

PIONEERING TASKS

- Evaluate early prototype construction hardware and techniques

- Deploy, test, and evaluate a prototype comm system
- Simulated a multi-phased "pioneering" task

JOINT ROBOTIC-EVA OPERATIONS



- Joint human-robot operations
- Autonomous site navigation and precision execution for tool handoff/delivery & diver leading
- IV-control for localization, detailed navigation, situational awareness, inspection, and intervention

NAVIGATION, MAP, & TRAVERSE PLANNING

- Assessed tool needs for navigation
- Traverse plan and map on cue cards showed crew regions and paths, and tasks to complete
- Utilized Doppler relative nav system for crew to find ROI/zones

WITH COMMUNICATION LATENCY CON OPS

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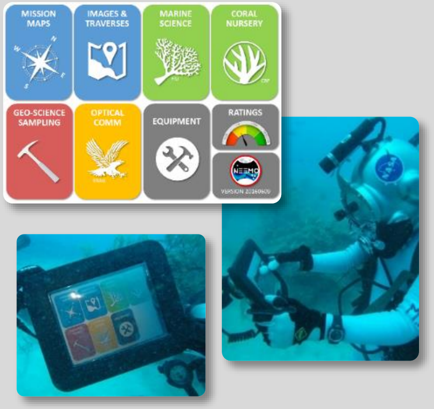
Hardware Evaluations

EQUIPMENT

HARDWARE EVALUATIONS AT NEEMO

ELECTRONIC CUE CARDS



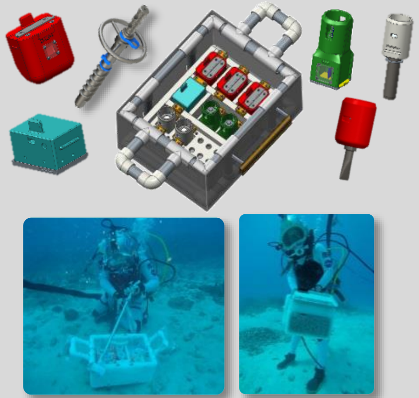
- Evaluate electronic cue cards for EVA crew that allow them to operate more effectively and offload IV tasks
- Additional crew autonomy requires further access to information in their hands
- Potential "one-device" for cue cards/procedures, images/video, instrument control, etc.

DEMO

IV SUPPORT SYSTEM

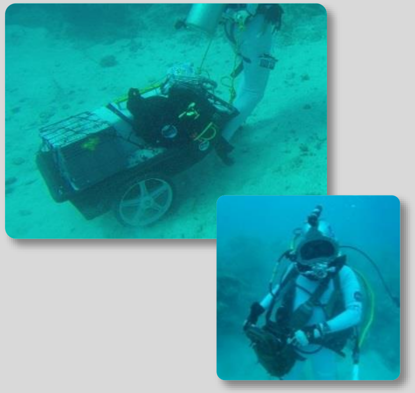
- Evaluated types of tools the IV crewmember needs to effectively handle the large amount of EVA information while directing EVA
- Evaluated effective setup in a constrained location
- Multiple displays included camera feeds, timeline, nav/comm/sub systems, procedures, logs, etc.

SCIENCE SAMPLING TOOLS & GEOLOGY SAMPLING KIT



- Test EVA tools and hardware for science sampling
- Evaluate Integrated Geology Sampling System for collecting geology & astrobiology samples
- Sample Briefcase houses various end effectors with two different drivers (manual and powered)
- Analyze methods to minimize EV crew contaminating an area

TRANSPORTATION & STOWAGE OF TOOLS



- Evaluated EVA hardware and operations for transporting and stowing tools and samples
- Initial look at sled/cart options for large equipment transport
- Evaluated sling bag options for small items & easy access (sample markers, hand tools, electronics, etc.)

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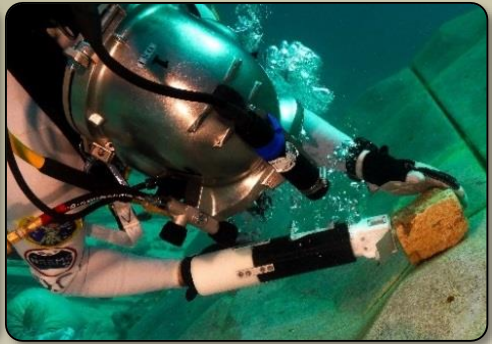
Evolution of Tools for Road-to-Flight

Example of Evolution Across Missions: Powered Rock Chip Hammer

SEATEST 2

NBL/MACES

NEEMO 18/19



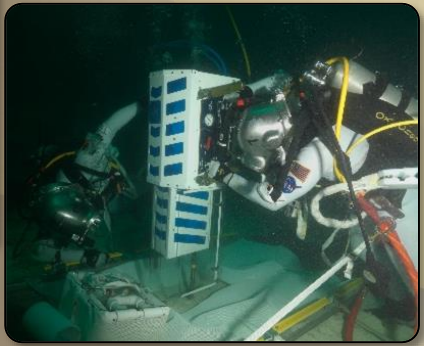
NEEMO 20

NEEMO 21

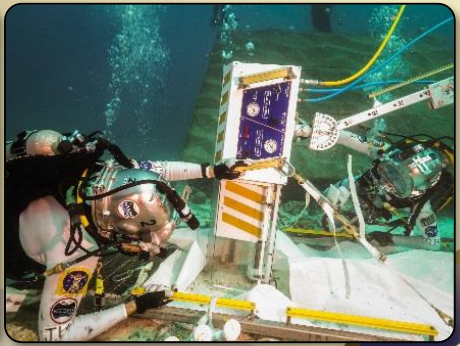
Powered Core Sampler

SEATEST 2

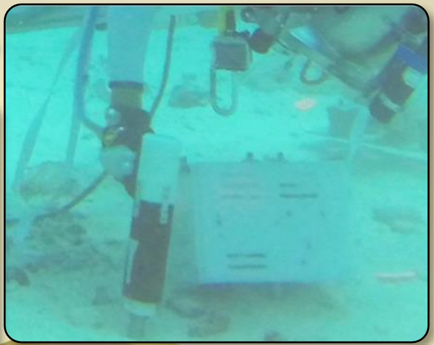
Deep Core Drill



NEEMO 18



NEEMO 19



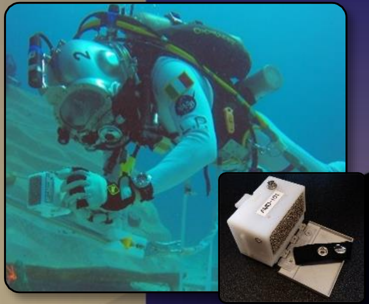
NEEMO 20

NEEMO 21

Surface Sampler Evolution

2014

NEEMO 20



NEEMO 21

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EVA Gap Closures from NEEMO 21 (2016)

SCIENCE

Nursery Construction
Nursery Science
N20 Reef Follow-up Science
Reef Exploration Science

OPERATIONS

Integrated EVA Science Operations
EVA Traverse Planning & Maps
EVA Navigation
Joint EVA-Robotic Operations
Effects of Comm Latency on Ops

EQUIPMENT

EVA Digital Cue Cards
IV Support System
Science Sampling Tools
Geoscience Sampling Kit
Tool Transportation

EVA Gap Closure Inputs

Integrated EVA Flight Control

Flexible Execution Methodology for EVA Science Operations in Undefined Environments

Tools for Interacting with EVA Over a Comm Latency

IV Support System for EVA Operations

Display (EVA Integrated Camera)

Navigation (EVA Short Distance Navigation)

Tools for Science Sampling on a Surface EVA

Tool Caddy Device on a Surface EVA

EVA-Robotic (Man-Machine) Work System

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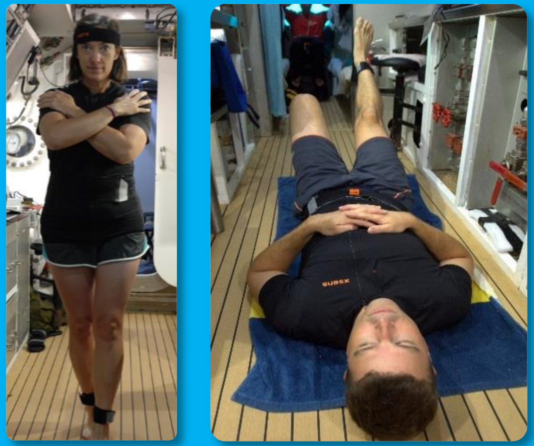
Intra-Vehicular Experiments & Evaluations

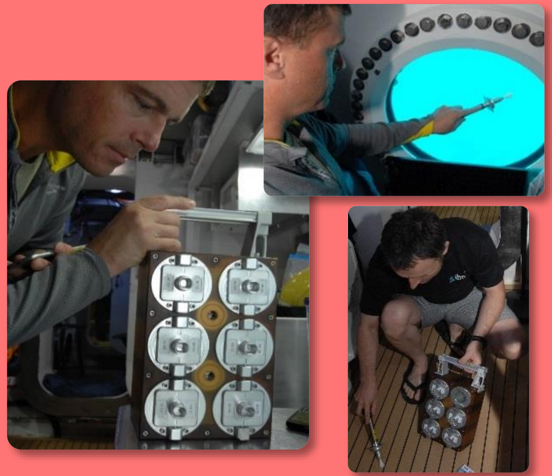
Portable Sensorimotor Assessment Platform (PSAP)



HoloLens for Cargo Transfer Assessment

Miniaturized Exercise Device MED 2.0

EVA Swab Tool

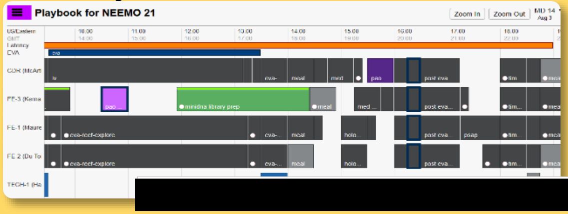


VEGA Telehealth - Portable monitoring devices

IHMC - Multi-Omic Study

Teloregen - Regeneration Study

Playbook - Timeline Tool



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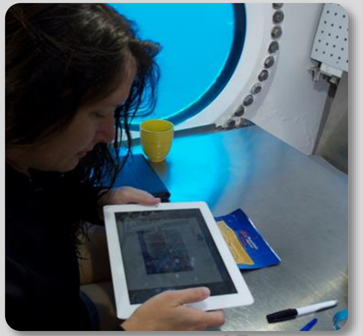
Miniaturized DNA Sequencer

esa Evaluations

MobiPV Evaluation

Aquapad Evaluation

Nutritional Assessment Tool



Other EVA & Science Operational Field Tests

- A number of other analogs have been used in the past to varying degrees for evaluation of EVA and science operations
- These are not actively being used by EVA today
- EVA is open to being involved in some of these in the future if the cost/benefit trade proves favorable

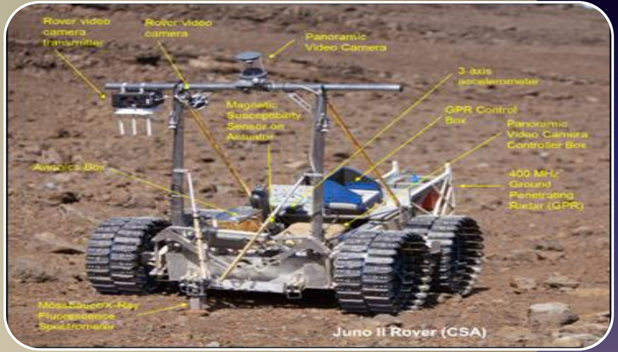
- **Research And Technology Studies (RATS)**
  - RATS 2012 was an asteroid analog mission
  - Took place at NASA JSC
  - EVAs conducted in VR Lab and on ARGOS
  - Vehicle/asteroid sim was tied to VR lab/EVA sim to allow vehicle and EV interaction
  - Reliable and cost-efficient test and validation of NASA next-generation human exploration mission concepts
  - Mission tested techniques, tools, planning, and communication protocols
  - Matured operational concepts and technologies through integrated demonstrations
  - Exercised overall ‘MCC style’ coordination between hardware, procedures, crew operations, mission control operations, science team operations, and engineering team

Other EVA & Science Operational Field Tests

- **Desert RATS**
  - Missions were a planetary analog
  - Took place at the Black Point Lava Flow near Flagstaff, AZ
  - Provided environment analogous to Moon and/or Mars, with crew conducting geoscience operations
  - Allowed immersion of whole team, both flight crew and flight controllers
  - Geoscience data still utilized for research
- **SSERVI RIS^{4}E**
  - RIS^{4}E: Remote, In Situ and Synchrotron Studies for Science and Exploration
  - SSERVI-funded project that investigates the effects of incorporating field portable instrumentation for in situ measurements into scientific EVA timelines
  - Examines the most effective instruments for answering science questions and how they integrate with the larger mission architecture
  - Fundamental science questions serve as basis for understanding how to operate on planetary surfaces
  - RIS^{4}E analog work at Kilauea, HI, and Potrillo Volcanic Field, NM

Other Analogs

- In-Situ Resource Utilization
  - Planetary analog mission
  - Hardware tested under stressful environmental conditions
  - Expands scope of international involvement and mission criticality for hardware and remote test operations
  - Expands integration of science and technology
  - Streamlines path to flight



- BASALT
  - Biologic Analog Science Associated with Lava Terrains
  - Funded by NASA SMD ROSES-2014 Program Element C.14 (PSTAR)
  - Objectives: Investigate terrestrial volcanic terrains and their habitability as analog environments for early and present-day Mars through 4 field deployments in 2015–2019.

Benefits of Operational Field Tests for Exploration & EVA

- Provides a means of advancing Human Spaceflight objectives by evaluating Exploration EVA concepts of operations and hardware/tool prototypes
- Enables authentic science objectives by directly conducting geoscience operations or utilizing proxy marine science to test relevant operations concepts
- Allows for end-to-end testing of techniques and hardware in an operational scenario
  - Has the crew in-situ and a ground team separated from them in a mission-like manner
  - Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
  - Drives out results for things that do and do not work in a mission environment
- Evaluates objectives mapped to specific <u>needs</u> and <u>knowledge/technology gaps</u>
  - Informs updates to the **NASA Exploration EVA Concepts of Operations** document by having crewmembers test relevant concepts in mission environments
  - Facilitates **SMT gap closures** by tying all EVA-relevant objectives to specific gaps and testing potential closures
  - Provides data for hardware design maturation to assist in road-to-flight, especially the **EVA science sample collection tools**
  - Assesses concepts of operations associated with science EVAs that require input from an MCC Science Team over a comm latency
- Ties in the right expertise to evaluate concepts being worked on across the agency
- Benefits programs from ISS to Exploration
- Enhances relationships with international partners, academia, and other NASA orgs

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Terrestrial Industry Applications

Medicine

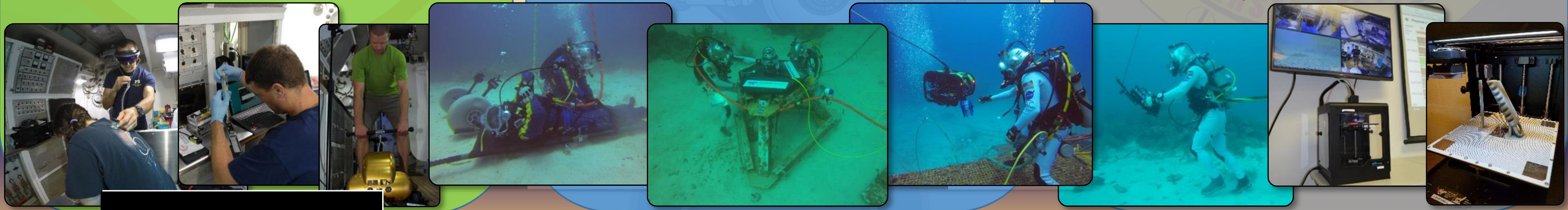
- Telemedicine
- Mixed-reality remote assisted medical treatment
- Confined space exercise at remote destinations
- Miniaturized DNA sequencing
- Portable breathing monitor
- Physiological (telomere) change in extreme environment
- Small team & solo extreme environment rescue

Maritime

- Underwater science operations
- Construction of underwater structures with diver latching/bolting mechanisms
- Long term exposure tests for underwater connectors and materials
- Underwater tools
- Navigation
- Diver-Robotic joint operations and interactions

Advanced Manufacturing

- Rapid prototyping (additive manufacturing)
  - 3D printing of tools
  - Repairing hardware with 3D printed components
  - Rapid delivery of unforeseen components
- Information technologies
- Advanced robotics and intelligent systems
- Automation
- Control systems



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Future of Operational Field Tests

- **EVA Office**
  - Currently looking at next round of operational field testing needs
  - Continued focus on objectives that facilitate closure of SMT gaps and updates to the Exploration EVA Concepts of Operations document
  - Will further evaluate different types of EVA tasks
    - Science operations
    - Pioneering
  - Examining other potential testing opportunities

- **NEEMO**
  - Potential mission in July 2017 (and subsequent years)
  - Significant focus on EVA and Science objectives

- **SSERVI RIS^{4}E**
  - Upcoming deployments in 2016, 2017, and 2018
  - EVA will be looking at possible collaboration

- BASALT
  - Upcoming deployments in 2016 and 2017

Collaborating on Operational Field Tests

- NASA is always looking for collaboration with external groups to help facilitate development of the next generation spaceflight systems for EVA
  - https://www.nasa.gov/suitup
  - Primary Exploration EVA Office POCs:
    - Brian Johnson (brian.j.johnson@nasa.gov)
    - Jesse Buffington (jesse.a.buffington@nasa.gov)
    - David Coan (david.coan@nasa.gov)
- If interested in collaborating on NEEMO (esp. NEEMO 22 in Summer 2017)
  - NEEMO Project Lead: Bill Todd (william.l.todd@nasa.gov)
  - NEEMO Mission Director: Marc Reagan (marcum.l.reagan@nasa.gov)
  - NEEMO EVA Lead: David Coan (david.coan@nasa.gov)
  - NEEMO Science Operations Lead: Trevor Graff (trevor.g.graff@nasa.gov)
- If interested in collaborating on SSERVI RIS^{4}E
  - Jacob Bleacher (jacob.e.bleacher@nasa.gov)
  - Kelsey Young (kelsey.e.young@nasa.gov)