NEEMO 22
EVA Overview & Debrief

EVA-EXP-0054

EVA Exploration Office | XX4
David Coan | NEEMO Mission Management Team, EVA Lead
December 5, 2017
• NEEMO Analog Overview
• NEEMO 22 Mission Overview
• NEEMO 22 Integrated EVA
• NEEMO 22 IVA
• Backup
NEEMO ANALOG OVERVIEW

High-fidelity integrated multi-disciplinary operational development missions that closely mimic the space environment of interest, and allow for end-to-end operations, thus developing and testing concepts that enable Exploration missions.

**WHO**
- MULTI-ORGANIZATIONAL TEAMS
  - PLANNING
  - EVA
  - SCIENCE
  - TECHNOLOGY

**WHAT**
- INTEGRATION THEMES
  - TOOLS
  - TECHNIQUES
  - TECHNOLOGIES
  - TRAINING

**WHERE**
- RELEVANT ENVIRONMENTS
  - AQUATIC
  - TERRESTRIAL
  - LABORATORY

**WHY**
To achieve mission readiness through integration and testing of technologies, systems, operations, and science in relevant environments
- Close technology, exploration, and science gaps
- Identify and develop the best systems, innovations, and operational approaches
- Drive out results not found in standalone testing, including things that do and do not work in a mission environment
- Inform strategic architectural and concept of operations development efforts
- Facilitate EVA concepts of operations development

**OUTCOME**: These efforts will ultimately lead to mission readiness and success, reduce the risk, increase the scientific return, and improve the affordability of NASA programs and missions.
EVA Goals

• Advance the future of the EVA System and operations
• Understand EVA capability, knowledge, and technology gaps and concepts of operations for a wide range of Exploration destinations being considered by NASA
• Assess the system and architectural interactions between Operations, Engineering, and Science
• Determine and document closures to gaps in EVA capabilities and knowledge for Exploration missions
• Develop and document concepts of operations for EVA at the Exploration destinations
• Realize the needs of EVA equipment and enable the development of concepts for design maturation on the road-to-flight
WHO: NASA, ACADEMIA, INDUSTRY, MILITARY @ NEEMO
**Tools**

**EVA Systems**
- EVA tools and equipment
- Large equipment transport
- Small tool transport on suit
- Informatics
- Crew rescue
- EVA Support System & IV Workstation
- Science instruments and sample acquisition tools

**Instrumentation**
- Sample identification / high-grading
- ISRU verification

**Sample Collection/Curation**
- Collection
- Contamination Mitigation
- Preservation/Storage

**Techniques**

**Exploration Operations**
- Procedure development/refinement
- Signal latency (time delay) & blockage
- Bandwidth limitations

**EVA Operations**
- EVA concepts of operations
- EVAs in undefined environments
- Advanced capabilities

**Science Operations**
- Flexecution methodology
- Decision making protocols
- Transverse planning

**Robotic Operations**
- Autonomous
- Crew controlled
- Human-Robotic interface & integration

**Technologies**

**Emerging Technologies**
- Virtual/Hybrid reality opportunities
- Relevant cutting-edge systems and capabilities for Exploration and EVA
- Rapid testing environment for development of emerging technologies

**Innovations Incubator**
- Relevant environments and operational constraints are a breeding ground for innovation

**Partnerships**
- Opportunities for external partners to demonstrate current capabilities
- Direct collaboration leading to proposal and other funding avenues
- Strengthens international partnerships

**Training**

**Cross-Disciplinary Training**
- Learning each others language, requirements, and drivers in EISD
- Ex. Geo-Science Field Training for managers and engineers

**Astronaut Crew Training**
- Additional expeditionary and leadership opportunities
- Enhances both operational and science training objectives

**Operational Training**
- Provides ops training prior to payload flights for payload PIs and teams
- Enables development of engineers and scientists not normally exposed to operations

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The document is an overview of various themes and concepts related to development and integration in the context of space exploration, including tools, techniques, technologies, and training initiatives. Each section highlights specific areas and activities that support these themes.
WHAT: INTEGRATED EVA OPERATIONS

Integrated EVA Science Operations

Aquarius Reef Base
Florida International University
CORAL RESTORATION FOUNDATION
Astromaterials Research & Exploration Science (ARES)
Mission Planning, Develop & Integration
EVA Strategic Planning & Architecture
Crew & Thermal Systems - Tools

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WHERE: NASA EXTREME ENVIRONMENT MISSION OPERATIONS (NEEMO)

- Premiere analog that allows for evaluations of EVA end-to-end concepts of operations with crew that are in-situ in a true extreme environment and provides for flight-like interactions between the crew and an MCC/Science Team, including over comm latencies
- NASA analog mission that sends groups of astronauts, engineers and scientists to live, work and explore in a challenging environment
- Series of 22 space exploration simulations conducted since 2001
WHERE: NEEMO FACILITIES

• Aquarius Reef Base, the world's only undersea research station
• Located 5.4 miles (9 kilometers) off Key Largo in the Florida Keys National Marine Sanctuary
• 62 feet (19 meters) below the surface next to a deep coral reef named Conch Reef
• Operated by Florida International University
HOW: NEEMO “SPACECRAFT” AND “SPACESUIT”

THE “SPACECRAFT”: AQUARIUS UNDERWATER HABITAT

THE “SPACESUIT”: KM 37SS HELMET W/ WETSUIT & HARNESS FOR SURFACE SUPPLIED DIVING SYSTEM (SSDS)

Dive helmet & system provide good analog to a spacesuit for concepts of operations evaluations

Both have different but comparable challenges for operations

37SS: Narrower FOV, Helmet movable
xEMU: Wider FOV, Helmet fixed

Wetsuit & harness: Flexible, but restrictive
xEMU: Pressurized, bulky
HOW: A DAY IN THE LIFE OF NEEMO EVA OPERATIONS

EVA prep and egress

Exploring the Reef and Locating Sites

Identifying Samples

Tagging & Documenting

Ingress

Sample Acquisition and Curation

Data Collection

Science Team Feedback
NEEMO 22 Mission Overview
Overview
• Successful 10 day mission living and working from Aquarius Reef Base
• Completed a combination of Exploration EVA and ISS related objectives
• Numerous participating organizations across NASA, JSC, ESA, JAXA, Research Institutions, Universities, and Industry Partners

Key Dates
• Engineering Week: May 8-16
• JSC Crew Training Week: May 22-25
• Test Readiness Review: May 30
• ARB Crew Training Week: June 12-16
• NEEMO 22 Mission: June 18-27

Crew Members
• Kjell Lindgren
• Trevor Graff
• Pedro Duque
• Dom D’Agostino
NEEMO 22 PARTNERS/COLLABORATORS

- **NASA**
  - **JSC**
    - **XM**: Mission management, mission director, integration
    - **XI**: Mission management, Science objectives, Science Team leadership, crewmember
    - **XX**: Mission management, EVA leadership, EVA objectives (ops concepts, tools development, informatics)
    - **EA (EC, ER)**: PI for multiple evaluation objectives, building EVA tools
    - **CB**: Crewmember
    - **SK**: PI for mission objectives
    - **PAO**: Public Affairs activities
  - **ARC**: Mission planners and timeline tool
  - **KSC**: Communications, data management, and logistics support

- **ESA**: Crewmember, research objectives
- **JAXA**: Ops Support

- **Academia**
  - **Johns Hopkins University**: Research objectives
  - **University of South Florida**: Research objectives
  - **Florida International University (FIU)**: Aquarius owner and operator, marine science support
  - **Georgia Institute of Technology**: EVA Cognitive Work Analysis graduate study
  - **University of North Carolina at Wilmington**: Science instrumentation
  - **University of Houston Clear Lake**: Research objectives

- **Institutions**
  - **Florida Institute for Human & Machine Cognition**: Research objectives, crewmember
  - **Coral Restoration Foundation**: Research and mission objectives

- **Industry**
  - **Honeybee**: Core drilling solution
  - **AllTraq**: Mission objectives
  - **Shark Marine**: Providing a navigation system
  - **Aexa Aerospace**: Providing HoloLens units and expertise
<table>
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<th>Category</th>
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<td>Ultrasound w/ Remote Guidance</td>
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<td>Inventory Management</td>
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<td>Life Supt system procedure</td>
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<td>Mobile Crew Planning Tool</td>
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<td>Integrated Science Team</td>
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<td>Small Tool Transport on EVA suit</td>
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<td>Large Tool/hardware transport</td>
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<td>Hyperbaric sleep effects</td>
<td>Autonomic Function</td>
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<td>Microbiome Study</td>
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<td>Dietary influence on psychology</td>
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<td>Reef mortality</td>
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<td><strong>Crew Preparation</strong></td>
<td>Expeditionary Training</td>
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<td><strong>Outreach Opportunities</strong></td>
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**MISSION PROGRAM RELEVANCY**
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### NEEMO 22 Mission Timeline (From 5/23/17)

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<th>MD 2</th>
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<th>MD 4</th>
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<th>MD 7</th>
<th>MD 8</th>
<th>MD 9</th>
<th>MD 10</th>
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### EVAs

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<th>EVA 1</th>
<th>EVA 2</th>
<th>EVA 3</th>
<th>EVA 4</th>
<th>EVA 5</th>
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<th>EVA 7</th>
<th>EVA 8</th>
<th>EVA 9</th>
<th>EVA 10</th>
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</table>

### Activities

- **Team Mission Safety Brief**: Aquarius, Wet Deck
- **Team Photo**: ARL Dock Side
- **Crew Transport**: George F. Bond
- **SPLASHDOWN**: Deploy USLS Transponder
- **Gear Check**: Aquarius
- **Safety Brief**: Aquarius
- **Mingal**: Aquarius
- **Gear Unpack**: Aquarius / Wet Deck
- **EVA Prep**: Aquarius / Wet Deck
- **Post-Ingress**: Aquarius / Wet Deck

### Locations

- **Aquarius**
- **Wet Deck**
- **Topside**
- **Nursery**
- **Science Driving**

### Schedule

- **Los**: (~30 min)
- **Traversal**: Exploring EVA; Reef Science Sampling Zone
- **Display USLS Transponder**: Deploy USLS Transponder
- **Retrieval USLS Transponder**: Retrieval USLS Transponder
- **Cleanup/IMC Tests/Ingress**: Cleanup/IMC Tests/Ingress
- **Storage Depth**: EVA Post-Ingress Aquarius / Wet Deck

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NEEMO 22 Integrated EVA
The primary goal for EVA was to inform the *Exploration EVA System Concept of Operations* document by exploring the combination of *Operations* and *Engineering* with *Science* for Exploration destinations in a mission-like environment.

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<th>EVA Objectives</th>
<th>SMT EVA Knowledge/Capability Gaps</th>
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<td>Integrated Geoscience Sampling System <em>Core sample acquisition (Honeybee Robotics)</em></td>
<td>Tools for Science Sampling on a Surface EVA</td>
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<tr>
<td>Large tool/hardware transport &amp; stowage <em>EVA Modular Equipment Transportation System</em></td>
<td>Subsurface samples (core)</td>
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<tr>
<td>Small tool transport on EVA suit</td>
<td>Tool Carrier Device</td>
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<tr>
<td>EVA/Science task tracking <em>Marvin &amp; Playbook</em></td>
<td>Tool Attachment/Harness for Surface EVA</td>
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<td>EVA Navigation <em>Shark Marine</em></td>
<td>EVA Suit Heads-Up Display</td>
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<td>EVA Augmented Vision Heads-Up Display <em>Navy Diver Augmented Vision Display demo</em></td>
<td>EVA Graphical Display</td>
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<td>EVA/Science Sampling on a Surface EVA</td>
<td>EVA Short Range Navigation</td>
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<td>Integrated EVA Operations with Science Tasks</td>
<td>Mixed / Augmented Reality Capability</td>
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<td>Integrating Informatics</td>
<td>EVA Suit Heads-Up Display</td>
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<td>IV support System &amp; Workstation</td>
<td>EVA Flight Control Methodology</td>
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<td>Flexexecution</td>
<td>Tools for Interacting with EVA Over a Comm Latency</td>
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<td>Traverse Planning</td>
<td>Flexible Execution Methodology for EVA Science Operations in Undefined Environments</td>
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<td><strong>Primary EVA Objectives</strong></td>
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<td>EVA Tools</td>
<td>Informatics</td>
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<td>Concepts of Operations</td>
<td>Robotic-EVA Ops</td>
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<tr>
<td>Secondary Objectives</td>
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</tbody>
</table>

**EVA Tools**
- Integrated Geoscience Sampling System
- Large tool/hardware transport & stowage
- Small tool transport on EVA suit

**Informatics**
- IV Support System & Workstation
- EVA/Science task tracking
- EVA Digital Cue Cards
- EVA Navigation
- EVA Augmented Vision Heads-Up Display

**Concepts of Operations**
- Integrated EVA Operations with Science Tasks
- Integrating Informatics
- IV support System & Workstation
- Flexexecution
- Traverse Planning

**Robotic-EVA Ops**
- Situational Awareness for IVA & MCC
- Robotic Payload Transport for EVA

**SMT EVA Knowledge/Capability Gaps**
- Tools for Science Sampling on a Surface EVA
- Subsurface samples (core)
- Tool Carrier Device
- Tool Attachment/Harness for Surface EVA
- EVA Suit Heads-Up Display
- EVA Graphical Display
- EVA Short Range Navigation
- Mixed / Augmented Reality Capability
- EVA Flight Control Methodology
- Tools for Interacting with EVA Over a Comm Latency
- Flexible Execution Methodology for EVA Science Operations in Undefined Environments
- EVA-Robotic (Man-Machine) Work System
SCIENCE

NEEMO 22 EVA SCIENCE OVERVIEW

NURSERY CONSTRUCTION & SCIENCE
- Modified and conducted continued science investigation on two long-term coral nurseries near ARB
  - 50’ nursery
  - 90’ nursery (deepest in the world)

REEF FOLLOW-UP SCIENCE
- Continued research and sampling conducted during NEEMO 20 and 21
- Crew successfully navigated to, located, documented and re-sampled colonies
- Science team developed the overall sampling strategy and traverse plans

REEF EXPLORATION SCIENCE
- Explored and expanded into new sites; coral science was correlated to nurseries as a natural baseline
- Described, documented, and sampled additional samples for long term research
Nonprofit conservation organization dedicated to creating offshore nurseries & restoration programs for threatened coral species.

Their mission is to develop effective coral nursery and restoration techniques and to train & empower others to do the same in their area.
Laboratory of Integrative Marine Genomics and Symbiosis (IMaGeS)
Focuses on the study of the symbiotic interactions between microbial organisms and cnidarian hosts, in particular reef-building corals, from different perspectives, including cell biology, eco-physiology & ecology.

Multiyear Science Investigation

Endangered Coral Species

Genetically characterize the coral symbiotic community
Provide time & depth components
Provide a natural baseline for coral restoration efforts
Ultimately inform ongoing coral restoration efforts & understanding of the changing reef environment

Growing Partnerships and Advanced Instrumentation

Peer Reviewed Results
Astromaterials Research & Exploration Science (ARES)

- NEEMO EVA science activities included deployment of handheld instrumentation, context descriptions, imaging, and sampling
- The marine science activities and associated research objectives serve as an appropriate proxy for planetary surface exploration activities
- Integration, coordination, and education from diverse disciplines and organizations

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
- Traverse Planning
- Operational Flexibility
- Human-Robot Ops
- Crew Science Training
INTEGRATED EVA & SCIENCE OPERATIONS

- Evaluated Exploration EVA operations that predominately include science tasks
- Examined con ops that enable interaction between the MCC & the crew over a long comm latency and blockage including:
  - Interaction with an integrated Science Team
  - Authentic scientific objectives and hypothesis
  - Flexecution methodology

EVA/IV SUPPORT SYSTEM & PLANNING FOR EVA

- Evaluated a Support System that utilizes an open-source digital timeline execution and life support system management tool designed to support Intravehicular Activity during EVA
- Examined ways to minimize number of computers and monitors required for operations, hence reducing space and launch mass needed
- Looked at using a projector for crew planning and briefing

EVA DIGITAL CUE CARDS

- Evaluated digital cue cards for EVA crew that allowed crew to operate more effectively and offload IV tasks
- Additional crew autonomy requires further access to information in their hands
- Tested concept for a potential “one-device” for cue cards/procedures, images/video, instrument control, etc.

UTILIZATION OF SCIENTIFIC INSTRUMENTS

- Assessed the effects of incorporating scientific instruments into EVA ops

NAVIGATION & TRAVERSE PLANNING

- Evaluated procedures for navigating both to previously-sampled regions and new exploration zones

WITH LUNAR AND MARS COMMUNICATION LATENCY & BLOCKAGE CON OPS
INTEGRATED EVA OPERATIONS WITH SCIENCE-DRIVEN TASKS

Objective

• Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a signal (comm & data) latency and blockage
• Determine what functions/capabilities and techniques are needed to enable the EVA crew to effectively operate more autonomously and communicate information to MCC over a signal latency and blockage
• Evaluate flexible execution methodology and decision making protocols for science tasks during EVA operations

Implementation

• An onshore MCC Flight Control Team (FCT) that includes a Mission Director, EVA Officer, CAPCOM, and other system/subject matter experts
• An onshore Science Team that includes a Science Lead, subject matter experts, and Science Communicator (SCICOM)
• Mission (flight) rules volume and mission priorities, heightened mission tempo and pressure with additional flight control rigor, spacesuit telemetry, FCT GO/NO GO calls, and IVA task/experiment timeline

Key Take-Aways

• EVA crew demonstrated the capability to operate more autonomously while simultaneously communicating with and incorporating input from an Earth-based MCC and ST
• With science instruments that take time to acquire data, it is possible to plan the EVA such that the crew can successfully receive input from the ST to execute science sampling operations during an EVA over a signal latency
• An EVA support system for an IV crewmember that is directing real-time ops will be critical for management of the large volume of data
• Additional complexity of airlock and spacesuit EVA operations will impact the way operations and science tasks will be planned and directed
• A flight control operations paradigm and decision making protocols will need to be developed in order to integrate science tasks and subject matter experts within the context of an EVA while executing in dynamically changing situations in a natural environment – including how decisions are made between a Mission Director, EVA Officer, and SCICOM/Science Lead
Objective

• Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the large amount of information and tasking that must contended with while actively directing an EVA

• Assess hardware needs for a workstation, including ways to minimize what’s required for operations to reduce space and launch mass

• Look at potential ways to incorporate augmented reality into workstation

Implementation

• Utilized Marvin timeline execution and life support system management tool

• Utilized Playbook Tactical EVA Execution Feature

Key Take-Aways

• An EVA support system for an IV to direct EVA operations will be key for Exploration missions

• A system that utilizes a single computer with multiple ways to display abundant information would enable to single IV crewmember to direct EV ops while incorporating input from an MCC science team

• Augmented Reality systems (such as HoloLens) may hold some promise as a possibility, though were not as useful at this maturity level

• Recommend continued evolution of the system to drive out more detailed capability needs

Evolution of EVA Support System for IV Operator

- NEEMO 20
- NEEMO 21
- NEEMO 22
Objective

• Evaluate digital cue cards for EVA crew that allowed crew to operate more effectively and autonomously while offloading IV tasking
• Assess tool needs (hardware and software) for short distance navigation data to support EVA geology/science

Implementation

• Utilized an iPad in an iDive underwater housing to demonstrate the potential for a single device for cue cards/procedures, images/video, instrument control, etc.
• All EVA-accessed and required information was put into a digital cue card set that was loaded on the iPad

Key Take-Aways

• EVA digital cue cards permit increasing crew autonomy by enabling EV crew to efficiently understand exploration areas, conduct general site navigation, identify specimens for potential sampling, and guide themselves through task procedures
• Information layout will need to be modified for different display methods, such as a heads-up display or electronic cuff
• Recommend continuing to look at digital cue card capability, and refining the types of information included in the data set
Objective

• Evaluate EVA navigation and IV/MCC crew tracking

Implementation

• Utilized the Shark Marine Dive Tablet (Navigator) and Dive Log system for relative navigation

Key Take-Aways

• Capability for EVA crew to navigate to a site of interest will be critical
• EVA crew will need a way to mark potential sample sites in order to return to them for sampling
• The aquanauts were not able to use the Navigator/Dive Tablet to reliably navigate, and ended up depending on digital maps
• Digital maps worked well for the relatively small test area
• For future missions, recommend changing from the current relative navigation system and exploring the use of an area scanning system (such as a sector sonar as a proxy to radar/LiDAR), and increasing the fidelity of the maps

Objective

• Evaluate utilization of a robotic equipment carrier during EVA ops

Implementation

• Utilized a Shark Marine ROV with a purpose-built trailer system
• ROV included a video camera for remote use by the IV and MCC

Key Take-Aways

• The ROV was not able to be integrated into the mission due to technical and weather (sea state) issues
• Due to challenges with underwater wheeled and steerable ROV systems that are tethered, focus robotic work system evaluations at terrestrial analogs
**Core Sample Acquisition**
- Evaluated EVA tools and hardware for science core sample acquisition.
- Leveraged breakaway core bit technology developed by Honeybee Robotics and implemented on Mars rovers to develop a drill bit for an EVA tool.

**EVA Equipment Transportation**
- Tested the Modular Equipment Transport System (METS), a concept for manually transporting & stowing larger tools and samples on exploration traverses.
- Evaluated potential concepts for transporting small tools on an EVA suite from a rover/caddy to a worksite.

**Lunar Evacuation System Assembly (LESA)**
- Evaluated a new crew rescue concept developed by ESA at the European Astronaut Centre.
- This technique is aimed to ease the lifting-up and securing of an incapacitated EVA crewmember on a Moon EVA Litter.

**EVA Augmented Vision**
- Based on Navy’s Divers Augmented Vision Display, which incorporates real-time data input and allows for augmented reality input in a heads-up display.
- EVA Office and astronauts evaluated lab version topside for potential incorporation on future missions and spacesuit design.
EVA CORE SAMPLE ACQUISITION SYSTEM

Objective
• Evaluate EVA hardware and operations for subsurface (core) science sampling in a surface/partial-g environment

Implementation
• Applied a breakaway core bit technology developed by Honeybee Robotics with an underwater battery powered drill to acquire core samples
• Used small tools, such as forceps, to stow samples for curation

Key Take-Aways
• Breakaway bit with powered tool worked well for taking core samples
• Concept of stowing directly into curation return tubes worked well
• Small tools, such as forceps, were useful for removing cores or picking up small pieces
• Need to consider the limited down-force that crew is able to put into a sampling operation due to lower gravity levels
• Recommend continuing partnership with Honeybee and testing bits in other environments

Core Sample Acquisition Tool Evolution
Objective

• Evaluate transport of large equipment in a mobile carrier
• Evaluate transport of small tools on an EVA spacesuit

Implementation

• The Modular Equipment Transport System (METS) is a method for transporting equipment from one location to another, grouping hardware into Modules for the appropriate planned activities
• For small tools transport on the spacesuit, crew utilized a forearm stowage device and thigh module strapped on after egress

Key Take-Aways

• METS concept of putting tools into modules has the potential to provide efficiencies during EVAs
  • A wheeled carrier works well, however future concepts may consider larger wheels or ways to get over/around obstacles
  • Requires close integration for planning to ensure all pieces of equipment are accounted for when populating/arranging the modules, including what’s needed for contingencies
• Small, lightweight, generic tools could be carried on the forearm, torso, and other locations to provide easy access and should be considered for partial-g surface operations
  • Small tools carried on the suit forearm work well and enabled crew easy visibility and access to the tools
  • Carrying tools on the thigh (or other areas not easily visible) was challenging due to lack of visibility
INCAPACITATED EVA CREW RESCUE – LUNAR EVACUATION SYSTEM ASSEMBLY (LESA)

**Objective**

- Evaluated a new EVA incapacitated crewmember rescue concept developed by ESA at the European Astronaut Centre.

**Implementation**

- Utilized the new concept Lunar Evacuation Systems Assembly (LESA).
- LESA allows an incapacitated crewmember to be lifted up and secured to a Moon EVA Litter for transport back to a habitat/rover.

**Key Take-Aways**

- Concept of hoisting an incapacitated EVA crewmember onto a litter for transport back to a habitat holds promise.
- Need to look into making LESA a smaller and more portable package.
- Future suit designs will need to take into account attach points for any rescue and hoist device.
Objective
• Evaluate the Navy’s Divers Augmented Vision Display (DAVD), which incorporates real-time data input and allows for augmented reality input in a heads-up display, for use in an EVA spacesuit

Implementation
• EVA Office and astronauts evaluated lab version topside for potential incorporation on future missions and spacesuit design

Key Take-Aways
• DAVD provides a capability to Navy divers that would be advantageous to EVA astronauts
• There is a promising collaboration between the Navy and NASA to develop an augmented heads-up display capability for an EVA spacesuit

Post-NEEMO Follow-on Testing Quick-brief
• Manned tests at the Naval Support Activity Panama City (NSA PC) Dive School and Navy Experimental Diving Unit (NEDU)
• Navy divers were able to utilize DAVD for navigation, identification of objects, and for receiving task instructions real-time
• All of the activities tested translate into operations concepts for EVA on Exploration missions
• Identified a use of the full face mask version of the DAVD for significantly enhanced ISS EVA training in the NBL
EVA GAP CLOSURE UPDATES AND RECOMMENDATIONS FROM NEEMO 22

EVA CAPABILITY GAP

- Tools for Science Sampling on a Surface EVA — subsurface samples (core)
- Tool Carrier Device on a Surface EVA
- Tool Attachment/Harness for Surface EVA
- IV Support System for EVA Operations
- EVA Graphical Display
- Mixed / Augmented Reality Capability
- EVA Suit Heads-Up Display

GAP CLOSURE UPDATES

- Update with break-away core bit and the operations concepts for acquiring core samples
- Update with lessons learned from the METS, utilizing a modular system, wheel size, and ability to get equipment near the worksite
- Update with application of forearm modules to carry small tools
- Update with visibility challenges of thigh modules
- Update with results from utilizing a single computer driving multiple types of displays configurable for various operations
- Update with concept of merging a map and high-level timeline overview into a single reference page with links to task details
- Formalize a gap to include mixed/augmented reality capability, which goes beyond standard informatics displays
- Formalize a technology gap to include an EVA suit heads-up display (needed for augmented reality)

RECOMMENDATIONS

- Continue collaboration with Honeybee Robotics and development of core bit
- Evolve the system to include curation
- Evolve the modular system concept
- Evaluate alternate concepts for traversing over rough terrain
- Evolve the forearm module concept and test at future NEEMO missions
- Develop a more visible and simple thigh module
- Iterate configuration and applications to enable more efficient operations, and evaluate at a future NEEMO mission and SHyRE
- Focus on the one-stop page concept and evaluate at a future NEEMO mission
- Collaborate with DAVD development and test at future NEEMO missions
- Incorporate capability into SHyRE testing
- Collaborate with DAVD development and test at future NEEMO missions
- Incorporate capability into SHyRE testing
EVA GAP CLOSURE UPDATES AND RECOMMENDATIONS FROM NEEMO 22

EVA CAPABILITY GAP

Integrated EVA Flight Control Methodology

Tools for Interacting with EVA Over a Comm Latency

Flexible Execution Methodology for EVA Science Operations in Undefined Environments

EVA Navigation

EVA-Robotic Work System

GAP CLOSURE UPDATES

Update with demonstrated methods for integrating MCC and the Science Team

Update with lessons learned from utilizing a Playbook-type system

Update the gap to include signal blockage

Update with decision making protocols and how decisions are made between a Mission Director, EVA Officer, and SCICOM/Science Lead

Gap closure unchanged

Gap closure unchanged

RECOMMENDATIONS

Increase mission tempo/pressure and flight control rigor, add spacesuit telemetry, and evaluate at future NEEMO missions

Factor in increased signal blockage and test at future analogs

Apply more rigor to integrated decisions, add spacesuit telemetry/consumables, and evaluate at future analogs

Explore utilizing an area scanning system such as a sector sonar (proxy to radar/LiDAR) and evaluate at future NEEMO missions

Focus robotic work system evaluations at terrestrial analogs
NEEMO 22 IVA
INTRA-VEHICULAR ACTIVITIES: OVERVIEW

Playbook – Planning, Procedure Viewing, and Comm Tool

AR Assisted Procedures

VETTS

DNA Sequencer

IHMC & USF Studies:

- Sleep
- Metabolomics
- Body Composition
- Psych

EVA EXP - 0054

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Purpose: Evaluate whether a real-time instruction and correctional feedback for crew members in the absence of real-time Astronaut Strength, Conditioning and Rehabilitation Specialist (ASCRS) support during exercise can prevent avoidable injuries, and optimize overall muscle strength outcomes.

Implementation: An instructional system was developed using a Microsoft Kinect depth-camera device, which provides marker-less 3-D whole-body motion (VETTS).
**Purpose:** The NEEMO 22 mission Playbook continued to serve dual goals of supporting the operations of the NEEMO 22 mission and conducting applied research to improve crew autonomy.

**Implementation:** Playbook used for mission planning, procedure storage/retrieval, and text based communication between mission control and crew. Numerous new features were added this year: acknowledgements in the mission log, ordering the mission log by receive time rather than sent time, new feature for representing groups, tactical EVA execution tool, and crew/timeline notes. Two strategies for crew-self planning were tested (Plan Fragments and Functional Activity Groups).
Purpose: Evaluate augmented reality assisted procedures on the HoloLens to provide advanced guidance and assistance with tasks that emulate those performed on the ISS and on future deep space missions. These tools are designed to reduce reliance on remote support and provide greater crew autonomy.

Implementation: Using HoloPD (Holographic Procedure Display) the crew performed medical (ultrasound imaging) and habitat maintenance tasks.
Purpose: Test an increasingly automated, simplified, and quicker method for implementing a swab-to-sample process. Additionally, demonstrate how the process can be used to systematically characterize the microbiome of a habitat, thereby establishing an application of the technology.

Implementation: Conduct swab-to-sample runs by each crewmember, soliciting their feedback for improvements applicable to spaceflight. Obtain additional samples related to understanding the microbiome of the habitat.
BACKUP
NEEMO provides an operational mission to Integrate Exploration and Science objectives across EISD

- Enabled by the unique skill blend found in EISD
- High “bang for the buck”
- Science component of missions now fully integrated (driven by authentic science)
- Well suited to meet a number of EVA exploration needs
- Plays a role in enabling and maturing ISS Objectives
- Enables lasting cross-pollination
  - Across EISD
  - Across Engineering/Ops/Science/Crew Office
- Visible and tangible way to highlight the work in EISD (e.g. national media, social media, events like SpaceCom)
Leveraging experience and lessons learned from...

Apollo Surface Operations
- 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
- Remote science operations
- Instrumentation / sample selection
- Utilizes terrain appropriate for geo-science tasks; Suit and robotic tested-bed

NASA Extreme Environment Mission Operations
- Utilizes unique facility & environment; rapid prototyping; Evaluations of both IVA and EVA objectives

Research and Technology Studies
- Each exploring various aspects of exploration
- Funded through grant programs
- Science focused

Other NASA Analog Programs
- Funded through grant programs
- Science focused

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WHO: THE UNIQUE CAPABILITY, EXPERIENCE, AND SKILL SETS OF EISD

**Unique blend of capability and skill sets within ...**

- **XM - MISSION PLANNING, DEVELOPMENT & INTEGRATION**
- **XI - ASTROMATERIALS RESEARCH & EXPLORATION SCIENCE**
- **XX - EXTRAVEHICULAR ACTIVITY**
- **XT – EXPLORATION TECHNOLOGY**

**Leverage extensive knowledge and experience from ...**

- **HISTORICAL MISSIONS**
  - Apollo Surface Operations
- **HUMAN SPACE FLIGHT**
  - ISS, Shuttle
- **ROBOTIC MISSIONS**
  - Mars Missions, OSIRIS-REx
- **“ANALOG” MISSIONS**
  - D-RATS, NEEMO & others

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WHERE: ENVIRONMENTS FOR TESTS

AQUATIC

Neutral Buoyancy Laboratory (NBL)

Aquarius Reef Base (NEEMO)

ESA's Neutral Buoyancy Facility

TERRESTRIAL

Geo-Science Field Exercises & Sites

Field Training Areas

Extreme Environments (ex. Antarctica)

LABORATORY

Active Response Gravity Offload System (ARGOS)

Virtual Reality & Hybrid Reality Laboratories

International Space Station
There are many different types of operational field test activities. EVA is looking for the following qualities when determining which rise to the level of fidelity and return to warrant involvement:

- Responsive to EVA Office input on mission and objective design (i.e., objectives mapped to specific needs and capability, knowledge, and technology gaps)
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Participation of experienced operators (crew and MCC)
- Participation of acknowledged stakeholders with expertise to evaluate concepts being worked on across the agency (e.g., science community (XI))
- MCC and Science Team components
- Incorporation of signal latency (time delay) and blockage
- Incorporation of partial gravity
- Availability of large area of un-engineered natural (planetary) surface
- Proxy science with high correlation to planetary science
- Participation of scientists invested in the proxy science outcome
- Inclusion of appropriate purpose-built prototype hardware for evaluation and maturation
- Full “mission” environment to drive out things that wouldn’t be found in standalone testing
- Potential to benefit ISS as well as Exploration
- Enhances relationships with international partners, academia, industry, other government agencies, and other NASA orgs
- Highlights work in Exploration in a visible and tangible way (e.g. national media, social media, events like SpaceCom)
- Intersection of the 4Ts
The Modular Equipment Transport System (METS) is a method for transporting equipment from one location to another, using an understanding of the planned EVA tasks to group hardware into Modules.

Depending on the planned activities for an EVA the crew would load only those Modules necessary to complete those activities.
SMALL TOOLS MODULES FOR EVA SUIT

**Wrist Tool Set**
- 1 per crew member
- Clean sets available (can be changed out, maybe not required for NEEMO)

**Leg Tool Set**
- 1 per crew member
- Diagonal Cutters
- Hammer
- Nails
- HOBO
- Cable Ties
- Chisel
- Permanent Tags
- Tongs
- NEEMO 21 304

**Instrumented Cuff**
- Depth Gauge

Small Tool Module

Small Tool Module
EISD – OUR PEOPLE MAKE IT HAPPEN!
Astronaut-Aquanauts

1. Carpenter
   (SEALAB II, 8/29/65)
2. Gerhardt
   (NEEMO 18&8, 10/22/01)
3. Lopez-Algrie
   (NEEMO 1)
4. D. Williams
   (NEEMO 18&9, 10/22/01)
5. Tani
   (NEEMO 2, 5/14/02)
6. J. Williams
   (NEEMO 3, 7/16/02)
7. S. Kelly
   (NEEMO 48&8, 9/24/02)
8. Walheim
   (NEEMO 4, 9/24/02)
9. Whitson
   (NEEMO 5, 6/17/03)
10. Fincke
    (NEEMO 2, 4/18/04)
11. Herrington
    (NEEMO 6, 7/13/04)
12. Thirsk
    (NEEMO 7, 10/12/04)
13. Coleman
    (NEEMO 7, 10/12/04)
14. Wakata
    (NEEMO 10, 7/23/06)
15. Magnus
    (NEEMO 11, 9/17/06)
16. Patrick
    (NEEMO 5&13, 12/9/06)
17. S. Williams
    (NEEMO 2, 12/9/06)
18. Steffyanish-Piper
    (NEEMO 12, 5/8/07)
19. Anderson
    (NEEMO 5, 6/8/07)
20. Olivas
    (NEEMO 3&8, 6/8/07)
21. Wheelock
    (NEEMO 6, 10/23/07)
22. Behnken
    (NEEMO 11, 3/11/08)
23. Reisman
    (NEEMO 5, 3/11/08)
24. Chamitoff
    (NEEMO 3, 5/31/08)
25. Garan
    (NEEMO 9, 5/31/08)
26. Nyberg
    (NEEMO 10, 5/31/08)
27. Arnold
    (NEEMO 13, 3/15/09)
28. Barratt
    (NEEMO 7, 3/26/09)
29. Feustel
    (NEEMO 10, 5/11/09)
30. Kopra
    (NEEMO 11, 7/15/09)
31. Hernandez
    (NEEMO 12, 8/28/09)
32. Stott
    (NEEMO 9, 8/28/09)
33. Creamer
    (NEEMO 11, 12/20/09)
34. Hadfield
    (NEEMO 14, 5/10/10)
35. Marshburn
    (NEEMO, 5/10/10)
36. Furukawa
    (NEEMO 13, 6/7/11)
37. Walker
    (NEEMO 15, 10/21/11)
38. Metcalf-Lindenburger
    (NEEMO 16, 6/12/12)
39. Acaba
    (NEEMO 17, 9/10/13)
40. Noguchi
    (NEEMO 17, 9/10/13)
41. Hoshide
    (NEEMO 18, 7/22/14)
42. Bresnik
    (NEEMO 19, 9/8/14)
43. Parmitano
    (NEEMO 20, 7/21/15)
44. Yui
    (NEEMO 16, 7/22/15)
45. Mogensen
    (NEEMO 17&19, 9/2/15)
46. Peake
    (NEEMO 16, 12/15/15)
47. Onishi
    (NEEMO 15, 7/7/16)
48. Rubins
    (NEEMO 17, 7/7/16)
49. M. Behnken
    (NEEMO 21, 7/22/16)
50. Wiseman
    (NEEMO 21, 7/22/16)
51. Pesquet
    (NEEMO 18, 11/7/16)
52. Lindgren
    (NEEMO 22, 6/19/17)
53. Duque
    (NEEMO 22, 6/19/17)
54. Vande Hei
    (NEEMO 18, 9/12/17)

Engineer-Scientist Aquanauts

1. W. Todd
   (NEEMO 1, SEATEST I, III, IV; 10/01)
2. M. Reagan
   (NEEMO 2, SEATEST III, IV; 5/02)
3. J. Dory
   (NEEMO 3; 7/02)
4. P. Hill
   (NEEMO 4; 7/02)
5. J. Meir
   (NEEMO 4; 7/02)
6. E. Hwang
   (NEEMO 5; 6/03)
7. T. Rutledge
   (NEEMO 6; 7/04)
8. C. Mckinley
   (NEEMO 7; 10/04)
9. M. Shultz
   (NEEMO 8, 4/05)
10. T. Broderick
    (NEEMO 9&12; 4/06)
11. K. Kohanowich
    (NEEMO 10; 7/06)
12. J. Schmidt
    (NEEMO 12; 5/07)
13. C. Gerty
    (NEEMO 12; 6/04)
14. A. Abercromby
    (NEEMO 14; 6/10)
15. S. Chappell
    (NEEMO 14; 6/10)
16. S. Squires
    (NEEMO 15&16; 10/11)
17. H. Stevenin
    (NEEMO 15; 7/14)
18. D. Coan
    (NEEMO 20, SEATEST IV; 7/20/15)
19. M. O’groofa
    (NEEMO 21; 7/16)
20. D. Kernagis
    (NEEMO 22; 6/17)
21. D. D’Agostino
    (NEEMO 22; 6/17)
22. T. Graff
    (NEEMO 22; 6/18/17)
| NEEMO 1 | 6 Days, Oct. 21-27, 2001 | DT/B. Todd, CB/M. Lopez-Alegria, M. Gernhardt*, CSA/D. Williams* |
| NEEMO 2 | 9 Days, May 13-20, 2002 | CB/M. Fincke, D. Tani, S. Williams, DTM. Reagan |
| NEEMO 3 | 9 Days, July 15-21, 2002 | CB/J. Williams, D. Olivas*, G. Chamitoff, SLSD/J. Dory |
| NEEMO 4 | 5 Days, Sept. 23-27, 2002 | CB/S. Kelly*, R. Walheim, DAA/P. Hill, SLSD/J. Meir |
| NEEMO 5 | 14 Days, June 16-29, 2003 | CB/P. Whitson, C. Anderson, G. Reisman, SLSD/E. Hwang |
| NEEMO 6 | 10 Days, July 12-21, 2004 | CB/J. Herrington, D. Wheelock, N. Patrick*, EB/T. Rutley |
| NEEMO 7 | 11 Days, Oct. 11-21, 2004 | CSA/B. Thirsk, C. Coleman, M. Barratt, CMAS/C. McKinley, M.D. |
| NEEMO 9 | 18 days, April 3-20, 2006 | CSA/D. Williams*, CB/N. Stott, R. Garan, TATRC/T. Broderick*, M.D. |
| NEEMO 10 | 7 days, July 22-28, 2006 | JAXA/K. Wakata, CB/D. Feustel, K. Nyberg, NOAA/K. Kohanowich |
| NEEMO 11 | 7 days, Sep. 16-22, 2006 | CB/S. Magnus, T. Kopra, B. Behnken, T.J. Creamer |
| NEEMO 12 | 12 days, May 7-18, 2007 | CB/H. Piper, J. Hernandez, SD/J. Schmidt, TATRC/T. Broderick*, M.D. |
| NEEMO 13 | 10 days, Aug. 6-15, 2007 | CB/N. Patrick*, R. Arnold, JAXA/S. Furukawa, Cx/C. Gerty |
| NEEMO 14 | 12 days, May 10-23, 2010 | CSA/C. Hadfield, CB/T. Marshburn, EAMDA/A. Abercromby, S. Chappell |
| NEEMO 15 | 7 days, Oct. 20-26, 2011 | CB/S. Walker, JAXA/T. Onishi, CSA/D. Saint-Jacques, NAC/S. Squyres* |
| NEEMO 16 | 12 days, June 11-22, 2012 | CB/D. Metcalf-Lindenburger, JAXA/K. Yui, ESA/T. Peake, NAC/S. Squyres* |
| NEEMO 17 | 7 days, Sept. 9-13, 2013 | CB/U. Acaba, K. Rubins, JAXA/S. Noguchi, ESA/A. Mogensen* |
| NEEMO 18 | 9 days, July 21-29, 2014 | JAXA/A. Hoshide, CB/M. Vande Hei, Jeanette Epps, ESA/Thomas Pesquet |
| NEEMO 19 | 7 days, Sept. 7-13, 2014 | CB/R. Bresnik, ESA/A. Mogensen*, CSA/J. Hansen, ESA/H. Stevenin |
| NEEMO 20 | 14 days, Jul 20 – Aug 2, 2015 | ESA/L. Parmitano, CB/S. Aunon, JAXA/N. Kanai, XX/D. Coan |
| NEEMO 21 | 16 days (split), Jul 21-Aug 5, 2016 | CB/R. Wiseman, M. McArthur, ESA/M. Maurer, IHMC/D. Kernagis, NMT/Marc O Griofa, NPS/N. du Toit |