The Reality of Space: Exploring Virtual, Augmented, and Mixed Realities and the Future of Spaceflight

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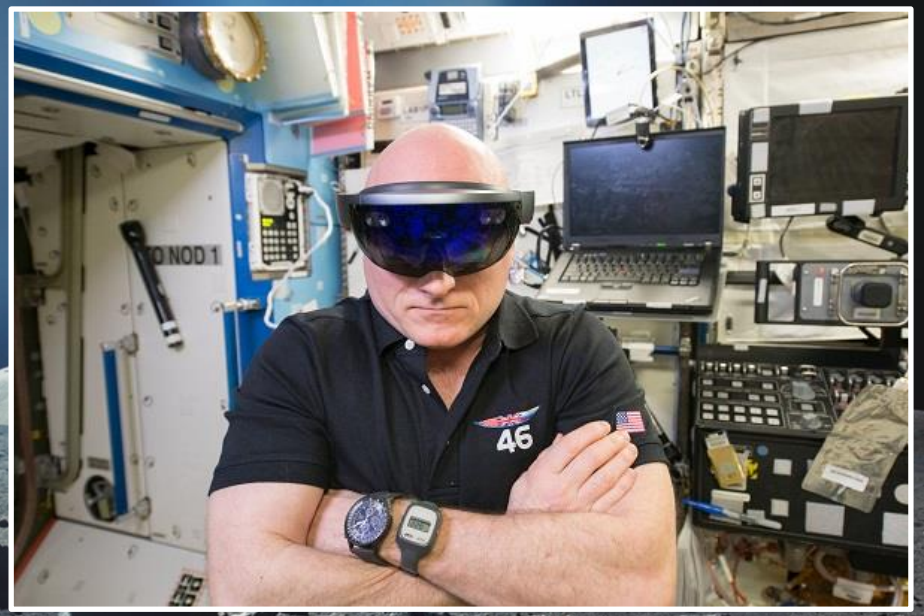
Background

Future successful long range human space travel beyond low earth orbit (LEO) will require a significant shift towards developing and implementing increasingly autonomous, crew-centered models of capabilities that will enable future astronauts to directly and independently manage in-flight conditions and health care needs.

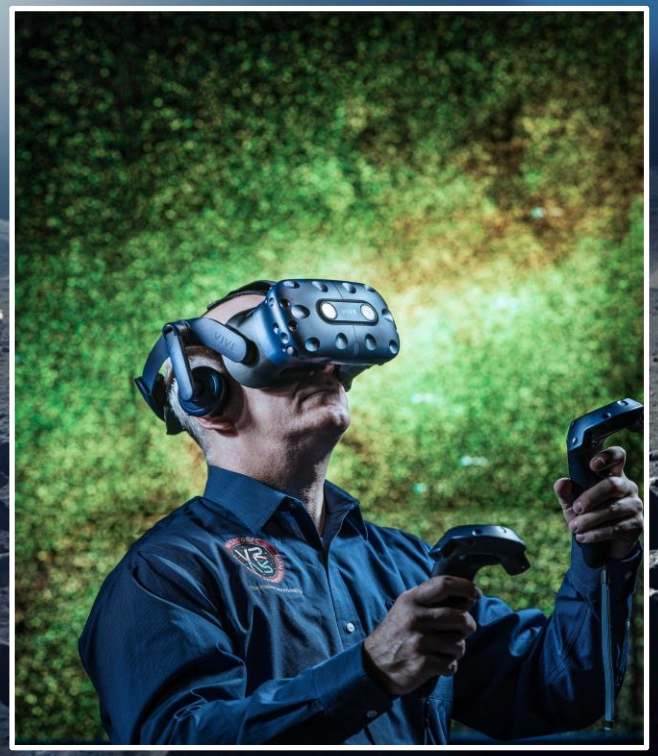
Advances in earth-independent capabilities will be exceedingly crucial in completing successful deep space missions where earth-based support capabilities and near real time communication are delayed or absent.



Courtesy: NASA

Background

- "Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are common terms used to describe technologies that "generate or modify" reality.[1] Extended Reality (ER or XR) is often used as an umbrella term for the aforementioned technologies.

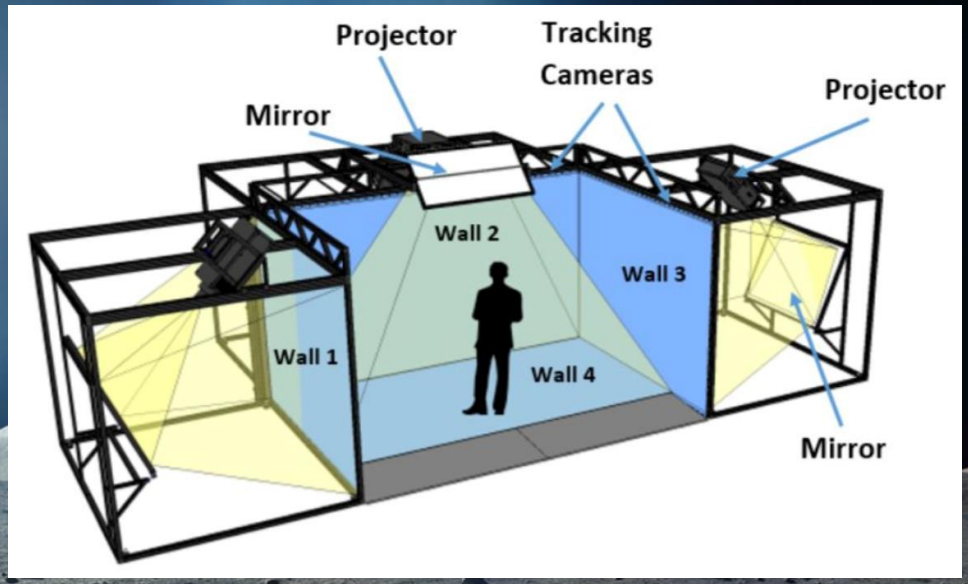


[1] (Rauschnabel et al).

Courtesy: NASA

Background

- Ames Research Center: Ames SimLabs
- Johnson Space Center: VR Lab, Vis Lab, NACOL
- Glenn Research Center: GVIS, GRUVE Lab
- Kennedy Space Center: AVR Lab
- Langley Research Center: AFRC, ACL
- Goddard Space Center: SVE Lab, SVS
- Jet Propulsion Laboratory: OpsLab



CAVE at GVIS

Methods

Literature review of NASA NTRS database and Space Station Research Explorer for VR/AR/XR applications and use case scenarios.

Discussion with subject matter experts across NASA and ESA.

Article review of use cases for future NASA applications of VR/AR/XR technologies.

Hardware

Head-mounted Displays (HMDs):

- Hololens 1 (MR) (ISS) & Hololens 2 (MR)
- HTC Vive Focus 3 (VR) (ISS) & HTC Vive Pro (VR)
- Oculus Rift (VR) (ISS)
- Magic Leap One (AR)
- Varjo (VR/XR)

Computer Automatic Virtual Environment (CAVE):

- VisCube M4

Companion Hardware:

- Microsoft Motion Controller
- Flystick2
- Microsoft Kinect
- Leap Motion Controller
- 360Fly Cameras
- OptiTrack Capture Systems
- Motionstar Ascension
- Electromagnetic Tracking System

Potential Hardware:

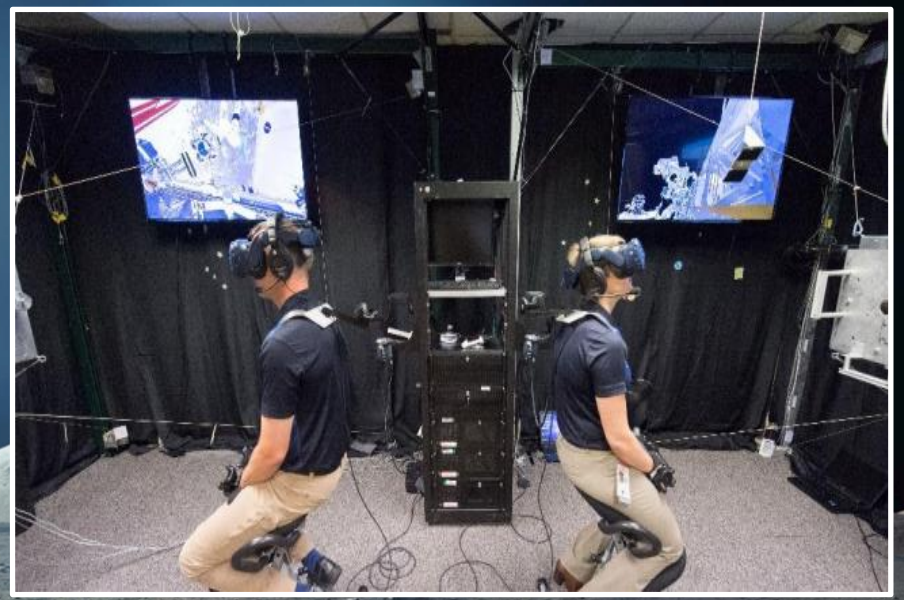
- Amalgamated Vision (Virtual Retinal Display)
- Magic Leap 2 (AR)
- Apple Vision Pro (AR)

General Training & Real-time Assistance

	Sponsoring Agency	Modality	Description
NASA Extreme Environment Mission Operations (NEEMO)	NASA	AR	The NEEMO 20 crew tested the "Sidekick" project using HoloLens technology for remote assistance in habitat maintenance and simulated medical scenarios, suggesting its potential to enhance guidance in spacesuit-equipped EVAs. ODG R6 Augmented Reality Headset was tested for maintenance in the Aquarius habitat, finding that its augmented reality features could potentially aid spacesuit-equipped EVA crews in performing unfamiliar or rarely practiced tasks.
Mass Handling VR-MR Training	NASA	VR/MR	The VR Lab's two Charlotte robots allow crew members to simulate handling large virtual payloads in micro-gravity, providing realistic training without the need for physical payloads, and preparing them for similar tasks on the ISS.
The Augmented Reality Application for Maintenance, Inventory and Stowage (ARAMIS)	NASA/ASI	AR	The ARAMIS investigation uses augmented reality to streamline space station operations, saving crew time for scientific research by consolidating maintenance and inventory tasks into a single portable device.
T2 Treadmill Augmented Reality Procedures	NASA	AR	The Autonomous Systems and Operations project uses augmented reality to streamline astronaut training and maintenance of the COLBERT Treadmill, crucial for missions with communication delays like those to Mars.
MedChecker	NASA	AR	MedChecker (Ax-1) uses AR and image recognition to identify medications on the ISS, enhancing crew self-sufficiency by enabling astronauts to administer drugs without medical guidance.
Dual EVA-1 and EVA-2 VR Training	NASA	VR	The VR Lab uses HTC Vive Pros and two immersive stations, EV1 and EV2, enabling dual astronaut training in a shared virtual space for efficient interaction and precise movement control.
Cold Atom Lab Upgrades	NASA	MR	In 2020, astronaut Megan McArthur used Hololens 1 to replace hardware in the Cold Atom Lab, enabling it to produce ultracold potassium atoms in addition to the rubidium atoms since its 2018 inception.
Virtual Environment Computational Training Resource (VECTR)	NASA	VR	VECTR is a flexible and scalable VR training platform at KSC that uses commercial hardware and game engine software to create customizable digital environments.

Mass Handling Robot

Navy’s Divers Augmented Vision Display (DAVD)



Dual EVA-1 and EVA-2 VR Training

Courtesy: NASA

“Just in time” Training (JIIT)

	Sponsoring Agency	Modality	Description
Project Sidekick	NASA	MR	Sidekick enhances communication and task management for ISS crew members by integrating high-definition holograms with physical environments, functioning as both a reference and teleconferencing tool.
Virtual Reality - On-Board Training (VR-OBT)	ESA	VR	The VR-OBT technology demonstration explores the effectiveness of using VR to provide specialized training content to ISS crews via a HMD, aiming to simplify and enhance training delivery during missions.
SAFER Onboard VR Training	NASA	VR	The first and only VR astronaut training system on the ISS, uses modified Oculus and DOUG technology to allow astronauts to customize and practice various flight scenarios in spacewalk training, refreshing their skills independently on-orbit.
Integrated EVA VR and ROBoT Training	NASA	VR	Performed in 2019, Integrated EVA VR and ROBoT Training was used in preparation for Alpha Magnetic Spectrometer Repair and Extravehicular Activities.
Autonomous Diagnostic Imagining	NASA	AR	Integrating AR technology into training by using a holographic display that projects 3D anatomical images over a subject, offers real-time feedback, and enhances astronauts' autonomy and situational awareness with hands-free tutorials during protocols.
XR and ARGOS CIF Lunar Lander Egress/Surface EVA Project	NASA	XR	Current integration and testing focus on a "short sleeve" XR egress system, using Vive pucks for full body tracking, and BeBop gloves for detailed hand and finger tracking.

SAFER Onboard VR Training

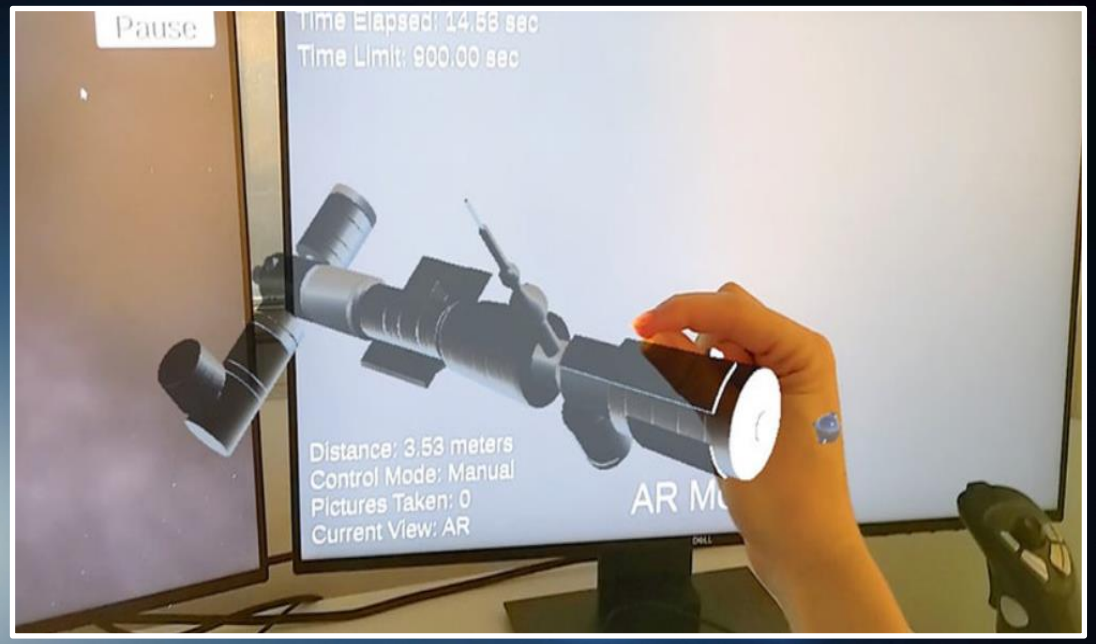
CIF Lunar Lander Egress/Surface EVA Project

Courtesy: NASA VR LAB

Human Health & Performance

	Sponsoring Agency	Modality	Description
Holoportation	NASA	MR	1st human holoportation (Holoportation-1) in space performed on ISS. Holoportation-2 simulated bidirectional PMC from ISS to Earth during AX-1 mission. Ground-based “Holographic Behavioral” teleportation system tech demo demonstrated using HoloLens2 and Aexa’s HoloWizard app.
Immersive Exercise	ESA	VR	The Immersive Exercise project develops a virtual reality environment interfaced with the ISS's existing Cycle Ergometer to enhance biking sessions.
VR For Exercise	ESA	VR	An updated study to the previous "Immersive exercise"
PERSPECTIVES	ESA	VR	To adapt to microgravity's disorienting effects and control body movements, astronauts use an adaptive virtual reality platform aboard the ISS, enabling the study of cognitive changes through controlled visual stimuli and reaction quantification.
Time Perception in Mircogravity	ESA	VR	The Time Perception in Microgravity experiment quantified how human time perception subjectively alters during and after prolonged exposure to microgravity using Oculus Rift VR already onboard the ISS.
GRASP	ESA	VR	ESA astronaut Thomas Pesquet pioneered the use of Perspectives VR gear on ISS to study how microgravity affects astronauts' perception and motor skills by reaching for virtual objects.
Neurocog	ESA	VR	This experiment investigates how gravity influences the reference frames used for 3D navigation and the perception of our body orientation and visual stimuli in a simple VR environment.
VECTION	CSA	VR	This study assessed how microgravity affects astronauts' visual perception of motion, orientation, and distance, and how these abilities adapt during spaceflight and change upon returning to Earth. All experiments were performed using a HMD to elicit a sense of self-motion or view objects
HERA Habitat	NASA	VR/AR	HERA use of VR aims to simulate EVA operations to evaluate crew performance, team dynamics, and decision-making in such scenarios.
APACHE	NASA	XR	Assessments of Physiology And Cognition in Hybrid-reality Environments” (APACHE) project is developing a mixed reality analog for planetary exploration EVA scenarios that combines virtual, physical, and hybrid realities to simulate realistic physical and cognitive workloads.
Space motion Sickness	NASA	VR	A study conducted by Lonner et al., (2023) suggested that providing motion-congruent visual cues using VR could effectively reduce moderate nausea and increase comfort after future space missions.
Sensorimotor Assessment	NASA	AR	Dr. Hannah Weiss Neuroscience Lab at JSC investigations involving AR (Hololens2) involves visual disturbance as a rehab and training tool, vestibular dominated distractions and sensorimotor comparison studies.
Pilote	ESA	VR	The Pilote investigation tests multisensory interfaces for controlling robotic arms and spacecraft in microgravity and explores novel control schemes using virtual reality and haptic-based user-machine interfaces.
VR Mental Care	ESA	VR	The VR Mental Care investigation demonstrates how virtual reality can be used for mental relaxation through immersive, high-quality video and sound scenarios delivered via a VR headset.

Holoportation team members are seen projected virtually on the International Space Station



Space station and inspector satellite hologram projections.

HERA Crew Member on Campaign 6

Courtesy: NASA

Discussion

Artemis, Gateway and the subsequent Mars missions present major physical, cognitive, logistical, and technical challenges for the future of spaceflight. NASA and its partners have already began addressing some of those obstacles.

- **Orion**: Ground Ops Project team at KSC used virtual reality visualizations to enhance spacecraft and ground systems design, improving operability and aiding in key engineering reviews.
- **Gateway**: VR testing allows astronauts to optimize Gateway's interior by simulating daily tasks and incorporating feedback for a safer and more comfortable space station.
- **Mars**: XOSS engine features full Martian days with authentic weather, and gravity set within 250 square miles of authentic Mars terrain.
- **Space exploration**: Goddard’s VR Team revolutionized the star classification process, leading to more accurate classifications and insights into our galaxy’s evolution.

Earth Independent Medical Operations

Autonomous Medical Officer Support (AMOS) highlights how software effectively guides untrained astronauts in medical testing without extended reality, suggesting that combining this technology with augmented reality could enable a virtual library of medical techniques and tests for crew members without relying on ground communication.

The Intelligent Medical Crew Assistant (IMCA) is a procedural tool, designed as an adaptive, voice-interactive interface providing astronauts with tools for health monitoring, medical care, and emergency response, integrating AR and AI technologies for optimized, autonomous long-duration spaceflight operations.

While still not fully validated in microgravity, VR/AR represents a possible avenue for surgical training and guidance for more autonomous medical support in emergent conditions.

Projects for Future Clerks

Comprehensive and serial XR software and technology reviews (e.g., NASA Engineering Network, trade studies, etc.)

Review NASA, partner (e.g., ESA) and industry capabilities (e.g., Medical, DoD, Commercial end users, etc.)

Courtesy: Buendea

Public Outreach and Education review

Artificial Intelligence integration in XR environments

Courtesy: Buendea

Conclusion & Acknowledgments

This review highlights the importance of communication and collaboration between NASA and its partners on the rapidly evolving area of extended reality and its broad applications across all sectors.

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