Virtual Reality-based Medical Simulation for Pre-Hospital Space Medicine Care: VALOR PHSMCC

Karthik V Sarma MD PhD, Michael Barrie MD, Col John R Dorsch DO, USAF (ret.), Nora Carr RN, Nilesh Patel MD, Michael Poppe MD, Talia L Weiss MS, Jennifer Polson PhD, Ryan J Ribeira MD MPH

SimX, Inc.

San Francisco, CA

{karthik.sarma, michael.barrie, john.dorsch, nora.carr, nilesh.patel, michael.poppe, talia.weiss, jennifer.polson, ryan.ribeira}@simxar.com

ABSTRACT

Human spaceflight support (HSFS) has been a Department of Defense (DOD) mission since the establishment of the National Aeronautics and Space Administration (NASA) in 1958. Medical support is a key component of this mission, including the provision of healthcare to astronauts and other space flight personnel during routine operations and mishaps. Providing high-quality care in these circumstances requires training for demanding, high-intensity, rare operations. However, full mission profile (FMP) training for the mission is highly expensive and complex, requiring medics and equipment to be dropped into the ocean for simulated capsule recovery. In this work, we developed an immersive virtual reality (IVR) medical simulation capability to broaden access to FMP-style simulation training across the full spectrum of special warfare medics who may be deployed for the HSFS mission. An interdisciplinary working group consisting of emergency physicians, space operational medicine experts, instructional designers, and IVR engineers was formed. The working group first determined a set of scenarios to implement in IVR. Then, a set of mission-specific platforms and environments with associated sets, kits, outfits, and equipment were specified. The specified materials were then implemented and iteratively refined using a previously developed IVR platform (VRMSS, SimX, San Francisco, CA). Ten scenarios ranging from normal operations to severe injuries and mishaps were specified, implemented, and refined within the IVR system. Virtual capsule replicas were developed in pad and ocean recovery environments. Aerial and naval platforms including the C-17, MH-60, Rigging Alternate Method Boat, and Advanced Rescue Craft were implemented. A complete equipment and outfit set was implemented, including 175 tools and equipment sets. A comprehensive IVR-based medical simulation capability for space operational medical support was developed for virtual FMP training. The resulting capability is currently being integrated into special warfare medicine training and may also have applicability to civilian commercial space flight programs.

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ABOUT THE AUTHORS

Karthik V. Sarma MD PhD is co-founder and Chief Technology Officer at SimX. He is a physician-scientist specializing in medical computing. He is the Principal Investigator of the DOD-funded Virtual Advancement of Learning for Operational Readiness (VALOR) program.

Michael G. Barrie MD is Medical Director for Special Projects at SimX. He is a board-certified emergency physician and grant-supported simulation investigator. He is the principal clinical instructional designer for the VALOR program.

Col John R. Dorsch DO, USAF (ret.) is Senior Military Advisor at SimX. He is a former USAF Colonel, Chief Flight Surgeon, and is a board-certified emergency physician. He is the principal military operational medicine subject matter expert for the VALOR program.

Nora Carr RN BSN is Lead Design Producer at SimX. She has a background in intensive care nursing and human-centered design and oversees creation and implementation of design standards for the VALOR program.

Nilesh Patel MD is a member of the VALOR Medical Oversight Board at SimX. He is a board-certified emergency physician, and also participates in clinical instructional design for virtual reality scenarios.

Michael Poppe MD is a member of the VALOR Medical Oversight Board at SimX. He is a board-certified emergency physician, and also has experience in military operational medicine, including prior deployments.

Talia L Weiss MS is Director of Product Operations at SimX, where she directs SimX's scenario and training production program. Talia has experience in medical visualization, digital media, and healthcare management, and previously served as the manager of the Stanford Virtual Human Interaction Lab.

Jennifer Polson PhD is Manager, Research Strategy at SimX. She has a background in medical computing and leads execution of research and development projects within the VALOR program.

Ryan J. Ribeira MD MPH is the founder and Chief Executive Officer of SimX, Inc. He is a board-certified emergency physician, Medical Director of the Stanford University Adult Emergency Department, and a member of the Board of Directors of the Society for Simulation in Healthcare.

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BACKGROUND AND PROBLEM

The Prehospital Space Medicine Mission

A variety of governmental and civilian entities around the world have the mission to provide medical support for human space flight operations (also known as Human Space Flight Support/HSFS). In the United States, the Department of Defense (DOD) has been the primary organization responsible for the provision of this support since 1959, when the Department of Defense Mercury Support (DDMS) office was established to support the country's first manned spaceflight mission in collaboration with the National Aeronautics and Space Administration (NASA) (NASA, 1963). More recently, with the advent of the Commercial Crew Program, private organizations have begun to share this mission in support of commercial missions.

Figure 1. Pararescue Specialists and Combat Rescue Officers from the USAF 48th RQS practice astronaut rescue. U.S. Air Force Photo by SSgt Christopher S. Muncy. In this full mission profile exercise, Airmen were deployed into the ocean off the shore of Florida.

The HSFS mission is highly complex, spanning both routine and contingency rescue operations. Rescue personnel are required to provide immediate assessment, triage, and emergency care in the prehospital setting at the point of recovery. With the end of the Space Shuttle program, even routine rescue occurs in a challenging ocean environment, requiring the extrication of astronauts from a floating space capsule and the provision of care on an oceangoing vessel (generally, in US HSFS operations, initially conducted on an inflatable raft or boat, see Figure 1). Though under nominal conditions, the approximate point of re-entry can be predicted prior to splashdown, HSFS teams must also be prepared for contingency operations and rescue at any point during the course of a mission, from the launch pad to an arbitrary abort landing point almost anywhere on the globe. To enable this global mission, HSFS personnel must be trained to respond from a wide variety of air and sea transport platforms, such as the MH-60 helicopter and C-17 fixed-wing aircraft.

Routine spaceflight operations can expose astronauts to extreme physiological stress that can be significantly exacerbated by operational irregularities in contingency settings. For example, in the event of an early abort, astronauts may be exposed to significant G forces. Depending on the conditions of the abort, both crew and other mission personnel may be exposed to a variety hazardous gases used as propellants or coolants by the spacecraft. As landings are parachute dependent, a partial or full failure of this system may result in an impact at unsafe speed or attitude, and even under normal deployment, can result in disorientation and vertigo. For the rescue of missions that must re-enter the atmosphere, a normal trajectory will result in high internal capsule temperatures due to the heating of the spacecraft surface to over 1,000 degrees Celsius. In the event of an irregular re-entry, these temperatures can be much higher, potentially leading to non-exertional hyperthermia and burns. For missions involving the rescue of crewmembers who have spent significant periods in low gravity environments, a variety of long-duration spaceflight-associated physiological responses can further complicate rescue, including significant changes to bone

mineral density, fluid distribution, and neurosensory function (Barratt et al., 2019; Nicogossian et al., 2016). These responses require deviations in a variety of standardized medical response protocols (such as the routine approach to treating traumatic injury and hemodynamic shock) due to concomitant changes in the physiological response to insults. As these responses are only induced by prolonged exposure to low gravity environments, they do not occur in any other circumstance, making deliberate training the only option for familiarization prior to mission execution.

Today, the DOD teams tasked with the medical component of HSFS Global Rescue are generally comprised of United States Air Force (USAF) Pararescue Specialists (PJs), with additional support from Combat Rescue Officers (CROs), US Navy personnel, and other DOD and NASA medical personnel. Those personnel assigned to the mission have already received the highest level of operational medical training, such as Advanced Tactical Paramedic, Advanced Cardiac Life Support, and board certification in Emergency Medicine. They must also undergo additional, mission-specific training to ensure their readiness for the HSFS mission. In order to maximize the efficiency and capabilities during the mission, platforms and equipment sets are standardized, ensuring that the right tools are available at the right time to enable the best outcome for spaceflight personnel.

Current Approaches and Limitations to Training

The current approach to the acquisition and sustainment of HSFS readiness within the DOD involves classroom instruction and live exercises to simulate the operational environment. These exercises range in setting from the classroom laboratory environment to full mission profile (FMP) exercises in the ocean. Though these FMP exercises provide the closest possible experience to the real mission, they are extraordinarily logistically complex, requiring the coordination of aircraft, watercraft, floating simulated space capsules, equipment, and a large number of personnel. To obtain the maximum benefit from these exercises, personnel must be fully familiar with the equipment and the medical knowledge to operate at the top of their potential.

To address this need, simpler simulated exercises are available to enable personnel to familiarize themselves with mission equipment and practice clinical skills using simulated patient actors and high-fidelity manikin simulators (HFMS). Though these approaches provide valuable educational content, they generally do not enable the reproduction of the full complexity of the mission, including the challenging environmental and psychological contexts that are inseparable from clinical knowledge in determining the success of the mission. Additionally, they require personnel to be physically present at an appropriately equipped training facility and the availability of complex replicated equipment sets (which include over 200 individual pieces of medical equipment). These requirements reduce the frequency and the efficacy of simulation training and slow the training of rescue personnel.

Predicates and Aims

The limitations exhibited for current simulation techniques in human spaceflight support align in many aspects with the limitations of simulation methods for Tactical Combat Casualty Care and En-Route Care. Previously, with the goal of addressing some of these limitations, the USAF funded the Virtual Advancement of Learning for Operational Readiness (VALOR). The objectives of VALOR were to improve the realism, increase the flexibility, and reduce the cost of medical simulation training through the use of immersive virtual reality (IVR)-based medical simulation (VRMS). See **Figure 2**. Early efforts of the VALOR program were focused on Tactical Combat Casualty Care (TCCC) training, with results previously published in the simulation and operational medicine literature (Sarma, Barrie, Dorsch, Ribeira, et al., 2022; Sarma, Barrie, Dorsch, Weiss, Ribeira, Polson, Namperumal, et al., 2022; Sarma, Barrie, Dorsch, Weiss, Ribeira, Polson, & Ribeira, 2022). In this project, we investigated the adaptation of VRMS for medical training in support of the HSFS mission in collaboration with the USAF, United States Space Force, and DOD HSFS office. The project was initially managed by the United States Space Force Space Systems Command and was later transitioned to the Special Operations Forces and Personnel Recovery Division of the United States Air Force Lifecycle Management Center (AFLCMC/WIS), with subject matter expertise provided by the First Air Force, Air Combat Command and USSPACECOM and funding provided by AFWERX via a Phase II Small Business Innovation Research grant.

We aimed to replicate FMP training for PJs within VRMS, with the goal of allowing PJs to perform complete equipment familiarization, transport platform familiarization, and HSFS-specific training for clinical skills and protocols.

Figure 2. Examples of HFMS and VRMS training from the USAF Medic Rodeo 2022 competition. *Left:* Example of HFMS-based simulation in an FMP setting. U.S. Air Force photo by 2nd Lt. Brandon DeBlanc. *Right:* Example of VRMS-based simulation. U.S. Air Force photo by Airman 1st Class Mateo Parra.

APPROACH

As with previously reported VALOR efforts, the methodology for this effort broadly followed the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model for instructional design and development, with each phase receiving input from IVR engineers, instructional designers, clinical subject matter experts, and military operational medicine subject matter experts.

Needs Analysis, Design Principles and Curricular Planning

In the first phase of the project a comprehensive analysis of training requirements and gaps was performed. An interdisciplinary working group consisting of PJs, Combat Rescue Officers, Aerospace Medicine physicians, Emergency Medicine physicians, IVR designers, and IVR engineers was formed to perform the needs analysis, set design principles for the project, and specify curricular goals. As a starting point, the previously reported VALOR design principles were adopted (Sarma, Barrie, Dorsch, Weiss, Ribeira, Polson, Namperumal, et al., 2022).

Once these tasks were completed and broad curricular goals were set, the working group then developed scenario and environmental designs for the proposed curriculum. These designs were based on the identified needs and curricular goals, as well as the materials used for the DOD Pre-Hospital Space Medicine Care Course (PHSMCC), with cross-references to current standard of practice materials developed by the Joint Trauma System and the Pararescue Medical Operations Advisory Board (Shackelford et al., 2021).

After the completion of curricular planning, the working group reviewed available hardware options for the project. The selection process was driven by the design principles and curricular goals, in addition to applicable regulations and purchasing preferences regarding the place of manufacture and contents of the devices.

Platform and Curricular Component Implementation Approach

Figure 3. Example environmental design produced by artists during concept specification. This rendering illustrates the challenges of limited space on the receiving raft and the need to transport equipment across different platforms.

The next phase of the project was the implementation phase. Implementation proceeded using a modified version of the previously reported platform-based approach initially used for VALOR TCCC. First, an underlying commercial medical simulation platform was adopted (VRMSS, SimX, San Francisco, CA). This underlying platform provided core clinical simulation capabilities (i.e., an underlying physiological model, a virtual interaction system, intervention and interaction tracking and reporting, etc.). The platform underwent modification to fit the foundational requirements of the specified design and curricular goals.

Simultaneously, implementation specifications were generated for the scenarios and environments designed by the interdisciplinary team. First, concept specifications detailing the overview, components, and clinical context of each scenario were produced by a supervising clinician for each scenario. Then, detailed teaching specifications were created for each scenario by the instructional design team, detailing the physiological state flows, transitions and critical actions, non-player characters and interactions, dialogue concepts, environmental factors (such as psychosocial influences and physical modifiers), and learner objectives and assessables. Simultaneously, concept design renderings were created in order to illustrate design factors that might influence learner performance (**Figure 3**). During development of concept and teaching specifications, stepwise iteration was performed with review from subject matter experts (SMEs) assigned from the interdisciplinary team. After completion of platform modifications and scenario implementation specifications, detailed engineering specifications were then produced, including all required components (vital signs, physical findings, events and triggers, environmental changes, facilitator controls, medical interventions, medical assemblages, point of care laboratory findings, etc.). These specifications were then used by the IVR implementation team to produce the scenarios making use of the platform domain-specific language (DSL) and/or underlying scenario engine source code.

Testing, Iteration and Validation

The Agile paradigm was used to direct engineering implementation of the specified curriculum. Individual components, such as environments, tools and equipment, outfits, transport platforms, capsules, etc., were implemented in draft form and then released to the interdisciplinary team for testing and feedback. Refinements were then made iteratively on a per-component basis until the component was deemed satisfactory. Components were then integrated into complete scenarios, and again released for feedback and iterative refinement. Testing and feedback proceeded in three stages: first, technical quality assessment was performed by the quality assessment team. Then, clinical and educational quality assessment was performed by the assigned clinical SME. Finally, an overall assessment was produced by the interdisciplinary team. Iteration was performed at each stage in order to maximize the value provided by each successive review stage. Once final approval was provided by the interdisciplinary team, initial validation was performed by a senior DOD PMSCC educator prior to the initiation of formal trainee and educator acceptance testing in a live operational training environment.

OUTCOMES

Design Principles and Hardware Selection

The VALOR design principles were adopted to form the basic direction of the project: Full Immersion, Multiplayer First, Psycho-environmental Realism, Dynamic Physiology, Complete Sets, Kits and Outfits (SKOs), and Mutable

Scenarios. For the PHSMCC curriculum, the interdisciplinary working group also set the following additional curricular goals:

1. *Full Mission Profile Training*: All scenarios should require participation in the full mission, including briefing, loadout/equipment selection, transport to the rescue site, egress/extraction from the capsule, initial assessment and triage of the patient, delivery of appropriate field interventions, and rescue from the landing site.
2. *Complete Protocol Coverage*: The curriculum should include scenarios covering the full breadth of the prehospital space medicine care course, and should include both clinical and operational protocols, such as operation of the capsule egress system and environmental control life support system.
3. *Integrated Communications*: During execution, trainees should be required to make use of communications systems for coordination and reporting as they would during real-world operations, including the physical location and controls in each platform.

Based on the curricular goals and design principles, the group also decided to restrict the curriculum to wireless headsets due to the requirement for simultaneous teams of learners to be able to move freely within the scenarios in order to accomplish the required tasks. Based on this requirement, compatibility restrictions of the selected platform, and regulatory compliance limitations, the Focus 3 (HTC Corp, Taiwan) and Quest 2 (Meta Platforms, Menlo Park, CA) headsets were selected for use in the project. These headsets offered wireless operation, platform compatibility, and compliance with applicable acquisition regulations.

Scenario Curriculum

The working group developed ten scenario concepts for development as the curriculum for VALOR PHSMCC (**Table 1**). In order to achieve curricular goals 1 and 2, the group chose to set a subset of the scenarios in an ocean landing environment and another subset in a pad abort environment, ensuring that the curriculum would allow trainees to practice mission profiles requiring remote deployment via fixed-wing aircraft and profiles requiring deployment via helicopter or to an on-site requirement. To provide mission protocol coverage, the group stratified potential responses into three levels of medical acuity inspired by the standard emergency severity index (ESI) classifications (Gilboy et al., 2012):

- *Stable* – No serious or life-threatening injuries. No urgent interventions required; however, interventions may be indicated for comfort or optimal recovery.
- *Unstable* – Serious injuries present requiring time-critical intervention. Injuries are life-threatening, but loss of life is not immediately imminent.
- *Critical* – Immediate, life-saving intervention required in the field without delay. Loss of life imminent or unavoidable.

Specific clinical scenarios were then selected for each level of acuity. To guide selection, the working group considered cases in which the differential diagnosis or appropriate prehospital treatment plan was different than the otherwise standard TCCC expectation. The former included cases in which the correct diagnosis would be otherwise unlikely for the demographic of astronauts (such as pulmonary embolism, seated orthopedic injuries, hydrazine gas exposure, meralgia paresthetica, orthostatic intolerance), or not seen outside of long-duration spaceflight. The latter included severe injury patterns requiring an adjustment to standard treatment patterns due to the physiological changes of spaceflight (i.e. management of hemodynamic shock, vertigo, infection, disorientation).

Table 1. PHSMCC scenario curriculum concepts. Summaries and acuity classifications of the ten scenarios designed by the working group.

Scenario Name	Medical Acuity	Short Description
Ocean Rescue	Stable	Patients are astronauts who have had an uncomplicated ocean landing after a long duration mission. The patients exhibit appropriate physiological manifestations of long-duration spaceflight, but otherwise have no acute complaints.
Pad Abort	Stable	Patient is an astronaut whose launch was terminated with a pad abort due to a rapidly progressing fire spreading up toward the capsule, with capsule splashdown close offshore. The patient has suffered smoke inhalation but is otherwise uninjured.

Orthopedic Injury	Stable	Patient is an astronaut who has had an ocean landing complicated by a partial parachute failure leading to elevated landing velocity. The patient has suffered a comminuted fracture of the left humerus.
Pulmonary Embolism	Stable	Patient is an astronaut who has had an uncomplicated ocean landing. The patient has suffered a pulmonary embolism during re-entry but is maintaining acceptable oxygen saturation.
Spaceflight-Associated Neuro-Ocular Syndrome	Stable	Patient is an astronaut who has had an uncomplicated ocean landing. The patient has returned from a long-duration mission that was terminated early due to signs of neurologic decompensation.
Severe Hazardous Gas Exposure	Unstable	Patient is an astronaut whose launch was terminated after takeoff due to a propellant leak, with capsule touchdown close offshore. The patient has been exposed to gaseous hydrazine and exhibits the signs and symptoms of acute exposure.
Penetrating Trauma	Unstable	Patient is an astronaut whose launch was terminated with a pad abort after launch due to the explosion of an overpressurized container within the capsule. The patient has sustained a penetrating traumatic injury to the abdomen from flying debris.
Severe Burns	Unstable	Patient is an astronaut whose launch was terminated after takeoff due to a rapidly progressing fire, with capsule touchdown in the ocean. On splashdown, portions of the capsule remain aflame. The patient has sustained severe burns.
Blunt Head Injury	Unstable	Patient is an astronaut whose launch was terminated after takeoff due to a critical engine failure leading to automated abort system activation. The patient has sustained a blunt head injury and exhibits altered mental status.
Unresponsive Crew Member	Critical	Patient is an astronaut who has had an ocean landing complicated by complete parachute failure leading to high impact velocity. Due to high g-forces, the astronaut lost consciousness during re-entry and remains unresponsive. The patient has sustained multiple traumatic injuries.

Implementation of Sets, Kits and Outfits

Replication of the sets, kits and outfits within the medical assemblage designated for the medical HSFS mission was an area of particular focus. Though the transport platforms used for the mission vary depending on objectives and location, a consistent assemblage is always used. This consistency is maintained to the level of individual bags and packs in order to prevent delay in location required supplies and equipment while on the mission. The complete allowance includes over 200 individual items, many of which are not routinely carried in battlefield deployments. Replicating the assemblage exactly presented several obstacles that were addressed during implementation, including computational performance limitations of the selected headset devices, and the minimum sizes at which IVR interactions are intuitive.

Performance Limitations

The selection of the all-in-one headsets Quest 2 and Focus 3 imposed a performance limitation on the application runtime. Because these headsets must perform all computation and graphics rendering onboard the device (rather than via connection to a workstation), limited resources are available to create the view. This limitation is further increased by the requirement to render a separate view for each eye, doubling processing requirements. These limitations impact both the number and the visual complexity of equipment, environments, and characters rendered into the virtual scene. As a result, displaying the full medical assemblage simultaneously was impractical. To address this limitation, two constraints were imposed on the medical assemblage. First, opening all of the kits and packs available simultaneously was made impossible. Instead, if too many containers were opened at the same time,

Figure 4. Example virtual medical equipment packs and sub-packs. Depicted aboard the virtual "front porch" raft.

some containers would automatically close. Second, within each large pack, equipment was categorized into sub-packs based on functional area (**Figure 4**). Only one sub-pack could be open at any given time. In order to avoid undue limitation, some equipment was replicated in multiple sub-packs (i.e. intravenous cannulation start kits) to ensure that equipment likely to be used together was available at the same time. These categorizations were created by the clinician SMEs participating in instructional design, reviewed by the working group, and then refined via iteration on the final scenarios.

Size Constraints

The nature of virtual reality interaction systems imposes a constraint on the minimum viable size of an object to be manipulated within the simulation. This constraint is created by the operational realities of tracking hands and controllers in the physical world and projecting those locations in the virtual space. When objects are too small (i.e. smaller than a 1-2 centimeters), it is no longer possible to accurately differentiate which of multiple adjacent objects the user intends to manipulate. This constraint impacted several small items included in the medical assemblage. To address this issue, some items (such as tubing connectors, inhalers, etc.) that medical personnel would ordinarily have to assemble on site were pre-assembled within the virtual kits. Additionally, each sub-pack within each kit, when opened in the virtual scene, unfurls to a larger size than when packed, creating more space between items for selection in order to facilitate the identification of which item a user is selecting.

Implementation of Platforms and Environments

Platform and environment implementation included the creation of the crew capsules (Orion and Dragon), the water rescue environments (ocean and near off-shore), the transport platforms used by HSFS personnel (C-17 fixed-wing aircraft, MH-60 helicopter, "front porch" triage raft, rigging alternate method boat (RAMB), and advanced rescue craft (ARC). See **Figure 5** for example. Additionally, platform-appropriate communications equipment (i.e., radios) and a patient flow system enabling the preservation of interventions and patient state throughout the mission profile was implemented.

Communications equipment was configured to enable pass-through to facilitators outside of the simulation in order to enable replication of the mission medical command environment. Facilitators are able to use the moderation laptop interface to communicate via the virtual radios within the virtual environment and can therefore respond in the role of various other components of the mission (i.e., mission control, medical supervision, etc.). Alternatively, pre-programmed dialogue can be initiated by facilitators to provide instruction and information as needed to facilitate scenario progress.

Enabling the preservation of patient state through transport across multiple locations and platforms required modification of the underlying platform physiological model to enable separation of scene and physiology. This requirement was driven by the propensity of different teams of learners to provide different sets of interventions at different points in the mission. As the selection of the temporal ordering of these interventions is clinically important (i.e., which interventions to provide on the triage raft versus after the patient is secured and in transport), practicing this medical decision-making (and the resulting consequences to the mission of different choices) is an essential part of full mission profile training. Though these adaptations, each scenario is able to progress through a variety of environments, such as the aerial transport platforms used to transport to/from the site and the water platforms used to perform egress/extrication and initial assessment and intervention.

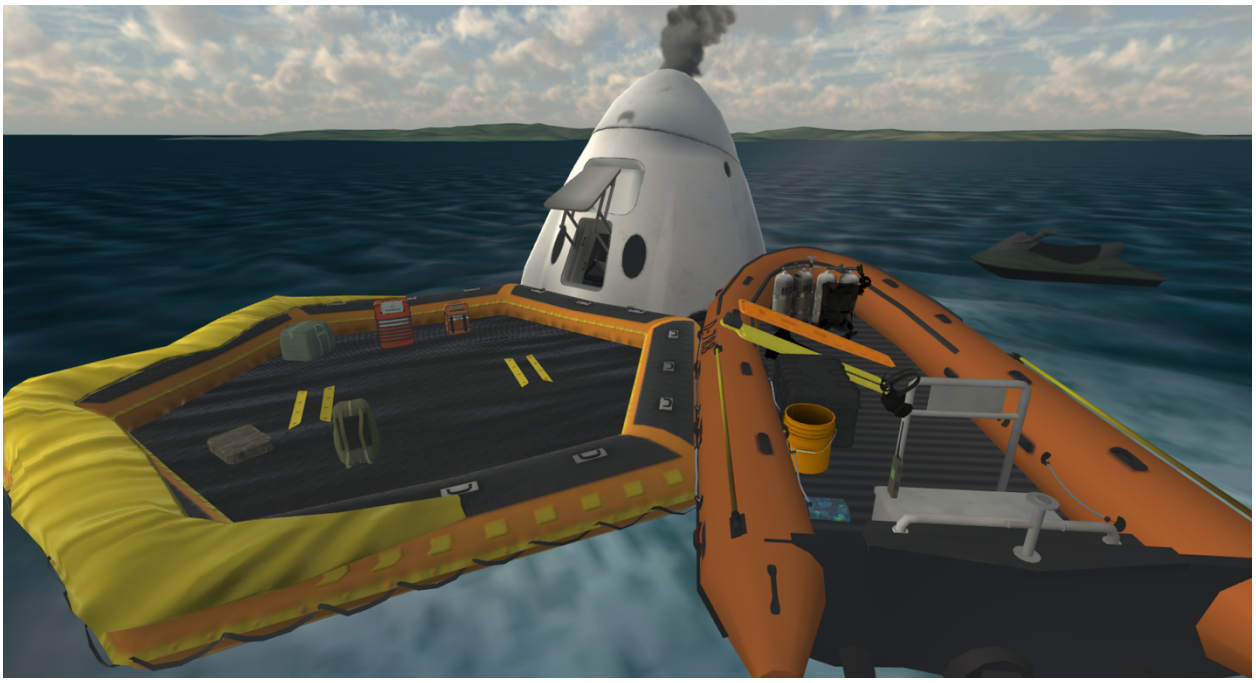

Figure 5. In-platform screenshot of a virtual environment from the developed Pad Abort scenario. This screenshot is from the Pad Abort scenario, including virtual Dragon vehicle and launch plume visible in background.

Evaluation and Ongoing Work

Following finalization of the curriculum, the completed capability was deployed for ongoing pilot evaluation at PJ training sites within the USAF Air Combat Command and Special Operations Command, including Detachment 3 of the First Air Force and the Special Operations Center for Medical Integration and Development, with additional evaluation deployments planned to synchronize with training requirements for future expected mission dates.

Because the resulting system created a previously unavailable capability for FMP-style simulation training without the need to plan a complete exercise, there was not a clear predicate against which to evaluate the efficacy of the system. Therefore, feedback was collected directly from use by individual end-user groups for the Agile process. With completion of the first version of the system, quantitative evaluation is planned through the integration of the system into pre-existing non-FMP training events, following the method previously demonstrated by the program (Sarma, Barrie, Dorsch, Weiss, Ribeira, Polson, Namperumal, et al., 2022). Early quantitative feedback from end-users has been positive, without concerns reported to date of negative training impacts from the modifications made to simultaneous equipment availability described above. Further quantitative evaluation will also seek to discover any alterations required to the sub-packing organization or spatial arrangement for optimal training.

DISCUSSION AND CONCLUSION

Here, we report on a collaborative effort between the U.S. Air Force, academic, and industry to create a novel medical simulation capability for human space flight support. Developing a virtual curriculum that met the mission need required close collaboration between end-users with mission experience, clinicians, designers, and engineers, and frequent feedback and iteration was critical to the success of the effort. This enabled the identification and solution of many unexpected complications (such as the sizes of pieces of equipment, the dimensions and limited space available on transport platforms, and the need for consistent physiology across mission phases) at an early stage. Since there was no pre-existing IVR solution for PHSMCC training, the Agile approach was used throughout the process to iteratively develop requirements and specifications for the new simulation system based on first principles developed by the working group. During the implementation phase, an iterative approach was again used to create the simulations. This approach facilitated the resolution of the project's major technical obstacles. When

performance limitations forced a reduction in the number of simultaneously visible tools and interventions, a sub-packing system was implemented and iteratively refined through SME testing to ensure that items were categorized in a manner that would not interfere with training. Later, when size constraints required modification of the spatial arrangement of individual items, SME iteration again enabled the creation of a display that facilitated effective use of the available virtual medical equipment. This process was also used for integration of the final training scenarios in order to ensure that deviations from clinical or educational protocols were detected and addressed at the earliest possible stage of implementation. These efforts to trap and address potential training limitations likely explain the positive feedback obtained after initial deployment.

Overall, the effort successfully developed a comprehensive curriculum based on the U.S. Air Force prehospital space medicine care course, as well as a core set of IVR capabilities, environments, and equipment sets that enable the rapid development of additional content for military and civilian end-users. The curriculum has completed initial testing by the interdisciplinary working group and is now slated for further evaluation in the field with personnel from the 24th Special Operations Wing and other formations.

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