



# **Operational Assessment Recommendations: Current Potential and Advanced Research Directions for Virtual Worlds as Long-Duration Space Flight Countermeasures**

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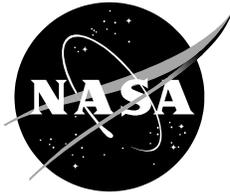
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## Acronyms

<b>AI</b>	artificial intelligence
<b>ASCAN</b>	Astronaut Candidate
<b>BHP</b>	Behavioral Health & Performance
<b>CMS</b>	Course Management Systems
<b>DADS</b>	delayed, asynchronous decision-making system
<b>ECA</b>	embodied conversational agent
<b>GPS</b>	Global Positioning System
<b>IA</b>	intelligent agent
<b>ISS</b>	International Space Station
<b>ITS</b>	intelligent tutoring system
<b>NLP</b>	natural language processing
<b>SFRM</b>	Space Flight Resource Management
<b>VE</b>	virtual environment
<b>VR</b>	virtual reality
<b>VW</b>	virtual world

## Executive Summary

This report summarizes findings and presents recommendations based on a year-long research effort on the benefits of virtual worlds (VWs) for astronaut and ground crew training for long-duration space flight. The components of this research included a literature review on existing applications of VW technology to space flight, an operational assessment on the most promising aspects of using VWs for training for long-duration space flight, interviews with a panel of six NASA experts on the use of VWs, and participation in a 3-day Behavioral Health Program Research Element workshop.

Based on the above components, this report summarizes the main findings of each of these components to describe current developments in VWs and use of virtual technologies as applied to the context of long-duration space flight. Furthermore, as a result of our research, we also assessed current training protocols at NASA and found exciting opportunities for augmenting existing practices for long-duration space flight. Lastly, based on our assessment, we recommend promising directions of future research for NASA long-duration space flight with an eye to implementation and cost effectiveness.

Our findings are that VWs are a promising technology for learning, preparing, and supporting long-duration space flight. Briefly, a VW can be described as a virtual environment in which people may use avatars (virtual representations of themselves) to interact with each other and various elements of the environment. Similar to video games (which are usually more goal oriented), VWs may provide engaging ways of interactive and embodied learning that cannot easily be replicated in the real world. Given that current and future learners are part of a “digital generation” that is comfortable with learning, sharing, and socializing through technology, we see a great benefit to the adoption of VWs for learning purposes.<sup>[1]</sup> As NASA increases cooperation with international space agencies, training is happening at a variety of different physical locales under increased time-constraining conditions. Although we do not propose to do away with face-to-face or physical (analog) training situations, we propose supplementing current training with the implementation of VWs.

The benefit of VWs is that they are cost-effective, malleable, interactive training environments that put astronauts into the various contexts that they will be encountering during long-duration space flight. The benefits of this type of training versus traditional classroom training are as follows: 1) portable, cost-effective, and malleable; 2) interactive and embodied; 3) safe; and 4) non-located. Put differently, VWs provide an easily configurable environment that provides astronauts with “hands-on” types of learning in an interactive manner. Furthermore, because the astronauts can replay and engage with learning material in a longer timeframe and on their own timeline, they are given a safe environment to practice before entering actual analog environments. Coupled with video game-based types of learning approaches (where unlocking newer environments is based on achieving specific skills and goals), such learning environments may prove very effective for more comprehensive types of learning. Furthermore, in international and dispersed training contexts, VWs factor in more effectively by providing an online pedagogical and social backbone to the increasingly diverse international locales currently used in aeronautic training.

We see VWs as a platform from which to support long-duration flight missions in a variety of different manners. Below, we describe promising developments in artificial intelligence and online learning that

may be combined with VWs to support NASA countermeasure goals. Briefly, these countermeasures can be described as being comprised of: a) part-task training; b) academy, Space Flight Resource Management, teamwork, and ground crew efficiency countermeasures; c) intelligent agents/tutoring systems; d) resiliency; and e) delayed, asynchronous decision-making systems.

One of the most promising aspects of VWs is their malleable nature, allowing for an easily configurable, inexpensive, and on-the-go online virtual training space. For part-task training, often involving routine or common operations, we see VWs as incredibly promising in their ability to liberate existing analog (physical) simulations and provide prolonged exposure to learning these operations through pre-analog, online digital training. In addition, by their nature, VWs are easily reconfigurable and thus can be programmed to reflect the latest up-to-date versions of equipment. Likewise, we see great promise in using VWs for physical training. For example, by coupling visual output to physical exercises, astronauts may train their vestibular systems to adjust to different types of microgravity, low-Earth and Earth gravity, which in turn would allow NASA to make a better informed decision for optimizing landing safety in various gravity situations and prevent unnecessary damage to flight equipment.

Another promising aspect of VWs is their ability to create social networks and provide support in a variety of contexts. With NASA's cooperation with various international space agencies and increasingly globally dispersed training modules, greater support for individual, team, and social interaction is required. Not only do astronauts need to "stay in touch" with their families, they also need to bond with other crew members if they are to function effectively during long-duration space flight. As part of this, astronauts may use VWs for various purposes, among which are staying in touch with home, taking virtual vacations, or using them to artificially create circadian rhythms and so feel connected to the common rhythms of Earth.

Furthermore, the use of artificial intelligence in conjunction with a VW (through, for example, *intelligent agents* or *intelligent tutoring systems*) also may provide learning of crucial communication, intercultural, decision making, and other types of tacit skills. Intelligent agents are virtual agents that use natural language processing and so respond semantically to user input. Likewise, intelligent tutoring systems use such processing to create simulations wherein user skills are tested, evaluated, and discussed post-session by way of a mentoring approach. In these simulations, the benefit of using a VW is that the VW creates a safe environment to fine tune these skills and provides a specific means of testing and benchmarking various types of crucial skills. As long-duration space flight will demand a greater emphasis on group cohesion, decision-making skills, intercultural/interpersonal and general communication skills, VWs may provide key practice spaces for these types of tacit knowledge and experience. Furthermore, in creating more complex simulations using various intelligent components, astronauts and crew may encounter greater complexity and understanding of real-world contexts.

Another element that will be crucial for long-duration space flight is training for resiliency, which can generally be defined as the ability to withstand hostile conditions and long-lasting adversity by using techniques to maintain a strong and positive outlook on a group and individual level. Long-duration space flight will be extremely taxing on astronauts and crew. Claustrophobia, social anxiety, feelings of isolation, loneliness, and depression may jeopardize group or individual morale. We propose using VWs to teach resiliency. For instance, in addition to being allowed to connect with "virtual buddies," astronauts

may connect (albeit asynchronously) with their family, ground crew, or, if deemed appropriate, the public in general through a VW. Knowing that they are not alone, maintaining communication and knowing when they need time for relaxation and socialization will be paramount for astronauts and mission success.

Because communication with long-duration space flights will be largely asynchronous (with at least a 20-minute time lag), it is crucial that flight crew and ground crew are trained in using a delayed, asynchronous decision-making system (DADS). Because there will not be an immediate ground crew response, astronauts will need to manage inquiries and troubleshoot largely on their own, and decide on the appropriate course of action, simply because sometimes there is not enough time to wait for a response. In using a DADS, astronauts will need to learn how to diagnose and troubleshoot a particular problem, relegate a relevancy, and transmit the issue to NASA ground crew. After transmitting the issue, astronauts are asked to come up with their own solution by way of using a DADS, which may include intelligent agents, recommender, and solution systems. At the same time, when NASA ground crew receives their initial inquiry, they will need to start creating a solution as well, so that both flight and ground crew converge on the problem and find a solution in the most efficient manner.

We see benefit in various efforts of research being funded in using VWs to prepare for long-duration space flight. Not only are VWs cost effective, they also are malleable spaces that can effortlessly be used for online learning. Using intelligent agents and intelligent tutoring systems allows VWs to be used to train various hard-to-learn tacit skills by providing a safe environment that is highly configurable for a variety of skills, and allows performance benchmarking. Research will need to be conducted in various areas, such as:

- VW part-task training
- VWs for social networking and crew understanding
- VW for online learning (intelligent agents and tutoring systems)
- VW resiliency training (relaxation, charging up the well)
- VW delayed, asynchronous decision making (converging on a task, decision making)

As VWs start functioning as a transition space between the human psyche and the outside physical world, they also may be suitable to transition us from the inner spaces of our mind to the outer reaches of our galaxy and beyond.

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## 1.0 Introduction

Cyberspace, the electronic space made up of myriad connections between people and information, is *the* transition from space to outer space. It allows us to move from Earthbound to the celestial terrains, and to proceed from the inner space of our minds to the outer space of the physical and beyond. In our networked, globally accessible society, the physical and the virtual continue to merge in ever more productive ways. Our mobile devices allow us to make use of an augmented reality wherein the features of the physical are explained in virtual terms through combinations of Global Positioning Systems (GPS), recommender systems, user shared information, and immediately available information about our surroundings. We share personal information through social networks, by playing online video games, and by living in virtual worlds (VWs), and we increasingly learn from networked environments and course management systems (CMS). We keep in touch with loved ones through instant messaging, email, voice, and video chat. And this range of communication and information is no longer Earthbound, as connectivity to the International Space Station (ISS) and remote exploration vehicles has expanded our spheres of connectivity into the near regions of our universe. Cyberspace technologies are rapidly evolving, and promise to expand our connections to, and exploration of, space in ways that are unimaginable today.

This report summarizes a year-long research effort on the potential of VWs for long-duration space flights (for a glossary of terms, see the end of this document). Given the purview of this effort, this report makes recommendations on the most promising near-term areas of use for VWs within the particular context of preflight training, but also covers possibilities for in-flight and post-mission support. We see a tremendous potential for these technologies to be used broadly, integrating them into part-task training modules, enhancing team cohesion and intercultural understanding, and fostering psychological resilience across the spectrum of preflight training to post-mission support. VWs also are noted for their capabilities to be highly malleable and rapidly built, and are therefore effective, cost-saving technologies.

Data from this report were culled from these various stages of research:

- a) A literature review on available research concerning VWs and space flight
- b) An evaluation of existing VW technologies
- c) Qualitative data gathered by interviewing a panel of NASA operational experts
- d) A 3-day workshop conducted by the Behavioral Health & Performance (BHP) Research Element

This report synthesizes our findings from the above to recommend the most promising directions for use of VWs for countermeasures and future opportunities to enhance training for NASA space mission crews.

## 2.0 Terms and Definitions

A virtual reality (VR) is a nonphysical, created construct that provides an alternate environment for real humans to use and inhabit. While a VR can be an imaginary construct, for our purposes it comprises computer-mediated systems created especially to present such an alternative environment to a participant through one or more sensory channels. The term itself, virtual reality, was popularized in the late 1980s by an astute group of researchers and entrepreneurs working to ready the technology for popular usage. Sometimes terms from science fiction literature are used interchangeably with the idea of VR. Cyberspace is a term that was introduced by author William Gibson in his 1982 short story *Burning Chrome*<sup>[2]</sup> (and used in his 1984 novel *Neuromancer*<sup>[3]</sup>) to describe a connected “consensual hallucination” shared by real people inhabiting the virtual space inside the computer. Science fiction writer Neal Stephenson coined the word ‘Metaverse’ in his 1992 book *Snow Crash*<sup>[4]</sup> to describe a similar concept of realistic, shared computer-generated spaces. Stephenson’s term also connotes that these environments are a metaphorical representation of the universe and besides Gibson’s psychological approach, thus also highlights the *spatial* and *metaphorical* dimensions of modeling space virtually.

Most early VR applications were singular environments where one or, at most, a few people could share the computer world. These applications were typically single purpose, with some created for virtual travel such as a visit to the monuments of Egypt as they might have looked in their heyday, some promoted as exciting new game spaces, and some even as artistic experiences. These virtual environments (VEs) also were explored for their more serious potential, including therapy to mitigate phobias such as fear of spiders, flying, heights, public speaking, as well as for training purposes, especially as promoted by NASA at its AMES Research Laboratories.<sup>[5]</sup> Using a VR environment, one could use virtual tools to affect a result at a distant place, where the actions in the VW controlled the motion of real tools at the other end.

VR and VEs provide environments that afford a person a sense of immersion and presence in the artificial, computer-mediated space. Early versions of VR featured head-mounted displays that could insulate and sequester users within a digital space, and thus provide an authentic experience of being immersed and present in a different environment. Various other interface instruments, such as gloves and tracking devices, were developed to traverse the virtual space or manipulate virtual objects. The tracking, manipulation, and immersion constituted a distinct spatial experience and, for this reason, VEs are often considered spatial VR. A spatial VR typically has limited or no connectivity to other VRs, is created for a single purpose, has a repeatable set of starting parameters (no persistence across usage), and minimal or no self-representation and, if it does, that representation is defined by the programs’ authors and not the individual user.

VWs, by contrast, are socially oriented VRs, built as persistent environments or worlds that may be inhabited, traversed, and manipulated by a person through their avatar (their virtual representation). VWs are characterized by multitudes of concurrent users who may interact and communicate with each other while in the world. This persistence, as well as the multi-user aspect, is a key differentiator of VEs from VWs. In providing extensive space and possibilities, VWs can permit participants to model, explore, and interact within a world that can be similar to our physical surroundings or which may present novel, imaginary, or fantastic environments that are not bound by physical reality. Unlike the physical universe, a VW suffers no such constraints, and therefore allows for a greater range of opportunities and

experiences that may help prepare an individual to inhabit even further dimensions than the Earth and Cyberspace.

Video games share much with both VR and VWs. They provide common spaces for players to interact with each other in a virtual space while connected to a server. However, video games are based on a more goal-oriented environment in which achievements are emphasized.

For our purposes, both VWs/VEs and video games can be beneficial in the context of space travel countermeasures. Whether one learns, socializes, or relaxes in a VW or in a goal-oriented game, we consider the experience more important than distinguishing whether the experience was defined as a VW or a game.

The popularity of video games as a pastime of many people is well known and publicized. The use of VWs has been steadily growing. According to GigaOm Research, one in eight people in the United States reports having used a VW.<sup>[6]</sup> The use of VWs, especially by the youngest demographic, kids from age 5 to 15, seems to be exponentially increasing.<sup>[7]</sup>

Indeed, between its game and VW use, the current generation can rightly be called a “digital generation” as they are comfortable learning, living, and communicating through computer games and computer-based environments.<sup>[1]</sup> The growth and prospects of the digital generation for NASA means that learning and communication through computers are familiar and expected ways of learning by current and future generations. Because of this and, for a number of other reasons, we see a tremendous opportunity for BHP to use VWs as digital learning environments in various contexts.

## 3.0 Methods

In our research toward the creation of this report, we used a variety of sources and methodologies to gather pertinent information. These sources included: a literature review; an assessment of those findings; an interview component with a variety of NASA experts; and participation in a 3-day BHP Research Element Workshop. Based on these sources, we present our recommendations within the following areas:

- VW and social networking potential for countermeasure training
- Gaps in preflight training that were found via research, interviews, and the BHP workshop
- Potential future directions for research (basic and advanced)

Below, we summarize the findings from each method. Throughout this report, and for more in-depth information, we will refer you to earlier work conducted as part of this research effort.

### 3.1 Literature review and operational assessment

For our literature review, we combed existing research and popular documents for anything related to VW technology in general, VR (as used in the NASA space program), human-computer interaction, video games, social aspects of VWs, space travel and preparation for long-duration missions (space and analog). This resulted in a good understanding of existing gaps in research pertaining to VWs and countermeasures, which are legion, and will be discussed in the recommendations section as possible promising directions for new research for NASA. Other literature that was consulted focused on intercultural/ interpersonal, and social human factors, theories of group management, crowd-sourcing, geographic information systems, telepresence, telemedicine, and resilience. From this work, a number of different areas for countermeasure research were indicated that could be of potential benefit to NASA, with use of VWs for pre-mission training countermeasures deemed as the most promising.<sup>1</sup>

Therefore, for our operational assessment, we limited our research to the efficacy of VWs on pre-mission countermeasure training, leaving their use for just-in-time training or during mission support purposes for future reporting. We predominantly focused on preflight training and the different types of countermeasures that could be facilitated for psychological, physical, and team performance. We divided the preflight training into individual, team, and task performance components. Based on our assessment, we described ways in which VWs could facilitate several learning forms. Briefly, these include: a) social and game-based digital training that provides active learning situations with emotionally resonant and embodied meaningful experiences for students; b) intelligent tutoring systems that provide review and reflection on learning situations and hone in on underdeveloped learning areas; c) embodied conversational agents, or ECAs, that serve as near-humans for various purposes in the VW; and d) artificially intelligent systems that can analyze performance and create benchmarks that are connected to databases of reconfigurable scenarios.

We recognized additional factors that can influence an astronaut candidate's (ASCAN) physical and mental health, such as individual well-being, team well-being, interpersonal relations, intercultural

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<sup>1</sup> Full results of the literature search can be found in our first report: Morie, Verhulsdonck & Lauria 2010a.<sup>[8]</sup>

factors, and group morale, as well as the impact of microgravity on individual physical abilities (hemodynamics, bone density, vestibular atrophy, “space brain,” etc.). Countermeasure training must include methods of coping with such factors, among them a variety of psychological elements such as:

- General feelings of anxiety, social isolation, claustrophobia, depression (caused by being away from home and family, loss of circadian rhythm, etc.)
- Interpersonal and intercultural team issues (as a result of increased duration of flight and recent increased international cooperation between various space agencies)
- Group and team dynamics (leadership skills, team communication, task performance, team socializing)
- Individual health/psychological dynamics (assessing and recognizing one’s mental and physical health and caring for self when appropriate)

Based on the idea that VWs should help mitigate these factors, we concentrated our interviews and resultant operational assessment on finding current means of training that could help astronauts and ground crew deal with these issues in productive ways. Furthermore, we also looked at existing NASA training protocols (such as Space Flight Resource management [SFRM], part-task training, and various flight simulators) to locate potential gaps and means of improving astronaut and ground crew training for long-duration space flight through the use of VWs. We identified a number of different gaps that we describe below.

Firstly, we identified VWs as extremely cost-effective simulations and digital training environments for astronauts. Compared to available physical analogs (e.g., physical simulations in a room), or high-priced VR simulators, VWs are malleable virtual environments that are easily reconfigurable, accessible from any computer with an Internet connection, and provide multimodal, embodied learning environments for ASCAN training. Current and future training environments can be easily converted to or created within a VW to address a wide range of situations. For example, a VW could simulate some of the salient effects of microgravity via VW experience and feedback and thus train the spatial and visual sense of an astronaut without requiring physical microgravity conditions.

Secondly, due to developments in social networking, we note that VWs also are well situated for creating a social network that can enhance team cohesion and allow for pre-mission bonding. For instance, astronauts could meet regularly in a VW and get to know the other people they will be working with during the mission. These meetings would include the participants taking on the form of an avatar (a personalized, three-dimensional representation of self) within the VW. Research shows that people bond with this virtual representation and “act” through it, revealing many aspects of their social selves and developing a better understanding of self.<sup>[9]</sup> As future space crews are expected to comprise diverse international members, VWs and social networks are ideal means for astronauts and ground crew to become familiar with the social and cultural norms of their future colleagues, in addition to practicing anticipated shared tasks.

Thirdly, coupling VWs with artificial intelligence (AI) and natural language processing (NLP) can make VWs highly effective online learning spaces. The use of ECAs with AI will lead to the creation of more high-fidelity and lifelike social simulations. Further, intelligent tutoring systems (ITSs) are especially promising for online learning purposes, as they can provide student feedback and post-performance assessment. With use of VWs, NLP, ECAs, and ITSs, all combined in a training simulation, NASA can

not only impart high bandwidth knowledge, the agency can track the learning of both first-year ASCANs and astronauts, and set benchmarks for future performance. For future purposes, when discussing the potential of VWs in this report, we refer to both groups under the inclusive umbrella term of “astronauts.”

For example, astronauts can be presented with an off-nominal/nominal situation using a scenario that tests their knowledge, allows them to interact with ECAs via NLP, tracks their actions, provides just-in-time feedback via intelligent agents and game state information, and follows up with personalized post-session tutoring. Through engagement, personal feedback and the ability to “try it again” (thus learning by non-disastrous failures), astronauts may prolong their exposure to learning material, and thereby create a more comprehensive cognitive model of various situations. In turn, NASA mentors and trainers can analyze the data from sessions and share their findings with the ASCAN.

Fourthly, we believe that VWs will function as social, entertaining, and therapeutic environments wherein an individual may temporarily “escape” his or her immediate reality for rest, relaxation, or recuperative purposes. These environments could provide virtual vacations, relaxation programs, and techniques to help regulate sleep, thus alleviating some of the need for pharmacological agents. They also may include communication connections with friends and family, whereby both parties interact via avatars or “virtual humans” in an embodied manner. We think the latter aspect will be increasingly important for long-duration space flight, where astronauts need to develop ways of dealing with isolation, homesickness, and cramped conditions.

Lastly, we see great promise for resiliency training in VWs. Resiliency training differs from traditional stress training in that it explicitly develops an individual’s ability to deal with adverse conditions in physical, psychological, and social contexts through specific techniques. While currently used primarily in sports training for elite athletes, these techniques can be adapted for dealing with the adverse conditions of long-duration space flight. Resiliency training focuses on instilling constructive, implicit methods that help individuals mitigate the effects of personal trauma through positive thinking, taking care of physical and psychological needs, and creating positive group interaction. We believe resilience will become increasingly important in NASA training for long-duration flight where conditions will be extreme, and astronauts will be in isolation and cramped space facing hostile environments. Like athletes preparing mentally for a marathon, training in resilience techniques will enable astronauts to create effective strategies to deal with the hardships that they will encounter during their missions.

## 3.2 Interviews

Interviews were conducted between June 1, 2010, and June 8, 2010, with six individuals representing different areas of operational expertise within NASA.<sup>[10]</sup> The purpose of the interviews was to operationally assess the potential of using VWs to augment current NASA training for ASCANs and flight controllers. The interviewees are briefly described below; their names have been withheld.

**Interviewee 1** continues to support human space flight programs and ongoing research projects. He is actively involved in various human space flight programs, including commercial space flight. He does business development in terms of real mission support; e.g., when new hardware is being developed, or when malfunctions with gear on orbit occur that require an early crew evaluation.

**Interviewee 2** is a high functionary who works inside the Mission Operations Directorate. She is involved in diverse activities, including developing metrics for feedback, training, and analyses, developing the training flows across areas like the Training Academy Course, common content for space station flight controllers, SFRM skills, and deals with the training program for astronauts and flight controllers for both the shuttle and the ISS.

**Interviewee 3** is a psychologist with ground crew experience who works in the training standards integration group. He states that this group basically does instructional design, curriculum development, evaluations, bench marking, and policy making for training in terms of the different divisions.

**Interviewee 4** is a senior scientist and scientific advisor for Space Life Sciences and has extensive experience in academia and medicine.

**Interviewee 5** is an ASCAN whose background includes training as a medical doctor for emergency medicine and aerospace medicine. He also has worked at NASA as a flight surgeon and is currently involved in candidate training, which involves robotic arm training, spacewalk and EVA training, Russian language, flight training, flying in the T38, and space systems training.

**Interviewee 6** is a senior scientist on the operational side of BHP and a representative from SFRM. She develops training for flight controllers and astronauts regarding the competencies in the SFRM area. She is a participant in the international working group to design the SFRM competencies that they consider necessary for long-duration missions, and performed the job analysis associated with those.

During the interviews, interviewees were asked open-ended questions regarding the potential of VWs for training areas. Important aspects that interviewees brought up were practical considerations that exist during current and recent ASCAN training, such as the demanding travel and time commitments, increased cooperation with international space agencies, and various other aspects that long-duration space flight will require. Interviewees also commented on their visions for using VWs in ASCAN training contexts for long-duration space flight, noting especially the following areas: VWs used as “mini-sims” and part-task trainers; VWs used as training for leadership; VWs used as training for boredom; VWs to help with loneliness, isolation, stress, relaxation; and VWs used for on-demand training and refresher courses. Key quotes from the various interviews are synthesized below in the results and discussion, and integrated to provide a field perspective on the recommendations that follow.

## 4.0 Results and Discussion

As mentioned, the focus of this report is on discussing VW countermeasures for pre-mission training. However, we do believe that many of the pre-mission training technologies could be carried over into just-in-time cross-training countermeasures and support/adaptation countermeasures.

Our research points to a variety of promising areas where VWs could be used for countermeasure purposes to support ASCAN and astronaut task learning, social interaction, and group cohesion. The following elements seem particularly promising when combined with VW technology:

- 1) Part-Task Training Countermeasures
  - a. VWs as portable, hands-on simulations
  - b. VWs and ITSs
  - c. VWs and ECAs
- 2) Academy, SFRM, Teamwork, and Ground Crew Efficiency Countermeasures
- 3) Physical Countermeasures
- 4) Resiliency Countermeasures
- 5) Delayed, Asynchronous Decision-Making Countermeasures

We will describe each of these elements in further detail.

### 4.1 Part-task training countermeasures

A common element of many professions is learning the “tricks of the trade.” Even though many of us are prepared for particular situations in theory, important learning experiences also are conveyed through experience gained on the job. Often this experience comes from exposure to real-life situations and provides a more coherent framework from which professionals can draw when making decisions. At times, such a framework is built upon a mix of tacit knowledge, muscle memory, and oversight as a result of prolonged exposure to particular situations. An appealing aspect of VWs is that they can provide in-depth ways of providing embodied experiences that are much more engaging than many traditional and passive forms of gaining knowledge (such as lectures, books, and manuals) by giving people direct, hands-on experience in a learning domain.

Part-task analog training methods currently used by NASA to train astronauts include custom-built physical objects and settings that mimic instrument panels, vehicle sections, and tool mock-ups. While we do not suggest that these methods be replaced, we certainly think that VW technology may offer a cost-effective, nonphysical, widely accessible method for training both astronauts and ground crew, precisely because VWs do not require physical presence and can be used from every desktop. VW simulations can present important information about physical location and accessibility of instrument panel elements, allow for kinesthetic training, and provide both groups with feedback about the consequences of making particular choices, all without the need for reserving time to practice in a physical simulation room. In other words, VWs provide embodied learning environments that are cost effective and portable, pre-training astronauts and ground crew in a more in-depth manner before heading into analog training situations.

A promising aspect of VWs is that they are suitable for digital, game-based learning. In many cases, this factor is a big selling point for trainees who are eager to get hands-on experience, but who also want the training to be engaging. The difference between game-based VW learning and book learning lies in the

*immediacy* by way of direct feedback that is experienced by people within the VW. Rather than reading about a situation, one is experiencing a situation in all its complexity and seeing the consequences of one's actions in a dynamic manner, which leaves greater sensorial and emotional impressions on individuals. For instance, interviewee 1, a former astronaut, noted a preference for interactive, rather than passive, forms of learning:

*“The hands-on things were always the most engaging, and I wager for all astronauts. People have intellectual curiosity and they’ll enjoy a lecture, but to have a hands-on simulation where you are actually participating as opposed to being just in receive mode, those are the things almost universally that people prefer.”*

Through a VW, astronauts and ground crew may become aware of the consequences of their actions through various forms of game state feedback, direct feedback (for instance, through a mentor that comments on their choices), or feedback via AI as the VW presents new challenges to overcome. Moreover, if a simulation uses narrative-based, emotionally resonant moments, a mental state of “being there” is formed that leaves astronauts and ground crew with important, deeply felt experiences, which are retained more easily than the abstract scenarios offered by simple book learning.

Another element of VWs that is positive for astronaut training is their ability to turn lost moments into learning moments by allowing students to explore learning material outside of classroom times in a playful manner. Pre-mission training requires NASA personnel to go through rigorous and time-consuming training schedules, and we think that VWs may offer astronauts and ground crew a more comprehensive means of understanding particular situations before entering real-time situations. For example, rather than constraining people to the analog, physical dimensions of a class or training room, the portable qualities of VWs allow astronauts to “play around” with a training room simulation before entering, and so they get a clearer idea of the different dimensions of a learning domain. A VW simulation can thus serve to “ramp up” astronaut and ground crew knowledge before they encounter the actual analog component. Astronauts and ground crew can maximize their classroom time, or more expensive training time, by engaging with learning matter at a deeper level in a safe environment. VWs can provide repetition of the material learned as well, giving astronauts and ground crew more opportunities to fully explore various aspects of the simulation on their own before or after being tested in actual analog, physical training rooms. Perhaps as importantly, because VWs are easily configurable, they can be modified easily to reflect novel and challenging or off-nominal situations, as needed.

Below, we will be discussing the benefits of using VWs as experiential learning systems in conjunction with intelligent tutoring systems, embodied conversational agents, and embedded assessment methodologies.

#### **4.1.1 Intelligent Tutoring Systems**

One of the most effective ways to reinforce experiential learning is when a knowledgeable mentor is available for a post-mortem reflection, so the trainee can see through expert eyes what has gone well and what needs improvement. Though this type of learning has proven effectiveness, it is often difficult to have experts available after every hands-on lesson.

AI systems are advancing concurrently with the growth of VWs, and their combination promises to be especially powerful. ITSs can now be used within real-time learning simulations to provide important feedback regarding student performance in the absence of an instructor, thus reinforcing and fine-tuning

particular skills. Briefly, ITSs can be described as (usually) text-based artificial intelligence systems that provide learning moments by reviewing the performance of a participant in real time within a simulation, or by conducting post-performance reflection.<sup>2</sup> An ITS simulation also can be coupled with a high-fidelity VW, adding a great deal of value and reinforcement. An example of ITS use in a VW might be in guiding a person through making a difficult ethical or personal decision that affects a group of people, by offering insight, suggestions, or specific techniques that can be applied to the situation when, say, an incorrect choice has been made or an unexpected turn has been taken.

Ideally, an ITS presents a student with a contextual framework from which to operate (for instance, an understanding of particular issues and knowledge required for their choice), lets a student test that knowledge in a practical situation, and then provides the student with feedback and reflection on their performance and the decisions they made. NLP is a key element of ITSs that uses either audio or text input, matching student output semantically with questions or suggestions directly related to the performance. The ability of an ITS to create such responses is an important asset, as teaching skills are often difficult to gain without person-to-person, scenario-based exposure, including various communication skills such as conflict resolution. An ITS can thus impart tacit knowledge skills that are difficult to learn on one's own, but that are critical to mission success.

When interviewed, interviewee 6, senior scientist for BHP Operations who has designed many simulations for training purposes, expressed her belief that ITSs will be integrated with other learning systems in the future and she was “hopeful” about developments in this field. Based on our research,<sup>[11]</sup> we see the ITS as a promising area of development for ASCAN training, because it provides experiential practice for hard-to-learn interpersonal “soft” skills that can help prevent problems between staff and create lasting impressions for understanding in situations where proper communication and decision making is key.

#### **4.1.2 Intelligent Agents**

Another promising research area is the development and implementation of artificially intelligent agents (IAs) that, unlike ITSs, are embodied in some way. That is, they are presented to the learner not simply as text, but as a character that imparts the knowledge via conversational means. Such agents are referred to as ECAs.<sup>[12]</sup> They are extremely useful within socially oriented VWs in that they can be quite expressive in their looks, emotions, and movements. Such agents can interact with trainees in many ways and thus create a more complex simulation for training. Current video games represent just the tip of the iceberg when it comes to developing IAs that can help in providing complex learning situations. For instance, subsequent installments of the game *Half-Life 2* feature a protagonist who is aided and addressed by a female IA who provides objectives, on-the-go tutorials, and generally offers assistance during intense situations. Similarly, ECAs could be very helpful in providing astronauts and ground crew with learning objectives, complex situations, and a practical application of their skills in basic and advanced simulations as part of a specialized and targeted social environment.

For instance, interviewee 2, a high-ranking official who works inside the Mission Operations Directorate, expressed great hope in using IAs to teach key skill sets that are currently not easily available to astronauts, but would be helpful:

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<sup>2</sup> For in-depth discussions of ITS see Morie, Verhulsdonck & Lauria 2010b <sup>[11]</sup>

*“I could see situations that I could put somebody in and have them interact with an IA to get some learning objectives I wanted. [For example] I could put somebody in a situation and I could take my IAs and give them the characteristics I wanted this person to deal with. Say I wanted to teach somebody conflict resolution and have them practice conflict resolution in a VI could give my IA certain characteristics. [For instance] they could be a difficult person, and I could get all of that into the IA. I could put folks into different situations because I could program my IAs to have those particular behaviors that they may not get in the real world because they may not have that combination in any given real-world situation.”*

Furthermore, the interviewee was convinced that these types of agents could be used for both basic (“fundamentals”) and advanced training purposes. As most people are aware, real-time situations are often complex, messy, and impacted by various elements such as group interactions. VWs coupled with ECAs offer an excellent “testing ground” to a person who can thereby experience such situations in an emotionally resonant and pedagogically meaningful way.

NASA currently has several facilities to train flight controllers. Training takes place incrementally using analog physical facilities. Part of the promise of VWs and IAs would be their ability to make ASCAN flight training more portable and less time constrained. Pre-training for analog situations could be facilitated, and more complex situations such as malfunctions also could be provided before ASCAN arrival at analog training facilities. For instance, a VW could provide an ASCAN with an off-nominal situation where various IAs may, at times, interact with the person being trained, and provide differing accounts about what needs to be done. When asked what types of training could be facilitated by VWs, interviewee 2 further expressed her idea of how this type of training could benefit and augment current ASCAN training:

*“We have several different facilities that we use to train our flight controllers. And they start from having one or two people talking about a specific system. And they may be working with that system, and calling up their displays for that system, and getting to know them, and looking at their procedures. But it’s just people in that system. And then it will grow, and they’ll have say, three more systems, and a flight director. Now you have a bigger team working together, and they’re engaging in nominal procedures, and malfunctions that happen, and their malfunction response. And then we get even bigger and get the whole team together who would be involved in supporting either a shuttle mission or a space station increment. So at any of those points, especially the first two, I think we could put that into a VW and practice. I mean even if it is just one person with some IAs at the other positions. They have an opportunity to practice their malfunction response. They can practice their procedures and procedure familiarity. There [are] a lot of things that we could do in a VW, even at an advanced stage I think.”*

When asked what a good application would be for VW training, interviewee 2 answered that she favored “mini sims.”

*“Just putting them virtually in their work environment and allowing them to work through scenarios, either with 1) IAs ; or 2) with other flight controllers there with them so they are all in the VW. So they can just practice those things that I mentioned before: running their nominal tasks, running their procedure, malfunction recognition and response.”*

Even further, the same interviewee saw the potential of using VWs and IAs (or other astronauts, ground crew) as a means of benchmarking crucial SFRM skills:

*“So I think, for the ASCANs, if we could develop some in-station or in-spacecraft scenarios that they can work or interact with other ASCANs or intelligent agents that we could put them in an environment that allows us to better assess their SFRM skills in a real environment.”*

Through such “hands-on” situations, we think that many crucial skills can be developed if NASA were to teach SFRM skills by creating VWs with IAs such as ECAs and ITSs.

In other words, there are great opportunities here for NASA to create benchmark components within VWs for ASCAN performance on a number of different elements, including:

- General SFRM skills (spatiotemporal skills, nominal/off-nominal task skills, diagnostic/malfunction skills)
- Communication “soft” skills (problem and conflict resolution, interpersonal/intercultural skills)
- Leadership and team skills (task diagnosis, management, execution)
- Individual ability to deal with stress for varying duration (further discussed under “resilience”)
- Technical tasks (maintenance, spacewalks, equipment repair/troubleshooting)

Some of these skills are currently taught by way of in-person board games or role playing requiring people to be physically present. Likewise, instrument training is done in analog training facilities. This makes training for these types of skills reliant upon scheduling facilities and multiple astronauts to be present. While we do not suggest that the traditional elements of training be replaced, we do think that using VWs with ECAs and ITSs can be a valuable supplement to such training, allowing, as it does, additional personal practice that does not require scheduling of physical assets, or coordination of trainees or role players.

Next to their ability to be portable, active, and “hands on,” VWs also can benefit astronauts and ground crew by providing a safe, personalized learning environment that they can access at any time. VWs provide a safe environment in which to test and improve one’s skills without fear of social ostracizing or repercussions due to failure, or risky outside approaches to challenging situations. Because they can practice at will, and perhaps take bigger risks, students may gain a deeper understanding of complex skills that can support the challenges of long-duration space flight.

As we discovered during our interviews, current SFRM training is tightly scheduled and uses learning flows, but there are few, if any, 24/7 training facilities that function as personalized learning environments for astronauts. Current developments in online learning show that course management systems can be effective for long-distance learning and minimizing the requirement for classroom presence. Like online learning, one of the obvious benefits of VWs is their accessibility for facilitating personalized types and on-time online learning. When asked if VWs were to be incorporated as supplemental training and whether they could accelerate training, interviewee 3, a psychologist who works in the training standards integration group, affirmed that it could have potential benefits:

*“Now, I agree it would increase their tacit knowledge. Hey, you’re part of the experience of it. Now you have experience as opposed to none. I don’t know how fast that would be in terms of speeding up their knowledge. But in terms of convenience and improving their tacit knowledge, that would be improved because you would be able to access this simulation based upon the individual student’s timeline as opposed to making sure it follows a particular flow with an instructor.”*

In conclusion, we see not only a benefit in providing VWs as part-task training simulations, but as a way of perfecting core SFRM and other skills by giving astronauts opportunities to work on these skills individually or through scheduled time with VW learning. Furthermore, working on personal, social skills may be less awkward for astronauts in VWs and may bolster their ability to perform in face-to-face contexts by giving them the opportunity to train for these crucial skills in the safety of a VW with IAs. This type of learning may be more motivating for some people to learn highly valuable skills that they may personally feel they lack without fear of social penalty. Coupled with intelligent tutoring, these systems can help astronauts gain greater insight and help them hone in on and rehearse various areas in which they need improvement.

## **5.0 Academy, Space Flight Resource Management, Teamwork and Ground Control Efficiency Countermeasures**

### **5.1 Virtual world social interaction and intercultural issues**

As part of long-duration flight mission preparation, we also foresee a great need for international, long-duration crews needing to “stay in touch” with colleagues and to develop opportunities to interact with each other socially and culturally, pre-mission. People who have known each other for a long time are able to communicate with greater understanding due to shared history, affinity, and social bonding. We see this as crucial for long-duration space flight crews, as they must rely greatly upon each other throughout the mission. VWs can facilitate social interactions by having astronauts and ground crew create avatars that resemble themselves (“veritars”), and that provide optimal remote (non-co-located) communication with fellow personnel. The obvious benefit of using the social network capacities of VWs (such as avatar co-presence, chat, instant messaging) would be in creating greater group cohesion, sharing learning experiences, and getting to know other crew members socially and culturally before they embark on their mission.

Interaction between different cultures requires overcoming not only language barriers, but also social and personal cultural histories. According to Hall,<sup>[13,14]</sup> a difference exists between cultures that rely highly on historical customs and social cues to establish context (high-context) versus those cultures that use verbal expression to establish context (low context). Roughly, Japanese culture can be identified as high context in that it places high importance on social customs and gestures during communication, whereas cultures such as the United States and the Netherlands can be characterized as low to middle context in valuing verbal expression over custom to help establish context. To those not used to it, high context culture may seem to favor ambiguous, distant, and indirect communication, whereas low context culture is more accessible but highly reliant on verbal communication to clarify. As a result, different cultures communicate differently, which is crucial for ASCAN training. Likewise, differences exist between various cultures in people’s level of comfort with ambiguity and uncertainty, hierarchy, social position, and community.<sup>[15,16]</sup> These intercultural factors will most definitely affect group communication in future international crews and require cultural sensitivity and social acclimatizing that can be rehearsed and learned through VW training.

In conclusion, as tight training schedules in multiple locations and the international diversity of future crews increase, we foresee the importance of VWs for providing a much-needed infrastructure and framework for social interaction and enhancing group communication and understanding.

## 6.0 Physical Countermeasures

During our research, we also focused on the physical training that would be necessary for long-duration flight. Astronauts will need to be trained for particularly strenuous conditions in which their physical state is severely tested. Much of this countermeasure training requires understanding of the medical consequences of microgravity on the human body. Briefly, the most serious of these conditions are loss of bone density and muscle mass, and vestibular and hemodynamic atrophy (“space brain”) affecting acuity, cognitive functions, balance, and spatial orientation. For this purpose, we recommend that NASA astronaut training involve benchmarking of balance performances, which can be accomplished through coupling VVs to haptic feedback (resistance or touch feedback). This can provide ongoing measurements and insight to medical personnel monitoring the crew members’ physical abilities, and help indicate their readiness to perform certain key tasks for long-duration space flight.

Physical performance within new gravities and environments can be simulated via VVs and can provide valuable metrics. As interviewee 4, a senior scientist within Space Life Sciences, remarks:

*“[People] evolved for 24 hours in a day, in 9.8 meters/second<sup>2</sup> - the acceleration for gravity. And virtually all life we know and understand on this planet evolved in that. So we, as best as we can understand, have no preformed design to adapt to a lower gravity. We have some design for hyper G, but not for lower G.”*

An important part of long-duration mission success thus rests upon developing models that can simulate these conditions. Part of the process of “adapting” to such an environment may come from modeling physical conditions in a VV as a transition space. Presenting a visual analogue to tasks that astronauts are required to perform in low gravity or microgravity environments, VVs may provide a good modeling space to train astronauts to adapt to such conditions through, for instance, a high-fidelity head-mount display or on a computer screen. Such methods would especially be useful when combined with physical tasks (i.e., moving an object), because they help people adapt and transition to these conditions. Because VVs are malleable, these conditions also can be quickly changed to prepare for the shift from microgravity to low gravity by providing a greater sensorial experience to astronauts of object weight through haptic feedback when doing manual tasks. We believe such VV training presents an excellent way to benchmark and monitor physical performances that are crucial to long-duration mission success.

## 7.0 In-flight Resiliency Countermeasures

In addition to physical health, long-duration missions also require great *resiliency* on behalf of crew members while in flight. For this reason, preflight countermeasures should emphasize successful techniques that may help create *individual* and *group* resiliency. Akin to an athlete training for a long marathon, the concept of resiliency is based on positive thoughts, effectively coping with stress, psychological self-protection, individual fitness, and generally making sure that one is prepared for adversity. Resiliency training is used by the military to prepare troops for coping with the extreme and conditions of war so as to avoid trauma by giving individuals skills to be emotionally, physically, and psychologically resilient to long-lasting adversity and duress.

We believe that long-duration space flight also requires astronauts to train for resiliency. Individuals selected for long-duration missions will need a complex skills set that includes vast amounts of intellectual, individual, and physical reserves, but also strong coping skills to deal with harsh conditions involving claustrophobia, social anxiety, and the high stress of adverse environmental conditions. As explained by interviewee 1, a NASA employee working for Wyle in human space flight programs and ongoing research projects, NASA currently trains for high-stress decisions, but does not specifically focus on individual or team resiliency:

*“I don’t think there was any training that specifically catered to that [resiliency]. We do get a lot of training in stressful environments. Granted we don’t do shuttle mission simulations anymore, or at least won’t once the shuttle is gone, but that was very high stress. Alarms flashing and things breaking around you, and you had to recover from them in real time. Also in the training pool, they would simulate things breaking, and we would have to respond in real time based on our knowledge and skills.”*

While NASA simulates stressful situations and off-nominal/nominal malfunctions, a gap exists in astronaut training for resiliency that prepares flight and ground crew to be physically, intellectually, and psychologically resilient and ready with techniques that can help them adjust quickly to hostile environments, troubling social situations, and conditions that test their mental and physical reserves.

VWs can be designed to mimic harsh conditions and physical impacts visually, and also provide a means of tracking information about a person’s mental and physical responses during the experience of such situations. Having this type of data can help a) determine information about the type of person and their natural tendencies; b) track progress and development of astronauts by way of ongoing data analysis; c) create benchmarks for individual resiliency; and d) develop successful strategies and learning methods for astronauts to be more resilient over time. When asked, interviewee 4 mentioned how VWs could be used to train for resiliency:

*“[As] I said, you go through your benchmark series with a number of people. And subsequently subject them to various types of strain. The sleep shift was one of the ones I told about. You could put them in a 6 degree-down head rest setting, which gives some of the analogue fluid shifts you have occurring in space. Then test their performances, and see how they do. And performances that are dexterous, not so dexterous, some that are solely cerebral, I think you would begin to find out where that resilience factor is, and you might actually contribute more to understanding what you need to do to keep people healthy and capable for very arduous missions.”*

Benchmarking is an important asset to NASA in establishing ways of ensuring mission success. By creating benchmarks, potential errors by personnel are minimized because benchmarks ensure that the person who is performing the task has been trained and optimized to do so. As interviewee 4 mentions, benchmarking resiliency will play a large role if long-duration missions are to be successful:

*“The resilience side of this takes in a part that I have a personal interest in, no expertise but a personal interest. That is looking at performance. We can measure performance in a number of ways throughout training, and you do this. But the realities are when you fly a spacecraft like the shuttle and you are up there for extended periods of like 17 or 18 days, which is a longer mission, and the Commander has to come back and land this spacecraft and actually operate that craft within minutes of reentering 1G, his vestibular system is not fully readapted yet. We are very fortunate because the landings have all been acceptable. So we haven’t had anybody out of nominal range.”*

Long-duration missions will require retraining and adaptation to gravity that can be done, in part, before the return to Earth through VW training. During the mission, flight crew could use spatial tasks to test their vestibular systems and so prepare for landing. By using VWs and coiled spring objects in space to train for these tasks, flight crew could readjust to gravity by helping them reorientate to increased gravity after spending a long time in microgravity. Another benefit to using VWs is that astronauts could receive a personalized training schedule that would provide them with direct biometric and visual feedback about their performance and so could help them improve their condition. Likewise, these data can be shared with ground crew to determine which person has adapted his or her vestibular system for optimal landing success.

## **7.1 Individual resiliency countermeasures**

Next to benchmarking, VWs could be crucial for individual relaxation and entertainment purposes and provide another means of resiliency. Given the time lag, prerecorded VW sessions could, for example, have mindfulness therapy to reduce stress. Current research at the Institute for Creative Technologies at the University of Southern California focuses on using VWs to treat soldiers with post-traumatic stress disorder, and more strides need to be made in finding out the potential of VWs for helping humans relax in otherwise stressful environments.

To further facilitate resiliency, our research indicates that other directions for VWs exist that potentially could be of benefit to flight crews. As a result of long-duration space missions, flight crews could experience social anxiety, claustrophobia, and depression or simply miss being “back home.” NASA understands the psychological impact of claustrophobic spaces and should look to the ability of VWs to mitigate such feelings. Briefly, examples of this type of research could be based on socially isolating crew and using VWs to help them relieve boredom, anxiety, and social phobias as a result of the isolation. A good example of the effects of an enclosed environment was the 2010 mining disaster in Chile, which left a group of miners in a small, enclosed space, where the miners could potentially suffer from depression and anxiety. NASA sent psychologists and other trained personnel to assist in the effort to keep the miners in good spirits until their retrieval from below ground. Being able to connect with the world (albeit virtually) will be an important aspect for long-duration space flight.

Long-duration space flight will not only create anxiety-inducing conditions, but also require adjusting to the loss of circadian rhythm as a result of being in space. As any person who has experienced jet lag

knows, the change in time severely affects functioning and creates less-than-optimal conditions for astronauts. Though we know that NASA research covers a wide range of ambient and mood-setting lighting to create an artificial day and night rhythm for astronauts, we see benefits to using VWs as a means of complementing these efforts. For instance, while waking up, the astronaut could be seeing a VW in which the lighting creates a mood of early morning. We also propose that VWs could provide real-world or imaginary spaces to explore if crew members feel the need to escape for a moment, have IAs that function as emotionally supporting “buddies” to flight crew, or provide the flight crew with “virtual vacations” in VWs. Regarding the potential of VWs for NASA, interviewee 4 particularly remarked about the last element as promising:

*“I can see how they [VWs] would be useful in a number of settings, particularly for virtual vacations. You have people who are living in a can for 30 months and have no place to go so to speak. There is not a one of us who does not seek some type of release at some time or another to get away from everybody, everything. To go on a vacation, get away from everything, go diving, do whatever you want to do. I think these kinds of technologies will enable that to be possible. And people will get a lot of reinforcement from being able to depart, get diverted away from the mission, the tasks, all that stuff.”*

The ability to be resilient also depends on retreating at times to regain strength and energy, and to foster new ideas. The importance of providing VWs to crew would be of tremendous benefit for relaxation, as well as an opportunity to focus on non-work ideas and to enhance a sense of circadian rhythm. As in regular professions, such individual relaxation is of tremendous importance to people in refocusing their efforts. In addition, VWs can provide social spaces for astronaut families to communicate in an asynchronous fashion with their loved ones in space.

## 8.0 Delayed, Asynchronous Decision-Making Countermeasures

Another element that will have a pronounced effect on long-duration flights is delayed responses from ground crew and home. Not only does this create a psychological barrier between ground staff and the flight crew, it also creates a need for support systems that introduce more autonomy to those on the off-world mission. This includes dealing with functional failures without immediate intervention by ground crew, as well as autonomy in setting schedules according to the needs of the crew in space. Due to the great distance, communication lags are expected to last at least 20 minutes or more each way. As a result, any communication must be optimized and task focused. According to interviewee 4, long-duration flight missions require great mental reserves, including “psychophysical, decision-making processes, perception processes.”

The consequences of long-duration space flight communication delays place a greater importance on the *autonomy* of the flight crew’s decision-making processes to resolve issues on their own without immediate assistance from ground crew. For this purpose, we also propose astronauts and ground crew interact with a VW system for decision making that simulates this delay and tests their ability to make successful decisions. This can help both flight and ground crew to train for such situations, while also giving NASA researchers the ability to benchmark and optimize personnel performance related to delayed responses. We propose a VW-based delayed, asynchronous decision-making system (DADS).

We envision this DADS comprising these elements, all involving a time lag for responses with ground crews and experts:

- A VW simulation that presents specific (known or expected) situations, as well as unexpected and particularly difficult situations that may cause the mission to fail.
- A decision tree system coupled to a database that allows astronauts and flight crew to diagnose and triangulate various types of problems. The paths through the decision tree can be designed to help in autonomous decision making and to determine which ground crew subject matter expert technicians may be optimal for a particular problem.
- The inclusion of IAs to guide the diagnostic process, and suggest possibilities that might not occur to the on-board crew members.
- An exhaustive database composed of reconfigurable narrative elements coupled with the decision tree system dealing with as many as possible exigent malfunctions and a range of solutions to them.
- A recommendation system that can present possible solutions or suggest solution elements based on input to search algorithms.

Current NASA training uses analog controls and crew feedback to practice for missions. For long-duration purposes, we think it will be extremely beneficial to develop an expert decision-making system to diagnose a problem, to provide possible directions for decisions for astronauts, and to provide time-lagged input by ground crew. Again, the benefit here would be to benchmark quality of decisions and a means of creating well-informed decisions for flight and ground crew. Furthermore, if NASA were to couple the spacecraft working equipment to remote sensing (such as radio frequency identification that would provide information on equipment components), ground crew would be able to pick up any equipment failure independently of flight crew, providing ground crew with a means to troubleshoot the issue while providing the flight crew with important information on how to resolve the issue.

Ideally, astronauts would be able to query ground crew about the sense of urgency, use the decision-making system while waiting for ground crew response, and determine what they need to do and be up to par with ground crew. If the decision-making system also streamed flight crew data from the DADS to ground crew in a data stream, NASA would have an opportunity to see flight crew decisions and, at the same time, work on the initial query (if, for instance, the remote-sensing system had already notified them of the issue before flight crew's notice). Ideally, flight and ground crew data would be transmitted to each other asynchronously to be used as the crew sees fit. A typical protocol to a query could be described as follows:

- 1) Flight Crew
  - Problem -> Initial query with possible resolution and urgency level -> DADS
  - Initial query is sent to NASA with accurate problem description and, if possible, initial proposed resolution to treat problem (malfunction, repair) and urgency level.
  - Flight crew then starts assessing potential solutions using DADS to refine query and find possible solution to problem.
  - Query found in database and matches problem – Solution found and, if possible, await ground crew confirmation. If not possible, flight crew decision can be made with knowledge of best possible solution presented by the DADS.
- 2) NASA Ground Crew
  - Based on initial query, confirm or wait for further instructions.
  - Based on initial problem description and proposed resolution, ground crew provides initial answer to proposed resolution (confirm/disconfirm) or hold for more information.
- 3) Wait for Further Instructions
  - Ground crew sends in-depth instructions to crew on how to resolve problem. After initial query, NASA receives stream of flight crew decisions and gets a better idea of the problem domain and the crew's thinking.
  - NASA crew, based on initial query and input information from DADS, formulates answer. If the problem requires in-depth knowledge, NASA can diagnose problem domain using input from ground-based experts in addition to the flight crew solutions based on their own knowledge and use of the DADS.
- 4) Flight crew combines own decision with that of ground crew for best possible problem resolution, if time permits.

Instead of overtly relying on ground crew, flight crews would be asked to take on flight problems and come to a resolution with the help of the DADS. In this situation, the decision-making system would help the flight crew and ground crew resolve a problem and do so by optimizing their time during the time lag. Rather than waiting for a problem to be solved by ground crew, flight crew would be able to figure out potential solutions to the problem themselves while waiting for a response. Coupled with the input of the NASA ground crew, the flight crew could then make an optimal decision. If the delay prevents this, then the DADS may offer the best immediate choice. In any case, we recommend extensive practice with delayed communication before flight, and optimized decision-making training through some type of DADS protocol when time issues preclude waiting for ground crew input.

## 9.0 Recommendations

In this section, we briefly make recommendations regarding the above results and discussion. Our focus is to provide a roadmap for promising research areas for NASA. Rather than in-depth descriptions, the following should be seen as general directions of research that would be desirable for VW use in preparation for long-duration space flight. We see great potential for research in the following areas, which could enhance NASA's current training procedures. Though we see all of these areas as important, we indicate the difficulty and depth of future research by mentioning whether this research is easy to implement or difficult (in which case it is mentioned as advanced research).

### 9.1 Research for creating virtual worlds as online part-task training countermeasures

VWs can mimic various flight, kinesthetic, and operational procedures. NASA part-task training can be conducted online in a VW before or after analog procedures. Potential technologies of interest for creating part-task training are portable, remotely accessible VW simulations using game-based approaches. Training scenarios should be narratively engaging and emotionally resonant and motivating, and should function as interactive digital environments for astronauts and ground crew to track their progress and performance. Since part-task training focuses on diverse elements, VW simulations need to focus on specific-but-diverse learning objectives for long-duration space flight, which may include:

- Standard Procedural Operations
  - Flight preparation/take-off/monitoring
  - Flight crew—ground crew interactions
  - SFRM
- Kinesthetic and Vestibular Performance in Simulated Microgravity and Low-gravity Environments
  - Flight landing/spatial orientation and perception using microgravity, low gravity, and terrestrial gravity as environmental variables
  - In-flight object handling using coiled springs and visual VW feedback
  - Exercises facilitating cerebral adaptation and vestibular normalcy switching between microgravity, low gravity, and terrestrial gravity
  - Longitudinal sleep angle studies coupled with VW to investigate vestibular and hemodynamic consequence of performing spatial tasks that simulate low gravity/microgravity/terrestrial gravity environments
- Part Task Training with Team Members to Practice Tasks that Require Coordination among Crew Members
  - This can be done even when team members are geographically distant from one another, enhancing the operational effectiveness of the crew when they actually perform team tasks
- Malfunction Responses to Common Nominal and Off-nominal Situations
  - Analytic ability/troubleshooting
  - Decision making
  - Communication
  - Task performance

## **9.2 Advanced research for creating intelligent tutoring systems and intelligent embodied conversational agents in virtual worlds for team-based countermeasures**

VWs can incorporate AI through ITSs and embodied interactive IAs. Through the use of NLP, such artificially intelligent elements can facilitate advanced simulations that go beyond procedural operations. Complex social situations can be supported where multiple elements of knowledge can be tested in a practical manner. Scenarios can include a cognitive framework and a simulation that tests ASCAN performance on different variables of these “soft” skills:

- Communication
- Intercultural (high/low-context, uncertainty avoidance/ambiguity comfort, hierarchy, social position, and community)
- Analytic/troubleshooting in complex and dynamic situations
- Performance under stress
- Decision making
- Interpersonal (e.g., using Myers-Briggs Type Indicator test)
- Group Leadership/Team
- Task performance

As part of this work, simple simulations could be created to test for any of these soft skills. Advanced simulations could be developed to create scenarios for nominal and off-nominal tasks that support learning directed toward more complicated scenarios. These simulations would be comparable to commercial video games and would include various branching scenarios, decision trees, and AIs that respond to ASCAN actions and responses. Complex, randomized algorithms can describe finite state operations and randomized states to create VW analogues to various long-duration flights for social and task-oriented situations.

## **9.3 Research in virtual worlds as online, embodied social networks for astronaut and ground crew (academy, Space Flight Resource Management, team-work, in-flight efficiency countermeasures)**

More focus on social connections and training through VWs may also create opportunities for group cohesion. Because long-duration space flight places greater stress on flight crew, more emphasis will need to be put into team compatibility and cohesion. VWs may create team cohesion by providing astronauts and ground crew with a means to meet other crew members virtually preflight, and form social histories, a deeper understanding of each other’s personalities and communication styles, and knowledge of each individual’s goals and objectives for the mission through the following methods:

- Creating avatars that resemble the physical person (“veritars”)
- Placing greater emphasis on online astronaut and ground crew training through VWs
- Encouraging sharing of learning experiences as astronauts and ground crew and socializing through a VW, and create a community of long-duration space flight crews

However, when one astronaut was queried during the BHP Research Element Workshop as to the perceived benefits of this social enhancement to their training, that astronaut replied that astronauts would NOT do this if it were left to them to do it on their own time. The reason given was that every spare

moment they have, they spend with their families. Therefore, for this to have the greatest benefit, VWs must be emphasized as a key element within long-duration space flight training flows. In turn, this strategic use of VWs would create a social backbone to unite physically remote training colleagues that are living and traveling all over the world, and who must recognize and adapt to different cultural norms.

#### **9.4 Advanced research in using virtual worlds for physical countermeasures**

Next to basic research in spatial orientation, advanced research for VWs for physical countermeasures could be used to study the effects of long-duration conditions (triggering social anxiety, feelings of isolation, loss of circadian rhythm, and others) by coupling VWs to analog physical training exercises in confined spaces to achieve various goals. Potential goals of this type of research would include testing physical feedback given by a VW and providing feedback to astronauts on their performance. Part of these exercises would need to use coiled springs, or other methods, to provide friction for physical exercises that are measured and displayed in the virtual environment. Various research directions can be distinguished based on this idea, such as:

- Establishing benchmarks for optimal physical, psychophysical, and psychological performance in different kinds of gravity
- Establishing protocols for providing biofeedback to trainees on aspects such as eye movement, and physical and hemodynamic activities during vestibular exercises, and creating exercises tied to established benchmarks
- Establishing artificial circadian rhythms that create artificial day/night rhythms for astronauts to latch on to while on long-duration flights, especially after “slam shifts” interfere with normal sleeping patterns
- Performing comparative studies on the difference in VW exposure versus regular, physical training protocols on bone density and muscle mass, acuity, cognitive functions, balance, and spatial orientation (2x2 design, with control and experimental group using alternately, regular training protocol versus VW biofeedback exercises)
- Creating advanced scenarios to test and create spatial and visual abilities using coiled springs and VW interface with audio-visual feedback

An important aspect would be to integrate and test how VWs may augment astronaut crew training by providing feedback to astronauts on their condition and performance during (immediate) and across (longitudinal) VW exercise regimes. This training would ideally be done in confined, isolated spaces such as those currently conducted by NASA in Alaska or off the coast of Florida underwater so that astronauts can prepare for optimizing their exercise routines for long-duration space flight missions.

#### **9.5 Advanced research in using virtual worlds for resiliency countermeasures**

Another promising direction for VW training is the addition of resiliency training to existing astronaut and ground crew training modules. In addition to standard training methods for nominal/off-nominal or stressful situations, creating resiliency techniques and learning methods using VWs can help flight and ground crew maintain a positive mental outlook and physical strength by providing lifelong techniques that mitigate the formation of stress and trauma during missions. Promising areas for resiliency can be found in the following research:

- Psychological effects of keeping in touch with Earth by communicating with family and ground crew through VW interface in the form of “embodied” asynchronous voice conversations with hugs/body language.
- Virtual space “buddies” in the form of a VW IA that supports each astronaut and may help his or her discuss personal issues without fear of reproach by human team members using techniques and scenarios for “virtual” counseling.
- Virtual vacations that give astronauts the opportunity to relax and escape from work by exploring VWs (could be coupled with entertainment, such as gaming, socializing with IAs, or asynchronous communication with public), as well as with simulations of varied weather patterns.
- Mindfulness stress reduction techniques (such as meditation, yoga) delivered via a VW to help destress astronauts and maintain resiliency.
- Virtual Reality Exposure Therapy to help astronauts overcome or cope with adverse, chaotic, or stressful situations that they may encounter during a mission. This is a graduated re-exposure to the triggers that may have induced the initial stress reaction, and is a standard, beneficial treatment for trauma survivors. Some form of familiarization with this technique should be included in pre-mission training.

As we found during our research, resiliency holds huge promise for mitigating the deleterious effects of long-duration space flight, by unequivocal preparation for and understanding of how such stressful or compromising situations can be positively approached from the outset. Astronauts going on long-duration space flights should be expected to be resistant against long exposure to the unfriendly and adverse conditions of outer space as a matter of survival.

Due to the harsh conditions when traveling such long distances, it is difficult to know where to draw the line with practicing for resiliency. It is important to prepare astronauts in the best manner possible, but emphasis should be placed on group and individual survival skills in these environments. Ethical treatment of participants in this type of research is paramount, and standards will need to be put into place to ensure that participants are not harmed or unnecessarily traumatized while training for resiliency. Safety measures to prevent astronauts from getting hurt unnecessarily will need to be carefully stipulated, and any research in this area must pass a medical and psychological ethics review board.

We can emphasize the importance of using VWs for positive ways of relaxing, destressing, socializing and vacationing, as well as for resiliency purposes, that pose little or no risk to astronaut trainees. Other protocols will need to be developed to help with the countermeasures that deal with the impact of long-duration space flight on the physical body as discussed above, but these too will be important countermeasures for improving health during long-duration space flights.

## **9.6 Advanced research in delayed, asynchronous decision-making countermeasures through a virtual world**

Advanced research should focus on creating new methods for ground crew and flight crew to communicate in a VW simulation that factors in a time lag of 24 minutes or longer. Due to this factor, greater autonomy is expected of the flight crew in determining solutions to problems after initial take-off. The delay requires simulating communication and decision making in which dynamic problems need to be resolved in short order. Communication will require express operational commands to indicate whether a problem is nominal or off-nominal, the urgency, and proposed solution as given by flight crew. Depending on urgency, flight crew will need to assess whether they can wait on ground crew permission

or whether they can proceed in resolving the issue. They should be able to start problem solving using a DADS before the initial inquiry even reaches the ground crew. Likewise, time will need to be optimized for ground crew to converge and reach a decision in assessing flight crew inquiry. New methods may include:

- Creating/implementing remote-sensing communication protocol for long-duration flight equipment (radio frequency identification to wireless to ground crew message of equipment failure).
- Creating communication protocols for transmitting initial inquiry and proposed solution.
- Creating DADS database that can be accessed by flight and ground crew, and used for training and long-duration mission purposes.
- Creating simulation with IAs, and a recommender system for problems with an accessible database using optimization algorithms for astronauts to practice in nominal and off-nominal situations
- Using flight crew autonomy and analytic skills first and, if necessary, possible ground crew input to decide and converge on a solution.
- Receiving and streaming solutions to help NASA use time productively, and gathering subject matter expert technicians and solutions quickly by working concurrently on the problem domain together with flight crew.
- Providing flight crew with the ability to assess their own solution and compare with NASA ground crew if time permits; else, proceeding with autonomy and being assured of quality of their own decision by database recommendation.

A VW may help astronauts practice these skills, especially if visual information can be tied to technical information. For instance, a powerful way of locating a malfunction in a flight cabin might be tying a VW model of the cabin to a database containing technical information about that particular area. If the area of the problem is unknown, a text database that functions to identify the problem and localize it in a particular area also may be useful. Protocols for this type of communication would need to be established and be based on the premise that flight crew solves most pressing problems on their own with minimal assistance from ground crew, while less critical problems may require waiting for ground crew confirmation.

## 10.0 Conclusion

The efforts of this year-long research project focused on looking at ways that astronaut and ground crew training for long-duration missions could be enhanced through the use of VWs. VWs provide various means of mimicking and simulating environments, afford social connectivity via avatar use and interactions, and can be very efficient and cost-effective training modalities. Depending on future developments in wearable computing, flexible interfaces, and processing speed, we may soon see complex augmented reality systems that form a virtual grid over the physical world. Current mobile technology is already at the forefront of such augmented reality (for instance, apps and GPS for mobile phones allow one to scan an area and receive information about nearby restaurants, hotels, pharmacies, and museums). On the other end, VWs also are getting closer to photorealistic environments and can even import aspects of the physical world through features such as Google Mars and geographic information systems. The merging of the physical with the virtual has great potential for long-duration space missions. Through wireless transmission, augmented reality, and novel, embodied ways of communication in VWs, newer forms of interaction with fellow humans and our environment abound.

VWs can play a crucial role in acclimating us to other versions and conditions of reality that exist in the extraterrestrial. Moreover, since they also can be mined for data, they can be used to monitor progress, both in pre-mission training, and throughout future missions where VW applications are incorporated. In mining data, benchmarks can be established for physical, psychophysical, and psychological strengths that are required to exist and operate in extraterrestrial realities. VWs can be personalized and enhanced with ECAs and ITSs, and with characters that can aid as countermeasures for negative factors associated with isolation and separation. As humans, we can learn about self in relation to other humans by connecting to these AI systems. Finally, through the broad range of scenarios possible through VWs, ASCANs can learn to prepare and strengthen their minds for complex problems and adverse conditions that they will encounter in long-duration space flight. They can learn how to deal with fellow human beings, and optimize decision-making and leadership skills. They can find relaxation, renewal, and comfort within the simulacrum of VWs, as well as connect to their loved ones, and learn to acclimate to and deal autonomously with the communication delays they will encounter. As we hope to have shown in the above examples and recommendations, the potential of VWs for astronauts, flight, ground crew, and overall mission success cannot be overlooked as NASA proceeds into the future. The benefits of the richness of VWs and their realization as embodied Cyberspace constitute a crucial bridge for ensuring successful long-duration space missions, those future voyages that will serve to evolve all humankind and bring us better understanding of our place in the universe.

## 11.0 Glossary of Terms

**Avatar** – literally, the “embodiment” of someone in a virtual space.

**Course Management Systems (CMS)** – online systems that are used to track learning, and that are currently used for distance learning.

**Embodied Conversational Agents (ECAs)** – virtual agents that can respond and interact intelligently with a person through natural language processing, which makes semantic inferences about what is being said by that person by matching their language to various scenarios.

**Intelligent Agents (IA)** – agents act autonomously to respond to a person using Natural Language Processing and thus appear as artificially intelligent.

**Intelligent Tutoring System (ITS)** – uses the input of a person’s responses to a task, gauges their performance on the task, and asks follow-up questions that provide that person with post-task reflection. An ITS can provide important mentoring opportunities for students.

**Natural Language Processing (NLP)** – the use of artificial intelligence to parse either voice or text input into understanding of what is being conveyed in the input, and responding to the input through computer artificial intelligence output.

**Virtual Environments (VEs)** – spatial virtual reality applications.

**Virtual Humans** – intelligent, embodied conversational agents that can converse with a person for a variety of purposes and create a more complex simulation.

**Virtual Reality (VR)** – early versions of virtuality where reality is simulated in an applied manner.

**Virtual Worlds (VWs)** – social versions of virtual reality environments and use computer-mediated communication such as instant messaging, chat, and avatar-to-avatar interactions.

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13. ABSTRACT (Maximum 200 words) This report summarizes findings and presents recommendations based on a year-long research effort on the benefits of virtual worlds (VWs) for astronaut and ground crew training for long-duration space flight. The components of this research included a literature review on existing applications of VW technology to space flight, an operational assessment on the most promising aspects of using VWs for training for long-duration space flight, interviews with a panel of six NASA experts on the use of VWs, and participation in a 3-day Behavioral Health Program Research Element workshop. Based on the above components, this report summarizes the main findings of each of these components to describe current developments in VWs and use of virtual technologies as applied to the context of long-duration space flight. Furthermore, as a result of our research, we also assessed current training protocols at NASA and found exciting opportunities for augmenting existing practices for long-duration space flight. Lastly, based on our assessment, we recommend promising directions of future research for NASA long-duration space flight with an eye to implementation and cost effectiveness. Our findings are that VWs are a promising technology for learning, preparing, and supporting long-duration space flight.				
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