# An Immersive Approach to Providing Mishap Awareness Scenario Training for Ensuring Readiness (MASTER)

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## ABSTRACT

Although aviation mishaps are relatively rare, such incidents are devastating due to the high probability of injury or death and financial loss. Factors such as spatial disorientation and lack of situational awareness are known root causes of many aviation mishaps and generally lack effective training. This situation is exacerbated by the fact that current training for such factors is typically confined to traditional methods (e.g., lectures)—which typically deemphasizes kinesthetic learning. To address this significant challenge, Aptima has developed a scenario authoring tool for experiencing realistic renditions of aviation mishaps caused by spatial disorientation. The MASTER system enables aviation instructors to create immersive mishap scenarios from realistic mishap data and intuitive creation tools while providing multiple methods for media export (e.g., 360-degree video, virtual reality [VR]). Some of the common causal mishap illusions demonstrated by the MASTER system include the following: false/fixed horizons, black holes, and the somatogravic illusion. This approach aims to enhance training efficacy by providing multiple methods of immersive mishap replay along with a dedicated plan for evaluating the effectiveness of various training media. In summary, the anticipated components of the MASTER system work to streamline scenario authoring by aviation instructors and provide optimized training for typical aviation mishap factors. Although more work is needed, our preliminary work indicate that rapid scenario authoring is feasible and that immersive training media—such as VR—can potentially increase training efficacy.

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## INTRODUCTION

Aviation mishaps continue to be a major problem for many Department of Defense (DoD) agencies. Conventional wisdom would lead one to believe that as technology continues to advance—especially as it relates to automation and autonomy—mishaps would decrease commensurately; unfortunately, this does not seem to be the case. An investigation into publically-available data regarding Class "A" mishaps (i.e., mishaps that involve the loss of life or aircraft damages in excess of $2 million dollars) shows that the frequency of such mishaps has remained relatively unchanged, and in some cases, even increased (see Figures 1 and 2). While these mishaps have numerous postulated sources of causality (e.g., training budget cuts, expedited training timelines, lack of effective training), the actions taken by human operators remain at the center of many investigations. It is important to recognize that not all mishaps are unavoidable from the operator's standpoint (e.g., equipment malfunctions); however, many of the reported aviation mishap have been shown to be a direct result of human error, with common causal factors such as spatial disorientation or loss of situation of situation awareness (McGrath, Rupert, & Guedry, 2003; Poisson & Miller, 2014).

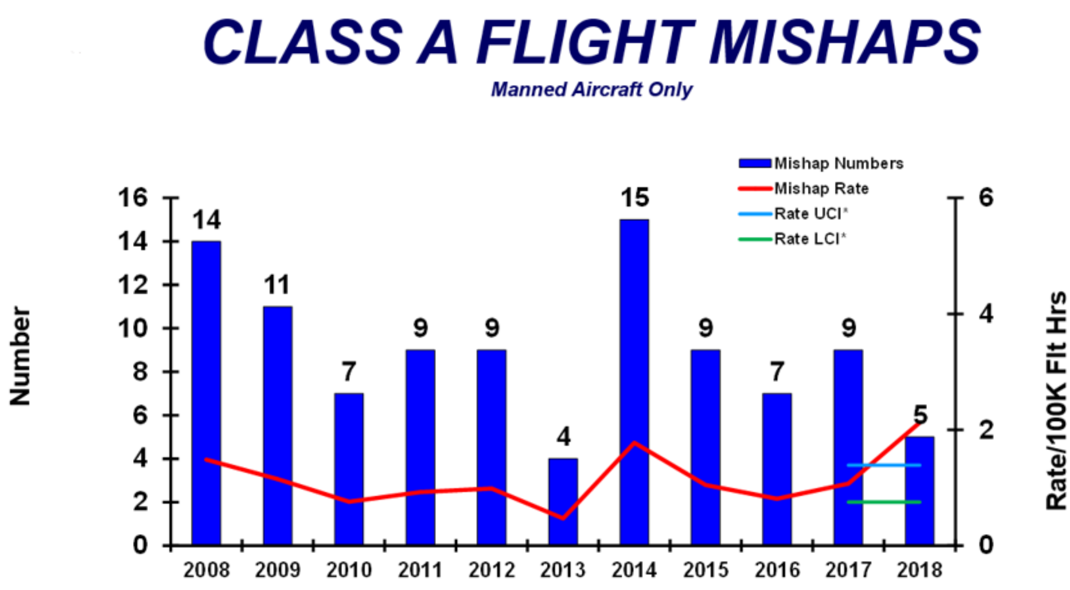


**Figure 1. Depiction of Class A Naval flight mishaps for manned aircraft over the last 10 years (figure and data courtesy of publically available statistics from the US Navy).**

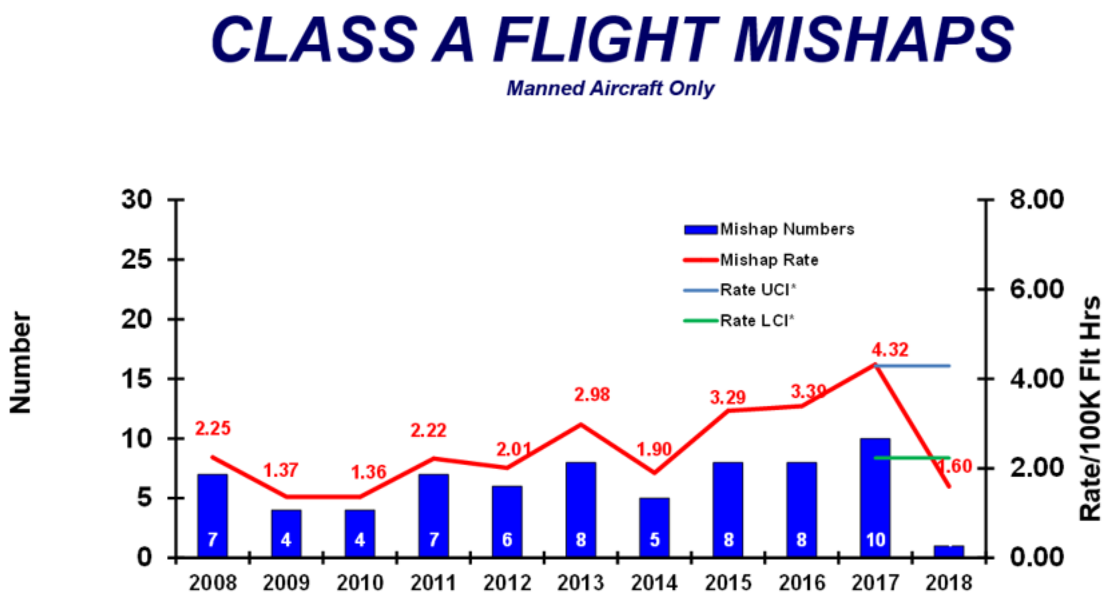


**Figure 2. Depiction of Class A Marine flight mishaps for manned aircraft over the last 10 years (figure and data courtesy of publically available statistics from the US Marines).**

The preceding figures show that while relatively infrequent in absolute terms, the importance of Class A mishaps and associated causal factors should not be diminished as their resulting shockwave can be felt in numerous ways. First and foremost, many aviation mishaps involve the loss of a life or multiple lives, a fact which cannot be overstated. Additionally, the financial ramifications from material losses and damage among other costs can also be significant. If such a mishap occurs in hostile or remote environments, the potential for theft or leakage of sensitive or classified technological innovations is also a possibility. A good example of this possibility is the technology that was recovered at a Sikorsky UH-60 Black Hawk helicopter crash site during the raid that killed Osama Bin Laden (Lorenzo & Liu, 2017). This list of devastating consequences could easily be lengthened—but for the sake of brevity, it is sufficient to say that Class A aviation mishaps have devastating stated and latent consequences for the involved parties. This observation is paramount among mishap research and serves as a guiding beacon for any related work.

**Spatial Disorientation**

While the aforementioned possible mishap factors are of great importance, this paper and associated work is specifically focused on spatial disorientation (SD) and, to a lesser extent, the lack or loss of situational awareness (SA)—as these phenomena have been identified as major causal factor in numerous aviation mishaps. SD and lack of SA occur when the perception of the pilot does not agree with reality. These conditions typically result in the erroneous interpretation or estimation of aircraft altitude, attitude, or airspeed—which can ultimately lead to grave mishaps if not remedied in a timely manner. The onset of SD or lack of SA can be attributed to multiple factors, which most notably include: physiological effects (e.g., vestibular sensations, visual illusions); weather, improper decisions or procedures; and psychomotor errors (Endsley, 1995; Endsley, 1995). A study in 1996 that examined all the F-16 Class A mishaps from 1975-1993 noted that factors such as SD, channelized attention, and loss of SA accounted for approximately 30% of total pilot errors (Knapp & Johnson, 1996). In 2011, Gibb and Ercoline reported that SD was a contributing factor in 33% of all mishaps (with a fatality rate of nearly 100%). These statistics are prevalent and point to an overarching conclusion that mishaps caused by factors such as SD and lack of SA are an old and challenging problem that is in need of new and innovative solutions.

Since aviation mishaps are unique, relatively infrequent, and arise from multiple contributing factors, it is understandably difficult to adequately train prospective pilots to avoid them. Aviation mishaps that result from SD or a lack of SA are especially difficult to train as the related vestibular effects are notoriously difficult to stimulate and measure—especially without access to a full-motion (i.e., six degrees-of-freedom [DOF]) simulator, which are prone to inducing simulator sickness. Even when full-motion simulators are available to simulate SD, a large portion of operators within the military do not receive this type of training—as such treatment is typically prescribed to those who battle motion sickness (Estrada, Adam, & Leduc, 2003). This predicament is exacerbated by the reality that when pilots are subjected to such phenomena in a live aircraft, those who are underprepared may not receive another chance to learn and utilize the appropriate procedures. In response to this worrisome situation, the US Navy has developed rigorous SD training that is required for each student naval aviator as part of the aviation physiology segment of the Naval Aviation Survival Training Program (NASTP). Such training primarily consists of classroom instruction, videos meant to prompt and support discussion, and kinesthetic training provided by platforms such as the Multi-Station Disorientation Demonstrator (MSDD) and Barany chair (shown in figure 3). The MSDD allows trainees to experience effects such as: sub-threshold rotation, somatogyral illusion, Coriolis effect, nystagmus, oculogyral illusion, somatogravic illusion, G-excess illusion, or autokinesis (Bles, 2008). However, the MSDD is notorious for requiring frequent repairs, is somewhat antiquated in its capabilities to emulate SD, and is in a fixed location.


**Figure 3. The Multi-Station Disorientation Demonstrator (MSDD)**

While these current training methods seem to be effective during indoctrination, there are numerous prevalent issues with SD mishap training in its entirety: 1) it is difficult to create and adapt mishap scenarios into a format that supports didactic instruction; and 2) the general lack of trainee immersion does not promote the retention of key knowledge, skills, and abilities (KSAs) in the instance the trainee is exposed to one of these events; and 3) refresher training efficacy and the devices that help achieve such training are generally lacking. These discrepancies indicate that modular, cost-efficient, and immersive approaches would be of great utility to the Navy and/or any other entities facing similar problems. The subsequent sections of this paper will discuss new methods, theory, and a potential solution for developing more-immersive training scenarios that recreate mishap events from some of the leading contributing factors to aviation mishaps. The solution described below will focus on the methodology and tools need to provide Mishap Awareness Scenario Training for Ensuring Readiness (MASTER).

The proposed MASTER solution consists of two complementary parts: 1) a literature-backed instructional strategy to ensure that operator readiness and learning are not sacrificed by innovative methods; and 2) a scenario authoring platform for aviation instructors to rapidly generate, tailor, and export aviation mishap scenarios to various immersive media based on realistic data. Each of these components will be discussed in the subsequent sections.

## INSTRUCTIONAL STRATEGY

To develop a conceptually grounded and operationally relevant instructional approach, the team leveraged evidence-based scientific research and subject matter expertise in the targeted training context. According to the Knowledge-Learning-Instruction (KLI) framework (Koedinger & McLaughlin, 2014), the process through which KSAs are acquired vary based on the specific training objectives. Understanding the context is critical for identifying and linking the essential KSAs (e.g., SD causal factors and detection of SD) to specific training objectives (e.g., maintaining spatial orientation during flight over featureless terrain), which in turn will guide the selection of instructional approaches that are likely to yield the best learning results within the target context (Cierniak, Scheiter, & Gerjets, 2009). For example, when dealing with dynamic, complex, multi-goal learning environments, such as aviation mishap simulations, researchers have increasingly begun to argue in favor of problem-solving-first approaches (e.g., exploration, discovery learning) despite the risk for heightened cognitive load (e.g., Kalyuga & Singh, 2016). Specifically, in some cases, engaging in productive failure (i.e., solving complex problems without support) prior to explicit instruction does not inhibit learning and instead leads to deeper conceptual understanding and greater transfer compared to explicit instruction-first approaches (Kapur, 2008; Kapur & Bielaczyc, 2012; Loibl & Rummel, 2014). Problem-solving-first approaches actively engage trainees in the learning process from the start, which can have learning benefits as well (e.g., Fonseca & Chi, 2011). However, there is also a "time for telling" in these approaches, where explicit instruction and feedback is necessary to fill in knowledge gaps and solidify the connections developed during the initial exploratory problem-solving phase (Schwartz & Bransford, 1998). Therefore, a solid instructional approach employs and combines a number of instructional strategies to optimally address the needs of the learner at different phases of the learning process.

Dynamically matching the instructional approach to the needs of the trainees, without impeding learning, is no easy task. Instructional techniques that are highly effective with inexperienced learners can lose their effectiveness, and even have negative consequences, when used with more experienced learners. This is known as the expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003). In an effort to help guide instructors through this challenge, and ultimately achieve operator readiness, a literature-backed overarching instructional approach, aligned with the problem-solving-first perspective, was developed and consists of six main steps (Figure 4). These steps walk an instructor through a series of critical instructional activities, from understanding and assessing the current state of a learner's KSAs (Step 1) to assessing the future, post-training state of a learner's KSA (Step 6). A brief summary of the purpose of each of these steps is provided below.

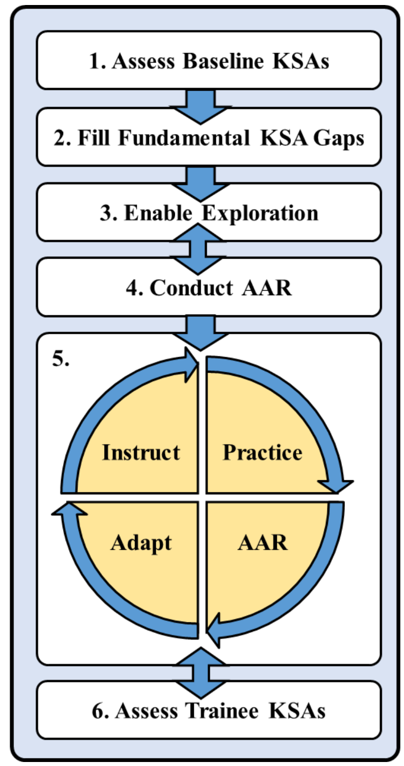


**Figure 4. Overarching instructional strategy for the MASTER system**

In Step 1, learner baseline KSAs need to be assessed to take into account individual learner proficiency levels, which should inform the level of adaptive guidance and instruction provided and can help avoid the expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003). This is critical as the ability to transfer learning to novel operating contexts warrants a solid foundation of prerequisite knowledge (Opre, 2015). Specifically, the goal of this step is to uncover fundamental conceptual, factual, or procedural gaps that may need to be addressed before any subsequent training tasks could be beneficial, especially if those tasks are additive and progressive in nature. For example, a student may need to be capable of listing the numerous causal factors of mishaps and the associated strategies for avoidance or remediation. If a fundamental KSA gap is identified that would preclude learning in the next steps, the instructor should take steps to develop that KSA or identify what scaffolding or guidance would be needed to facilitate learning (Step 2). Adaptive guidance has been shown to elevate trainee self-efficacy, on-task attention, and interest (Bell & Kozlowski, 2002).

Once a learner's baseline KSAs have been assessed and addressed, as necessary, the goal of Step 3 is to enable exploration by immersing the trainee in a realistic training scenario with some level of adaptive guidance (e.g., providing enough information to put boundaries around the learning experience without telling learners exactly what to do; Bell & Kozlowski, 2002). By providing a period of exploration prior to explicit instruction (e.g., about relevant factors that contribute to SD and loss of SA), it requires trainees to draw on intuition and prior knowledge to make connections and uncover principles, which will ultimately facilitate deeper levels of learning (Bell & Kozlowski, 2008). This exploratory phase also helps promote trainee engagement and motivation while helping them to self-discover current gaps in their understanding and KSAs.

To help maximize learning during the exploratory phase, instructors can engage in a range of interventions either during or after exploration (Step 4; Kopainsky, Alessi, Pedercini & Davidsen, 2015). These instructor interventions can serve as scaffolding to learners and be adapted based on how well the learner is doing or their known level of expertise (e.g., novices may require more intervention than experts). For example, instructor interventions during the exploration phase may include: (a) incorporating goals and assignments into the scenario to help trainees gain intuitive knowledge that is critical for SA, (b) asking questions before or after the scenario immersion to direct the trainee's attention to relevant task and scenario features, (c) using metacognitive prompts to encourage learners to elaborate on their decision-making and provide a rationale behind certain actions, (d) providing constructive feedback after the scenario, and (e) gradually increasing the complexity of the scenarios as learner proficiency increases, while simultaneously fading (i.e., reducing) the amount of support provided (De Jong & van Joolingen, 1998; Kopainsky et al., 2015, Renkl, 2014). The timing of support must be considered in the context of these instructional approaches. Research has shown that providing information right before or during interaction with a simulation environment does not benefit the trainee and is not effective for acquiring functional knowledge (De Jong & van Joolingen, 1998; Schwartz & Bransford, 1998). This finding also emphasizes the importance of a two-way discussion between instructor and trainee following completion of the scenario in order to foster learner introspection, self-assessment, and construction of adequate mental schemata.

Following the initial exploratory and after action review (AAR) phase, the next phase should include a cycle of explicit instruction, practice and feedback to further deepen learning (Step 5). Explicit instruction by the instructor should focus on filling in KSA gaps by providing specific knowledge, facts, examples, and strategies related to the concepts of interest. In MASTER, for examples, instructors could provide detailed instruction about specific SD and lack of SA causes, cues, and strategies for avoiding or overcoming them. After explicit instruction, it is important to provide learners with additional opportunities to apply what they learned in multiple practice scenarios. Each practice scenario should be followed by an AAR where feedback is provided. This cycle should be repeated multiple times, with the goal of exposing the learner to a variety of mishap scenarios to achieve deeper levels of expertise. The level and focus of instruction as well as the scaffolding during practice should also be adapted over time to reinforce learning and understanding of key concepts (Brant, Hooper, & Sugrue, 1991). If possible, the trainees should be encouraged to take risks during practice, observe the results of different courses of action, and reverse decisions that may lead to catastrophes, such as an aviation mishap (Kopainsky et al., 2015).

Finally, it is important for instructors to track changes in a learner's KSAs as they engage in the training experience, as well as at the end of the training cycle (Step 6). Assessing KSAs during training allows instructors to continuously and actively monitor learner progress and probe learner's thought process to ensure comprehension, application, and integration of information and direct future learning as needed (Koskela & Palukka, 2011). Post-training KSA assessments are critical for gathering evidence of programmatic effectiveness and uncover specific areas of focus for future training.

## DEVELOPMENT OF PROTOTYPE

As mentioned previously, the instructional strategy serves as a complementary framework to guide the overall MASTER solution—which is currently in a prototype status at the time of this paper. The following section will discuss some of the current and envisioned features of the MASTER system. It is also worth noting that support for MASTER is through a Phase I Small Business Innovation Research grant from the Naval Air Warfare Center Training Systems Division (NAWCTSD). As such, the team has not conducted any human subjects research to produce data for validation of the aforementioned and subsequent ideologies (see discussion section)—thought this is certainly a future objective. The team behind the MASTER system has developed an early-stage prototype scenario authoring tool for immersive mishap replay. This tool—hereafter referred to as a prototype—is the first iteration which demonstrates partial functionality of the MASTER system. A mature version of this tool will be used to support aviator training effectiveness evaluation and assessment activities in later phases of the project. The main features of the envisioned MASTER system include: a mishap scenario authoring, environmental customization, and various export options for diverse media types. Each of these capabilities will be discussed in the subsequent sections.

### Scenario Authoring

The current process for mishap scenario authoring is laborious and results in images or 2-D videos to be used in didactic instruction (often through slide presentations). Scenario designers, aviation instructors, or other curriculum personnel are required to manually interpret the mishaps and construct the associated scenarios and curriculum. The general lack of automation in the process leads to copious amounts of time being dedicated to non-value-added activities. To enhance the efficiency and effectiveness of scenario authoring, the MASTER tool will exhibit—and currently does with limited functionality—data ingestion capabilities along with tools to rapidly change the scenario (e.g., weather sliders, flight path editor). The following figures (i.e., Figures 5 and 6) and additional subsections provide additional detail into the aforementioned prototype.


**Figure 5. 3-D in-cockpit view of an F-18 (left). Scenario sliders for controlling certain aspects of the mishap scenario, such as weather (right). Images developed from custom software & commercially-available models.**

**Environmental Customization**

It is generally recognized that immersive simulations require a high degree of simulator fidelity (i.e., realism). This observation brings the second main feature of the MASTER prototype into focus: streamlined environmental customization. Environmental factors are a major causal factor in SD, and aviation mishaps as a whole. As such, the prototype and planned complete system will leverage setting sliders, 3D-models, and terrain data (see Figure 5) to control various environmental conditions (e.g., landscape and terrain, time of day, and weather). Some specific examples include the following: height and density of clouds, fog, various forms of precipitation, and sun and moon position and luminosity.

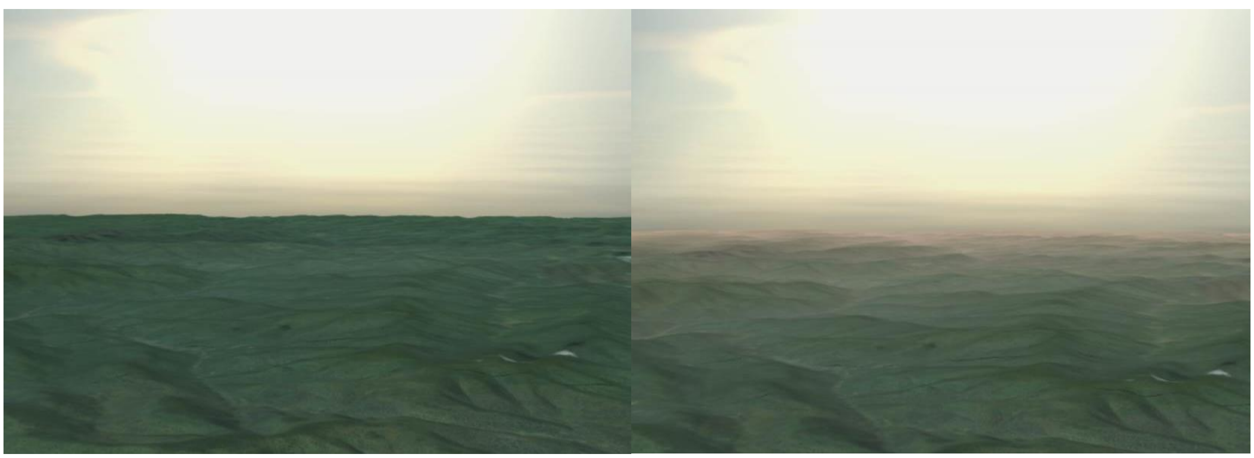

**Figure 6. Depiction of the same landscape with height-based fog both disabled (left) and enabled (right). Images developed from custom software & commercially-available models.**

**Media Export and Cross-Platform Compatibility**

Lastly, the MASTER prototype also exhibits the capability to export realistic mishap scenarios to various training media. Some of the specific media capable of exportation include 2D images and video, 360-degree video, and immersive VR. Since instructor and student preferences often differ, the MASTER solution ensures that mishap scenarios can be experienced through both traditional and immersive methods. This capability coincides with the aforementioned instructional strategy by accommodating all types of instructional and learning strategies (e.g., visual, auditory, or kinesthetic). As this technology continues to progress, the objective will be to provide aviation students with a sense of presence in the scenarios through the use of immersive mishap replay. Another noteworthy feature is that all of the proposed main features (e.g., scenario authoring, environmental customization, and media export) will require no prior programming knowledge for successful scenario development and exportation.

## DISCUSSION

One of the biggest assumptions with the governing theory of the MASTER solution is that didactic material presented through immersive media will either equal or surpass the effectiveness of current training methods. As referenced previously, examples of "immersive media" include 2D video, 360-degree video, and virtual reality (VR). While there is little doubt that these types of media are much more immersive then traditional approaches, questions still remain regarding its impact on training efficacy. These questions are exacerbated by the fact that measurements and assessments of immersion, presence (which can be thought of as the highest level of immersion), and performance in mishap scenarios has largely been left unexplored. However, this is not the case with many other training domains. For example, a study in 2010 empirically confirmed that a higher level of immersion can lead to significant performance improvements in mentally demanding tasks (Ragan, Sowndararajan, Kopper, & Bowman, 2010). Another study demonstrated that training conducted through fully-immersive VR achieved greater learning and knowledge retention when compared to 2D-video instruction (Patel et al., 2006). There have also been numerous studies that have validated that virtual environments can increase training effectiveness in myriad environments—such as military, medicine, and education (Lackey, Salcedo, Matthews, & Maxwell, 2014; Seymour et al., 2002; Merchant et al., 2014). Additionally, there are also generally established objective (e.g., physiological) and subjective (i.e., survey or questionnaire-based) measures of presence and immersion (Meehan, Insko, Whitton, & Brooks Jr, 2002; Witmer & Singer, 1998). Thus, the team behind the MASTER solution believe that there may be a correlation between high levels of immersion and measurable increases in training efficacy. Further experimentation and data collection will be required.

Portability is another envisioned feature of the system, as effective and portable refresher training is scarcely lacking. Most SD training involves classroom training and static motion simulators—such as the MSDD. This observation highlights a critical need for systems that are both portable and more immersive than traditional classroom-based methods. The immersive replay of mishaps scenarios provided by MASTER will allow for a sense of presence in mishap training provided a user has access to a computer and/or a low-cost head-mounted VR system. In the near future (early CY 19), more advanced COTS VR equipment will become available for the entertainment market that may be appropriate for use in the MASTER solution. This new equipment, which was demonstrated at the Consumer Electronics Show in January of 2018, will be completely self-contained, with all the processing and networking capabilities to forego tethering to a PC or image generator. Tools or systems that adopt this methodology can hypothetically achieve similar levels of operator readiness at a fraction of the price when compared to full-motion simulators. While this technology and governing strategy are immediately applicable to the present use case of aviation mishaps, there are numerous domains—both DoD and commercial—that could benefit from adoption of similar systems. Perhaps the greatest asset of the envisioned system is the ability to experience dangerous situations (e.g., combat, hostage rescue) in a quasi-mistake-tolerant environment where the loss of life or other severe consequences are confined to a virtual world.

## CONCLUSIONS AND FUTURE WORK

Without empirical data, many of the aforementioned suggestions are theoretical in nature and based on prior literature and the team's collective expertise. Thus, this paper's main objective is to socialize innovative methods for immersive mishap replay along with a pragmatic (i.e., literature-backed) instructional/learning strategy. This acknowledgement also serves as an invitation to the greater scientific community for collaboration or discussion with regard to the posited notions. However, the team behind the MASTER solution plans to empirically test our hypotheses related to training efficacy, immersion and presence, and virtual reality in the later stages of this work. While copious amounts of research and validation is still needed, we believe that immersive replay of high-risk scenarios will likely improve the retention of key KSAs associated with SD.

The team behind the MASTER solution has also identified numerous ancillary research foci: namely, simulating the effects of acceleration or deceleration on the vestibular system, simulator sickness, and the efficacy of immersive training delivery for ensuring readiness. Each of these research foci are currently ongoing and major advances in these fields would likely augment the efficacy of the MASTER solution. Galvanic Vestibular Stimulation (GVS) is one innovative research area that is of particular interest due to its ability to simulate the vestibular effects of acceleration or deceleration through mild electrical stimulation—which has shown positive effects in mitigating simulator sickness (Cevette et al., 2012). While the technology is established in the scientific research domain, applications to the applied world are just now coming to fruition. As with all burgeoning technologies, there are still numerous considerations and impediments to wide-scale adoption; however, advancements of this caliber give credence to the utility of systems like MASTER and the associated instructional strategies.

As briefly mentioned previously, future experimental activities are anticipated. The team would like to conduct experimentation that included data collected using the NASA Task Load Index, so that questions related to cognitive load can be addressed. The team would also like to conduct a larger scale study by repeatedly sampling aviators at their training sites to collect a larger amount of both subjective and objective data in a quantity sufficient to analyze using normalized statistical methods. We believe the MASTER solution to be an enabler for these experimentations and look forward to exercising its capabilities.

In summary, the notions outlined within this paper and planned future work only scratch the surface of the larger bodies of research in SD, aviation mishaps, and immersive replay and media. Immersive media—such as virtual or augmented reality—will likely continue to be a burgeoning method for ensuring readiness and delivery of training. However, virtual worlds present many challenges (e.g., simulator sickness, acceleration simulation, movement within the world) that must be researched and elucidated to achieve the most effective use of such media. The MASTER team—with the culminating objective of lessening the number of Class A mishaps— will keep these challenges in mind as the prototype is advanced and the collective work moves forward.

## ACKNOWLEDGEMENTS

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## LIST OF ACRONYMS

AAR – After Action Review
DoD – Department of Defense
DOF – Degrees of freedom
KSA – Knowledge, Skills, and Abilities
MASTER – Mishap Awareness Scenario Training for Ensuring Readiness SD – Spatial Disorientation
MSDD – Multi-Station Disorientation Demonstrator
NASTP – Naval Aviation Survival Training Program
SA – Situational Awareness
VR – Virtual Reality

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