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White Paper

Use of Virtual Environments for Simulation of Accident Investigation

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Introduction

Aircraft accident investigation (AAI) requires extensive theoretical and methodological knowledge as well as hands-on application. While there are a handful of training centers that offer crash site reconstructions as training aids, these facilities offer limited static tools that can only be accessed by a minimal number of trainees who have flexible work schedules and access to available budgetary resources for travel, lodging and tuition to attend what is generally not-for-credit hands-on training.

The use of a virtual interactive aircraft crash training environment can deliver a virtual crash laboratory to an infinite number of trainees, worldwide, provided computer technology is present. The virtual hands-on experience allows students to apply complex theories and investigative methodologies in a secure, interactive, portable learning environment. Training can be modularized to specific airframe and crash scenarios, and can be geared toward initial, recurring, or advanced training and assessment needs.

This research demonstrates the application, current capabilities, and future potential of the Embry-Riddle Aeronautical University-Worldwide (ERAU) Aircraft Accident Investigation training/education in a Virtual Lab environment (VLE) and addresses issues and challenges associated with adapting this technology in academia and industry. Issues to be addressed relate to current training/educational challenges for aircraft accident investigation, quality in context, student satisfaction, integration into curriculum, and assessment protocols.

Background

Education and Training of AAI Today

Training is composed of knowledge that imparts specific, discipline related skills, to understand and apply theory and principles within their context. Education is composed of imparting theoretical knowledge and thus instills new or extends existing knowledge of a discipline, to know why things are (within their context) (Essenhigh, n.d.). Stakeholders for AAI knowledge and skills therefore are manufacturers, operators, users, the government, and of course, those on the ground who may be presented with the possibility of injury or financial burden due to an aviation accident. Education and training in the requisite knowledge and skills to conduct proper AAI is well established.

Education and training in AAI comes from several entities, such as professional organizations, educational institutions, and the government. Professional organizations help specific stakeholders such as manufacturers, and operators. These organizations can be specialized, low volume and consultative, to high profile and certificated training that provides for professional certification. Educational institutions, usually in the form of higher education (colleges and universities), best provide AAI education within the theoretical realm, and provide for exceptional research in AAI and related disciplines. These institutions support customers that have the time and resources to invest in this process. Colleges and universities are also participating in the professional (not-for-credit) education or continuing education courses. These appear to be popular due to their flexibility and responsiveness. Table 1 below outlines the scope and capabilities of civil aviation oriented AAI education and training.

Entity	Scope	Educational and Training Capabilities
Consultants and small enterprise AAI entities	Provide targeted AAI training.	○ Training is usually specialized to a targeted audience
Vocational/ Professional associations and entities	Provide targeted AAI training at a somewhat larger scale Can lead to certifications or credentials from self-accredited entities. These are a provided by various professional and higher education entities.	○ Regularly scheduled training ○ Diverse and relevant knowledge imparted
Higher Education	Provides theory on aviation safety and AAI related discipline. Programs offered from a degree awarding, accredited institution. Graduates from these programs are ready for employment in the safety industry.	○ Imparts broad knowledge and deeper understanding in well-defined, relevant programs. ○ Usually offered at Associates and Bachelor of Science granting institutions.

Table 1. Scope and capability for civil/commercial entities with AAI capability. Information from organizational websites.

Government entities provide for foundational AAI training and certification for those AAI workforce professionals directly or indirectly responsible for conducting AAI. These include the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), International Civil Aviation Organization (ICAO), and the military services. The NTSB and FAA (Transportation Safety Institute) also provide training to non-governmental entities, but the military does not. Table 2 below identifies the scope of government agencies in regard to AAI.

<table>
<tr><th>Agency</th><th>Scope</th><th>Educational and Training Capabilities</th></tr>
<tr><td>NTSB</td><td>An independent safety board investigating civil and some public use accidents in the US.</td><td>o Hosts NTSB Training Center
▪ Hosts approx 15 two-day to 2-week courses a year
▪ Aviation courses offered
• AS101 AAI
• AS 301 AAI for Professionals
• AS302 Survival Factors in Avn Accidents
• AS103 Helicopter Accident Investigation</td></tr>
<tr><td>FAA</td><td>Responsible for aviation safety and supports the NTSB in AAI Operationalizes NTSB recommendations</td><td>o FAA Academy provides workforce and industry technical and management training
▪ There are safety courses but no AAI coursework</td></tr>
<tr><td>DOT</td><td>Hosts the Aviation Safety Division to provide AAI training to FAA, DOT, DOD, NTSB, industry and others.</td><td>o ASD contains the Transportation Safety Institute
▪ Offers 11 aviation safety courses
• Seven AAI courses offered</td></tr>
<tr><td>Military</td><td>Conducts AAI for military services</td><td>o Service dependent training courses
▪ US Army
• Professional level safety management
• AAI specific course
• Heavy prerequisites
▪ US Air Force
• Professional level safety management
• AAI specific courses
• Some prerequisites
▪ US Navy and Marine Corps
• Mostly safety management
• No specific AAI coursework evident
• Some prerequisites
▪ US Coast Guard
• Training is received offered through external agencies; governmental, professional and at educational institutions.</td></tr>
<tr><td>ICAO</td><td>Set ground rules for international member states</td><td>o Supports a directory for aviation training providers of member states.</td></tr>
</table>

Table 2. Scope for government agencies with AAI capability. Information from organizational websites.

Needs of the Industry

Aircraft accident investigation (AAI) occurs for several reasons and, depending on the agency, includes safety initiatives, corrective actions, punishment, or compensation (Lewis, 2011). Safety initiatives and corrective actions are those that determine cause and contributing factors as a means to recommend requisite actions by any number of entities and are most likely a result of an incident or accident, to improve aviation safety and crash survival. Punishment is typically a result of an AAI event where the findings resolve fault or negligence and applicable actions are taken. Compensation usually occurs as a result of a related action and usually involves civil litigation. These stated reasons for AAI (safety initiatives, corrective actions, punishment, or compensation) create a need within the industry (manufacturers, regulators and operators) for essential training and education in AAI.

Aircraft accidents create a need for a comprehensive post-crash investigation team (“Operating plan”, 2013; “Investigative Process”, n.d.). Industry standards for AAI can logically be linked to the lawful structure and investigation processes established by the NTSB and other international investigative bodies. The NTSB has identified specialties in which a designated investigation team organizes. The areas of specialization include:

- Operations
- Structures
- Powerplants
- Systems
- Air Traffic Control
- Weather
- Human Performance
- Survival Factors

Within these areas of specialization, the NTSB will identify other parties to the investigation. These parties consist of corporations, or other governmental or non-governmental organizations or individuals who can provide technical support in the conduct of the investigation (“Investigative process”, n.d.). By default, these factors provide justification for manufacturers, and operators to have personnel trained and educated in the AAI processes, which is also a recommendation by the International Civil Aviation Organization (ICAO, 2012). As air travel increases, so does the potential for aircraft accidents and the post-crash operations that support AAI.

The US Department of Commerce reports (2012), that the aerospace industry is one of the most productive and largest industry's in the US. Passenger travel and aerospace related industries will continue to grow (FAA, 2013; Bureau of Labor Statistics, 2007). In a demand-based model that encompasses 2014-2033, the Flightglobal Fleet Forecast reports estimates that the industry is expected to realize increasing demand for new and converted airframes. Growth is evident for the aviation and aerospace industry, and this creates a need for not only manufacturers and operators, but also the responsibility for those who are able to investigate and discern incident or accident causation, and recommendations. Demand is one factor relevant to determining the needs of the industry.

Costs Associated with Learning/Training

Benefits of continuing and professional training and education (CPE) for those in a particular industry are clear ("Continuing professional", 2013; Nandan, 2013; Temple & Sykes, 2012), and in disciplines where the environment is non-static (i.e., aviation), the need to remain current in technology, operations and advancements is paramount. Continuing and professional training and education often suffers as the first budget item to be cut in poorly performing economic times (Fabian, 2010). The diversity of expertise required in an AAI as discussed above does provide a target from which to fiscally plan. Manufacturers may not have a need to extend CPE to all areas germane to an AAI, but to the areas where their product directly relates, and this can have an effect on cost for CPE. Large manufacturers and corporations are capable of supporting the need for CPE and typically have subject-matter experts within the organization who also must keep up with their certifications and expertise as it benefits the company. These individuals are invested in by default as CPE has a high return on investment.

Costs of continuing and professional training and education in AAI vary. In review of government and non-government (basic or entry level) AAI training, the average costs are indicated in Table 3, below. Depending on the depth of the company and breadth of the industry they serve, other considerations for investing in sending employees for AAI training must identify what AAI skill sets are needed. These are necessarily resource-centric decisions.

AAI Course	Location	Onsite Lab	Length	Cost
NTSB AS-101 Aircraft Accident Investigation	Ashburn, VA	X (Comm/GA)	2 weeks	$4000
Training Safety Institute (DOT) Basic AAI	Oklahoma City, OK	X	10 days	$2100
Southern California Safety Institute. AAI	Long Beach, CA	X (GA)	10 days	$3300
ERAU OPE AAI and Management	Daytona Beach, FL	X	5 days	$2000
			Average	$2850

Table 3. AAI course cost estimates. Information from organizational websites. Note: Costs in 2014 USD, and are rounded to the nearest $100.

An example of the challenges to some organizations can be seen if comparing small corporate air transport entites (with few aircraft) who may be economically challenged in sending personnel to live training where large corporate aviation organizations budget and can affor to send multiple persnnel to live on-site training. In this case the use of a virtual lab environment may provide the level of expertise (topical knowledge) at a contracted site as a more high volume organization with many airframes. What about manufacturing companies that has production and test aircraft? Do companies that operate in austere environments have non-standard AAI needs?

Defining Virtual Reality and Virtual Laboratories

Virtual Reality (VR) is a term still in a state of flux and has grown beyond how Webster's Dictionary would individually define the words *Virtual* and *Reality*. It is a relatively new technology that morphs every few years, as immersion multimedia technology advances. Having said that, a laymen's definition would define VR as an artificial environment experienced through sensory stimuli, such as aural, visual, and tactile, and which employs computer modeling and simulation to enable the user, represented as an Avatar, to interact within a three-dimensional real or artificial world. Human input, sensed by virtue of joysticks, goggles, gloves, and/or body-suites, simulates the experience of the human being immersed in the created environment. The more sophisticated the modeling, input, and output systems become, the more physically and mentally immersive the interactivity sensation becomes.

Augmented Reality (AR) is a term sometimes used interchangeably with VR. According to Sherman and Craig (2002), AR is a type of virtual reality, which incorporates artificial technology with real-world objects. An example would be the superimposition of products such as make-up, watches, and sunglasses on a prospective buyer, via the use of a smart-phone application; or glasses, such as Google Glass, which can superimpose Global Positioning on terrain, via the lenses. For the purpose of this research, the term Virtual Reality will be used but may include applications of augmented reality.

The science of virtual reality finds it roots in the early 60's, when military simulators were seen as the most cost effective means to teach users to fly planes, drive tanks, and shoot artillery. Aviation industry simulation systems from the 1980's, while still primitive, expounded on the hardware, software and motion-platform technology of the 60's, providing a more realistic training environment. The 1980's also saw similar technologies mass produced in household video gaming systems. Collaborative environments, where multiple users can occupy and share the same virtual experience, were also incorporated. Today, technology has matured and continues to mature, to a standard that makes sensory feedback immersive multimedia a more common technology in households, industries and medicine.

Modern applications

Current applications of Virtual Reality are too many too mention, but the most predominant are in the fields of healthcare, military training, and engineering.

Healthcare. Surgical VR simulations track miniscule hand movements to provide haptic (tactile) sensory feedback, which recreates the sensations of touch, force, pressure, vibration and movement. Surgeons experience the realistic sensation of touching live organs and utilizing surgical tools, which allows surgeons to practice procedures via simulation, rather than on live patients or cadavers.

Robotic and remote robotic surgery are forms of VR and entail the human surgeon controlling the robotic device that actually interfaces with the patient. Remote robotic surgery allows the surgeon to perform surgery on a patient not in the same location. For example, Dr. Mehran Anvari has conducted more than 20 surgeries from Hamilton, Canada on patients in other parts of the country. This practice holds promise for surgically treating patients in third world countries and space outposts, who might otherwise not receive appropriate treatment (Eveleth, 2014).

Military. The military has been one of the longest standing entities to incorporate VR, using it predominantly in training applications as a means to reduce costs, minimize threat, and reduce the potential for catastrophic loss of life and equipment. Most prevalent is the application in combat simulation training. Military members are fully immersed, both mentally and physically, in dangerous combat scenarios to learn what to expect and how to react. Military (and some civilian) pilots are initially and recurrently trained via VR simulators, which teaches them not only stick and rudder skills but also how to react to emergency situations.

Engineering. Engineering and aircraft maintenance fields also employ VR in design stages, to visualize how systems interact and to identify potential flaws and unsafe situations prior to design and deployment stages. Automotive designers use VR to develop prototype vehicles for testing prior to any production. This process saves millions of dollars in redevelopment and mitigation costs and ensures more efficient and productive life cycles.

Educational applications. Education is an industry that has lagged other industries in adopting VR technology, but it is picking up steam, as immersion learning is becoming a powerful learning tool in K-12 institutions, technical schools, colleges and universities. With more students and institutions turning to e-learning or online classrooms, education leaders are finding new ways to not only attract and retain students but to provide them with the necessary collaborative and hands-on skills otherwise provided to students who attend classes, in-person. “Potential educational applications include virtual field trips, immersive digital learning games and simulations, and therapeutic experiences for students with special needs” (Enrique, 2014).

Touring Colleges and Universities. Understanding the costs to families associated with visiting several colleges with their high school graduate, some institutions of higher learning are adopting VR as a means to show off the attributes of their schools. Virtual tour firm *YouVisit* now allows parents and potential students to take virtual college tours using Oculus Rift goggles. Students can visit classrooms, dorms, dining halls and sporting events, and can see student interaction at each location. The device detects head and eye movement and the student controls what they see without use a hand control (Metz, 2014).

Virtual Laboratories. Embry-Riddle Aeronautical University-Worldwide is one such example. Developed in unison with the College of Aeronautics and Pinnacle Solutions, Inc., the *Virtual Aircraft Crash Lab* was developed in 2013-2014 and integrated into the graduate course, ASCI 615 Aircraft Accident Investigation and Analysis, predominantly as means to allow students to apply and practice theories and techniques learned throughout the course. The vast majority of students would not otherwise have access to real-world accidents or accident reconstructions. The Laboratory is comprised of a virtual crash scene, created in Unity Web Player and allows students to become accident investigators and conduct a virtual accident investigation of a fictitious airline 737. Students enter the crash scene as avatars, after having studied investigative technique theory, such as documenting and analyzing evidence of survival factors, structural deformities, and system failures, and can take part in witness interviews, on-site safety, and accident reconstruction. Currently, the system allows partial immersion into the crash lab, but the authors of this research are testing full immersion accident investigation training utilizing Oculus Rift goggles.

Efficacy of the Virtual Environment

The benefits of Virtual Laboratory Environments are many, but there are also setbacks, mainly initial equipment and software costs, technology glitches and fidelity issues, and keeping systems current, with such a fast paced and blossoming state-of–the-art technology.

The benefits of VLE, and what makes it so adaptable to industry training, include the following:

- Training units are easily modularized, meaning trainees get exactly the units they need. Labs can easily be built specific to the needs of an airline, manufacturer, or flight department within an organization.
- Updating virtual laboratories is much easier and cost effective than updating brick and mortar labs, providing greater flexibility and consistently current technology.
- While initial financial cost outlay may be a setback, the overall cost to set up and maintain virtual labs, in comparison to fixed labs, is a fraction of the cost.
- Virtual labs are far more accessible and flexible than their brick and mortar counterparts, allowing students/participants to learn and practice skills from any part of the world at any time of the day, without concerns of maximum capacity.
- Virtual labs allow for connected networkability-that is participants from around the globe and connect, network, and work together on projects, allowing for literally thousands of students to work in one lab, in-group learning environments.

Conclusion

Virtual Laboratories may not necessarily be appropriate to replace fixed labs, however the intent in the context of this research, is to propose that VLE enhances otherwise two-dimensional online learning environments and supplements training and education of AAI in industry, where fixed laboratories may not be an option. As virtual technology becomes more advanced, the gap between fixed accident investigation labs and virtual labs will be bridged with the help of 360-degree, mental and physical immersion software and hardware. Currently the rage in movies and gaming (e.g. Call of Duty video game series), VR technologies such as Oculus Rift 3D head tracking goggles, can be adapted to learning environments to enhance the realism of VLE, through full immersion (Halley-Prinable, 2013). The literature refers to immersion as “the state of consciousness where an immersant’s awareness of physical self is diminished or lost by being surrounded in an engrossing total environment; often artificial” (Miller & Vandome, 2009, p. 3). This advanced technology is becoming more commonplace and affordable, and engages senses through a 3-dimensional virtual environment, with the benefit of participants having the sensation they are actually at a crash site. Currently, filmmakers are exploring ways to tackle sensory manipulation, like taste, smell and touch, to further enhance the immersive experience.

While the authors of this research are embarking on the second phase of research, to include the application of full immersion technologies, research into such neural and behavioral correlates of 3 D visual-spatial transformations are currently beyond the scope of this research.

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