Hyper Immersion or Just Hype?

Opportunities and Challenges in Virtual Reality and Augmented Reality for Military Simulation and Training

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Abstract:

Faced with ongoing budget challenges and readiness gaps, military organizations have frequently leveraged commercial technologies to support simulation and training. Where today's high-end simulators rely on large and expensive display environments using domes and collimated displays, next generation training systems may benefit from emerging VR and AR technologies that enable solutions that are not only orders of magnitude less expensive but also provide higher resolution, a smaller footprint, and general portability.

Issues with VR and AR systems for military training present opportunities for further innovation. Simulator sickness, which is linked to frame rate and latency, is an ongoing challenge. Another is user interaction in a virtual environment. With a goal of developing muscle memory, ideally movements and gestures performed in the real world would illicit the same responses in the virtual world. Advances in sensing technologies appear promising, but testing and validation is required.

In this paper, we will discuss the opportunities and challenges associated with implementing VR/AR technologies for military training. BISim will share a case study of efforts to integrate VR/AR technologies to produce a high-fidelity F-18 training system. We will outline the results and provide recommendations on where virtual reality implementations provide the most training value and where technologies still need further development.

Contents

1. Introduction

Ongoing budget challenges and readiness gaps have the Department of Defense (DoD) following developments in the commercial multimedia sector in hopes of finding solutions to support simulation and training. Recent investments in key enabling technologies by the likes of Google and Facebook have produced enabling technologies that may dramatically change how training is delivered. Where today's high-end simulators rely on large and expensive display environments that include domes and collimated displays, tomorrow's training systems may benefit from availability of low cost (<$700) helmet mounted displays (HMD) which are not only orders of magnitude less expensive than current solutions but could also provide higher resolution and brightness in a portable form factor. Sensing technologies are being developed that can track a trainee's movements to produce a new user interface paradigm to minimize or eliminate the need for a physical cockpit. Coupled with compelling virtual environment technology based on video games rather than expensive, purpose-built image generators, it should be possible to build highly realistic simulations to supplement existing live and virtual training and dramatically increases readiness. The solution concept is illustrated below.

Figure 1- Virtual Reality Training System

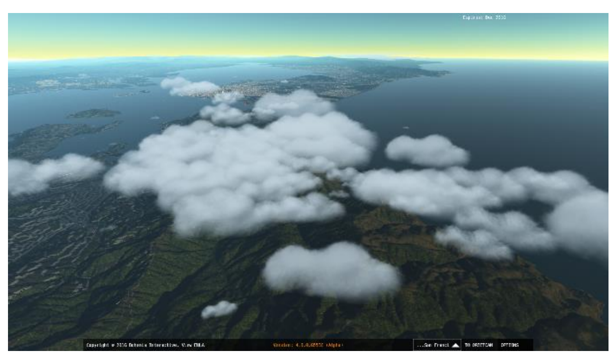
Where industry has long promised VR based solutions with sufficient capabilities to support real-world training, previous offerings have fallen short in terms of both visual quality and latency (leading to a poor user experience including motion sickness). Primary deficiencies have been resolution where VR solutions are far from providing the desired 20/20 visual acuity. The latest VR offerings, however, show significant advancement as purpose built display technologies designed specifically for VR (rather than being leveraged from the cell phone industry) are making their debuts in the latest offerings. Several companies including Facebook, HTC and Sony recently launched consumer versions of HMDs and are now competing to deliver a market-acceptable solution primarily for gaming. If patterns hold, we'll see new versions emerge every 12-18 months with significant advances each round. Provided the technologies mature, and can be integrated into a complete training system, tremendous benefits can be derived as follows:

- Cost avoidance enabled by a new class of low-cost, portable trainer that travels to the point of need and provides capabilities previously only available in full mission simulators or live training;
- Ability to simulate complex missions that cannot regularly be performed in the real world or using current virtual simulation technologies;
- Integration with video game and open source technologies providing cheaper, robust and easy-to-upgrade simulation and rendering software and cost-sharing with desktop training and other military simulation applications;
- Enhanced user acceptance, naturally encouraging trainees to use them; and,
- Overall increase in readiness for pilots and crew.

To better understand how these emerging VR technologies can be applied to real-world training challenges, Bohemia Interactive Simulations (BISIM), working with the US Navy, embarked on a project to build a VR-based training system for an F-18 Super Hornet. The prototype was designed to be used to demonstrate the art of the possible using the latest technologies and to provide a capability that can be used in future studies to conduct training requirements analysis and develop system requirements specifications. These concepts form the basis of the project.

2. Background

Largely based on the visionary ideas of Jaron Lanier and Jean-Jacques Grimaud at VPL Research in Silicon Valley, along with parallel developments funded by the likes of DARPA and NASA, a new medium known as "Virtual Reality" was developed in the 1980s that promised to revolutionize all aspects of our lives. What was essentially an intuitive user interface to a computer that used an HMD, early VR implementations initially thrilled audiences but ultimately disappointed, suffering from a variety of technical and cost challenges. Far ahead of its time, the VR industry faded before it had a chance to get started. In subsequent years, largely driven by advances in electronic technologies, computer and graphics technologies have evolved to where incredibly realistic virtual environments can be produced. Examples are shown below.



New interface technologies have developed to support the commercial video game market. Video and display technologies evolved to support the emerging mobile telecommunication market. Finally, the internet has evolved to serve as an enabler for remote users to connect. Missing elements have been display systems capable of supporting a high-resolution, fully immersive environments and interface technologies to connect the live and virtual worlds. That was until Facebook acquired Oculus in 2012 for $2B. [1]

Oculus started out as a small, Kickstarter-funded company building an HMD known as the Rift. Where products like the Rift have been around for a long time, they have never been available at price points targeted by Oculus (originally under $500/unit). The proposed price performance hits an inflection point for mass production that would lead to development of usable products for consumer entertainment. Where early incarnations of the Rift appeared promising, many of the same technical issues of past products persisted. Caused by a well understood mismatch of visual and motion cues presented in the HMDs, acceptable solutions that would not cause discomfort in users remained elusive. Facebook's ownership of Oculus, together with parallel investment from rivals such as HTC and Sony, resulted in the release of two different consumer-targeted HMDs (Oculus CV1 and HTC Vive) in the spring of 2016. These devices appeared to support the minimal features and performance required for a viable air crew training solution and it was expected that fierce competition based on technical upgrades would follow over the coming years.

With military budgets under extreme pressure, the hypothesis is that the application of VR for training can help maintain or increase readiness. The belief is that users will be able to experience a highly immersive virtual environment that simulates the real world, presented using low-cost, portable technology. Solutions should provide a high-fidelity visual environment where trainees can interact with elements in the scene in natural ways — as they would in the real-world. Individual and multiplayer versions are desired where real and/or synthetic entities seamlessly engage with the trainee over a network. Existing constructive simulations should seamlessly work in the mix. Testing this hypothesis required the development of a prototype system and this forms the basis of this project.

3. Project Overview

Under contract to the Naval Air Warfare Center Training Systems Division (NAWCTSD) for PMA-205, BISim embarked on the project to test the feasibility of emerging VR technology targeted for air crew training. The project was undertaken in response to a need by the US Navy for an affordable, portable training system that could be deployed on carriers at the point of need. The primary goal was to develop a prototype F-18 Super Hornet training system that leverages emerging VR technology. The prototype would be used to demo the art of the possible and provide a platform that can be used in future studies to determine training requirements and associated system requirements. Goals of the development included the following:

- Develop a portable solution that can be used on a carrier in a ready room. The prototype had to be portable so it's possible to carry all the components in a backpack or suitcase so it can easily be transported to where it's needed with no special facility considerations.

- Identify potential training requirements that can be met with VR-based solutions. Building a prototype system to see the art of the possible is the best way to truly assess the capabilities an integrated solution can provide. Where a definitive statement of training requirements VR solutions could meet was beyond the scope of this effort, the prototype alone should support a preliminary assessment.

- Develop a full featured, high-fidelity solution. The goal of the prototype was to simulate major functions of the aircraft and produce sufficient fidelity to support sophisticated missions and associated training requirements.

- The system could not cause simulator sickness. VR systems are notorious for causing simulator sickness. For the technology to be viable, it should not cause any discomfort in users.

- Understand User Interface Issues. Existing training systems rely on physical cockpits with operational buttons, dials and switches. Virtual crew stations can support portability requirements and can easily be reconfigured to support different versions of an aircraft or entirely different aircraft by simply loading a different profile. A perceived need for tactile feedback expressed by some pilots drive requirements for physical cockpits. Virtual crew stations that leverage sophisticated sensors, trackers, and rendering techniques may minimize the need for physical cockpits.

- Support mission rehearsal. If used aboard carriers, one of the primary use cases would be mission rehearsal. The prototype needed to provide features necessary for mission rehearsal including support for large area, geospecific databases.

- Standards and interoperability. The prototype had to support some level of standards and interoperability with legacy systems where applicable.

- Identify integration challenges and limits of the new technology. With all new technologies, challenges are encountered that effect solution performance and usability. Until integrated into a full solution, new technologies pose risk to development that can be mitigated through knowledge of the issues and potential workarounds.

Current military training simulations provide a compelling virtual environment presented in a dome or high-performance collimated display, a physical cockpit that faithfully replicates aircraft functions, a realistic weapon system simulation and threat environment, an intuitive user interface and assessment capabilities to monitor and assess human performance. Mapping these functions into a VR environment, the following major subsystems were developed:

- Full field of view immersive display. Leveraging emerging HMD technology, a VR headset was used to create a highly immersive, full field of view environment.
- Mixed reality, intuitive user interface. Avoiding the use of a physical cockpit and traditional keyboard and mouse to support portability requirements, a virtual crew station was developed leveraging a Leap Motion sensor built by Leap Motion.

- High-performance, whole-earth rendering system. Supporting new high frame rate requirements, a new whole earth rendering system was used to generate the virtual environment and support mission rehearsal.
- Vehicle and avionics simulation. A traditional vehicle and avionics software system was re-hosted in a VR environment.
- Computer generated forces. A Government off-the-shelf (GOTS) software product was integrated to support complex scenarios and to demonstrate interoperability.

Sections below describe the implementation details for each subsystem.

4. Technical Approach

The feasibility study was aimed to exploit the latest in HMD and hand-tracking technology to create a highly immersive and realistic training environment. Our hypothesis was that the new Oculus Rift CV1, combined with technology to interactively display the operator's hands, could be used to create an environment where pilots can practice a wide variety of tasks without the associated feelings of discomfort common in previous implementations. We believed the combination of technologies could provide sufficient field of view, resolution and immersion in a portable format that could be deployed to the point of need. Finally, the resulting software-centric solution could be rapidly reconfigured to represent other aircraft (fixed wing or rotorcraft) or operator stations on a ship as would be seen in a combat information center (CIC). The concept is illustrated below.

Figure 2 - VR Training System Concept

Development of the prototype system involved integrating several hardware and software components. Because of the vast capabilities required to meet targeted use cases, and the short development schedule, we leveraged existing software tools and libraries that were integrated and re-hosted in a VR environment. Missing elements such as the virtual crew station, were developed and integrated with the

COTS software. Only commodity, commercial, off-the-shelf (COTS) hardware were used to reduce costs and support long-term development and deployment goals. The following block diagram illustrates the major subsystems of the prototype solution with explanations below:

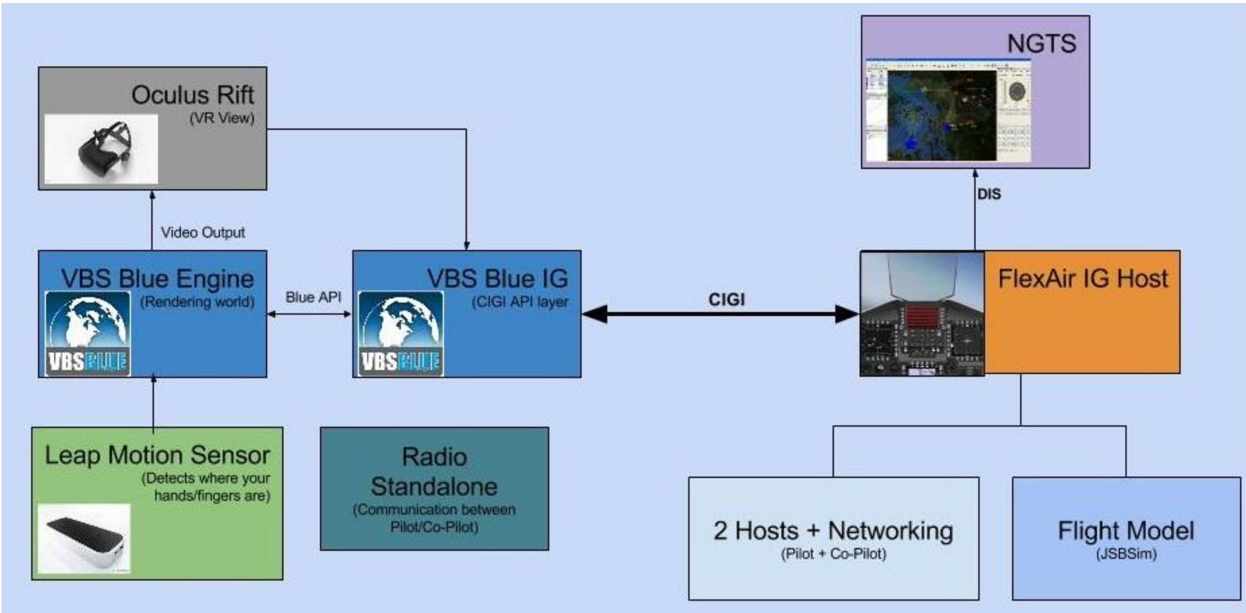


Figure 3 - F-18 VR System Block Diagram

The following primary software components were integrated in the VR environment:

- VBS Blue. VBS Blue is a planetary rendering engine that was used to create the out-the-window scenes.
- FLEX-air. FLEX-air is an accredited flight simulation host which provides the flight, weapons, and avionics simulation that was integrated with the virtual crew station to drive the multi-function displays (MFD)s. FLEX-air is developed by SA Simulation.
- Leap Motion SDK. The Leap Motion SDK was leveraged to support hand tracking for crew station interactions.
- Next Generation Threat System (NGTS). NGTS is a synthetic environment generator used to support training, testing, analysis and research and development. NGTS models both threat and friendly aircraft, ground and surface platforms, and their corresponding weapons and subsystems. NGTS is a Government off-the-shelf product developed by NAVAIR.

The following COTS hardware components were integrated:

- Oculus Rift CV1. The Oculus CV1 is the latest immersive VR HMD released by Oculus in spring 2016. The CV1 will provide the fully immersive display environment and sound delivery platform.
- Leap Motion controller. The Leap Motion controller is a sensor used to support hand and finger tracking needed for interacting with the virtual cockpit MFDs and switches.

- Simulated flight stick and throttle. A physical flight stick and throttle that simulates the primary controls in the F-18 was integrated with the FLEX-air software. Because of cost and schedule details, an A-10 HOTAS from Thrustmaster Inc. was used.
- High-performance PCs. A high-performance PC is required to drive each Oculus Rift CV1. For the dual seat operation, two PCs were required. Small form factor PCs were used to support portability goals.

BISim focused on a standards-based, open architecture integration built upon the Common Image Generator Interface (CIGI) communication standard. CIGI can support communication between the simulation host (FLEX-air) the simulated aircraft cockpit, and the rendering system. Plug-ins were developed for the different subsystems that were integrated directly with the visual system to support the Oculus. This modular approach segments each major system and defines interfaces which supports modularity and enhancements in the future. The entire solution fit in a single pelican case suitable for transport as checked-in luggage achieving the portability goal.

5.1 Full Field of View, Immersive Display

We chose the Oculus Rift CV1 as the display technology for this project. We selected the CV1 because it was projected to provide the highest performance in terms of resolution, field of view and overall features of any of the new HMDs. Oculus Rift support was implemented using the Oculus PC SDK version 1.3.2 that fully supports features such as Asynchronous TimeWarp and Adaptive Queue Ahead that were important to test so see their effect in minimizing discomfort. These features provided extrapolation between visual frames to condition rendering performance. Correct stereo rendering was enabled by independent viewports rendered for each eye with an offset defined using the interpapillary distance from the CV1 device. The distance can be adjusted in real time using the slider on the CV1. Full six degrees of freedom head tracking is supported without limitation on tracked space. The head tracking uses Oculus' "eye level" tracking mode which was ideal for cockpit-style scenarios. Finally, the implementation made it possible to have the rendered view mirrored on an external monitor without lens distortion applied to support assessment and instruction. Figure 4 below illustrates the new Oculus Rift CV1 and associated tracker.

Figure 4 - Oculus Rift CV1

5.2 Mixed Reality, Intuitive User Interface

With a desire to support a realistic, intuitive user interface where the simulator is operated using the same sorts of movements and gestures as a real aircraft, a mixed reality cockpit was developed that provides both virtual and physical controls. The solution allows the trainee to interface with a virtual crew station using natural hand movements that are detected by a Leap Motion sensor that is attached to the front of the HMD. Figure 5 shows a Leap Motion sensor mounted on the front of an HMD.

Figure 5 - LeapMotion Sensor Mounted on an HMD

Data captured from the sensor is used to generate realistic representations of hands in the virtual environment. The Leap Motion sensor is integrated as a plug-in to the visual system. The integration supports the following:

- CIGI packets to define trigger areas for buttons, and notification packets when the hand/bones intersect. This allows the simulation host to determine where and when a button is pressed to perform some logic.
- Leap Motion SDK to detect bone positions and orientation, which is used to:
- Manipulate a custom hand mesh, which is rendered using the visual system rendering API
- Perform collision testing between bone positions and the trigger areas, then send a notification CIGI packet to the simulation host on intersection.

A highly detailed, 3D virtual cockpit model was developed for the pilot and weapon system operator (WSO) stations that includes an XML map used to determine interactions between fingers and the virtual crew station.

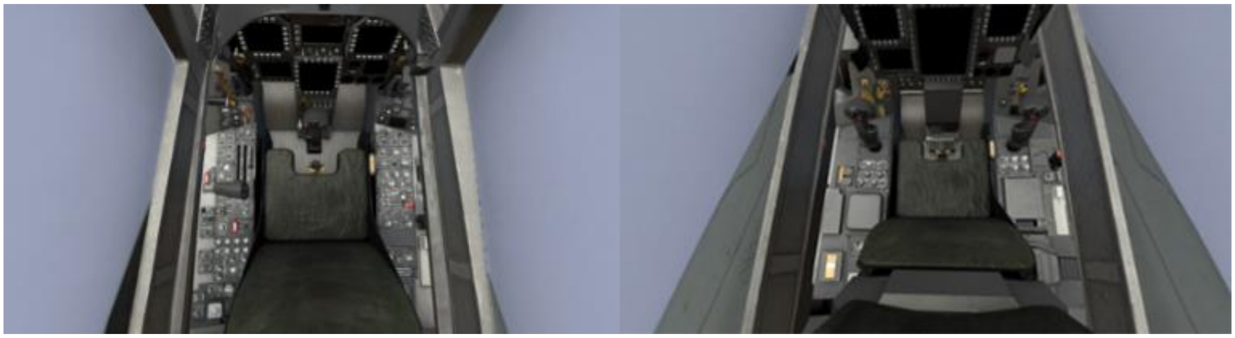


Figure 6 - F-18 Virtual Pilot Station (left) and Virtual WSO Station (right).

The implementation was designed to provide visual feedback to highlight the button/switch over which the virtual finger is hovering, making it possible to interact with the cockpit in a purely virtual domain. Preliminary findings indicate that these highlights provide significant feedback to pilots that buttons have been pressed and appear to mitigate requirements for haptic feedback. Figure 7 illustrates one type of highlighting that provides feedback to users.

Figure 7: Green highlight provided when the finger is contacting a button.

A physical flight stick and throttle (HOTAS) was integrated as it was felt a virtual representation without tactile feedback would not supply a sufficiently immersive experience and to provide a physical reference point for the pilot's hands. The intent was to match the location of the physical HOTAS with what the pilot could see in the virtual world. Acting as an anchor point for the virtual crewstation, all hand movements from the physical controls to the virtual would be represented as offsets from these points.

5.3 Whole Earth Rendering System

The VR training system leverages a new, whole earth scene generation technology known as VBS Blue to address mission rehearsal requirements which require basic terrain and features for any location.

Combined in a hybrid solution that supports traditional imagery and high-resolution insets, the system renders highly realistic scenes and can fully support whole-earth rendering requirements with minimal need for traditional database modeling. Leveraging rendering algorithms that place geotypical objects in geospecific locations, the system provides the ability to support scene generation anywhere in the world without the need for vast amounts of storage or streaming. With built-in support for emerging HMDs, the solution is optimized to support the high frame rates (90Hz+) desired for the new VR devices. Sample scenes from the visual system are provided below.

Figure 8 - Sample VBS Blue Scenes

One of the common issues with VR technology is motion sickness, which prevents its use with some users for even short periods of time. Our hypothesis was that motion sickness can be overcome by implementing a comprehensive solution that addresses the following:

- Smooth image update. One primary factor related to the prevention of simulator sickness is smooth image rendering which can be achieved with implementation of asynchronous timewarp functionality in the Oculus device. Asynchronous timewarp is a technique that generates intermediate frames from existing data, even if the virtual environment is not running at the desired 90 Hz.

- Reduced transport delay. Lag in movement of the head and changes to the visual scene cause a cue mismatch and are known causes of nausea. The transport delay from the time when head movement occurs until the last pixels are painted on the display must be minimized to avoid discomfort. Enhancements to the Oculus CV1 tracking mechanism and a 90 Hz update rate provided by the rendering system should dramatically reduce lag and minimize discomfort.

- Reduced image smearing. Previous HMDs used mobile phone displays that could not change color fast enough to support presentation of an image directly in front of an eye. The new Oculus CV1 has new, custom-made low persistence displays that should automatically reduce smearing.

- Reference objects. Studies have shown that rendering objects like a nose, hands, or other reference object in the immediate field of view of the user can reduce simulator sickness. The solution supports rendering a user's hands and the virtual cockpit in the immediate field of view of the trainee which should support reduced cue mismatch.

- Newtonian physics. Objects in the real world move according to the rules of Newtonian physics. If objects in the virtual environment do not move according to these principles, a mismatch of cues can result that may lead to discomfort. Ensuring that all items in the virtual environment are controlled by a common, high-performance physics engine, discomfort should be reduced or eliminated.

The selected rendering engine was specifically designed to support this implementation and we expected research to confirm our initial testing that showed dramatically reduced motion sickness.

5.4 Vehicle and Avionics Simulation

FLEX-air from SA Simulation was used to provide the aircraft, avionics, and weapon simulation. The advantage of using FLEX-air is that it provides a holistic simulation of the battlespace, in addition to providing a simulation host for the F/A-18 (ownship), which means that simulated aircraft, ground targets, weapon systems, sensors, etc., are all immediately available once the necessary capability is integrated with the visual system. Integrating FLEX-air with the visual system was performed using the following standard CIGI protocols:

- The ownship provided by FLEX-air controls the eye point in the visual system.
- Cockpit screens are controlled via CIGI symbology and rendered into the F/A-18 cockpit in the visual system.
- Hand interaction is coordinated by FLEX-air, determining what action should be performed depending on what button or switch was pressed (e.g. change MFD page, switch to air-to-air mode, etc.)

Sensor simulation is a further enhancement that is simulated by FLEX-air and rendered into the cockpit displays.

5.5 Computer Generated Forces

The Next Generation Threat System (NGTS) was integrated with the prototype to support the ability to run realistic and complex scenarios using validated models. NGTS supports simulation interoperability standards including DIS, HLA and CIGI. We chose to use DIS for simplicity and modularity. This interface also demonstrated the ability of new, emerging technologies to interoperate with legacy simulation technologies. The integration process also required that entity types be mapped across the system so that if NGTS was controlling an SU-27 that VBS Blue would render an SU-27 model. Matching the enumeration types accomplished this task. Geographic locations also had to correlate so NGTS generated targets operating over a specific geographic location could be seen in a matching geographic location in VBS Blue. The resulting integration efforts showed a high degree of correlation between NGTS and the VBS Blue whole earth rendering system.

5. Results

The goal of this project is to produce a prototype demonstrator to guide future efforts and develop training requirements as well as qualitative and quantitative data relative to the efficacy of the technology for training. The development was undertaken by two separate teams, one focused on the virtual environment and VR integration, and another on the cockpit rendering and integration with Leap Motion and the simulation host, FLEX-air. Following a brief design period, development commenced in mid-summer 2016 and was complete by October 2016 in time for a scheduled demonstration in Orlando, FL. The results of spiral developments produced working versions that were taken to the Tailhook conference in September 2016 where we had access to hundreds of experienced pilots. We also took interim versions to Strike Fighter Wing Atlantic at Oceana NAS and CNATRA in Kingsville, TX. At each of these meetings, we let users experience (fly) the prototype and gathered feedback (see Figure 9). We also had some subject matter experts (SME) participate in the early development and captured their inputs for use in further development.

Figure 9 - VADM Shoemaker Flies the Super Hornet at Tailhook 2016

We solicited general feedback from users on about the types of training that could potentially be conducted with this technology, what advantages and disadvantages they saw with it, whether they felt any sickness or nausea after using the system, and other general feedback that would help shape our development process. We did perform a lot of observation as to how trainees interacted with the virtual crewstation, how long it took them to feel comfortable flying the aircraft, and the specific tasks they tried to perform once they were comfortable with the technology. Where the study was far from a formal scientific analysis, we did gather significant input which is summarized below.

1. Users do not get sick or nauseous when using the system.

The primary issue identified by previous users of VR technology was that they became sick shortly after donning the HMD and that long exposures resulted in moderate to severe cases of nausea. However, with the new Oculus CV1, coupled with VBS Blue, these effects were virtually non-existent with users of the prototype, even after extended exposures. With the lower latency position tracking, higher update visual system, low persistence displays, reference points provided by the cockpit and hands and physics-based movement of objects in the environment, preliminary results appear to indicate that discomfort effects have been eliminated. If this result bears out across a larger sample of users, this is truly a major advance for the industry.

Figure 10: Feedback from a sample of the VR flight simulator prototype users and SMEs at conferences and events in 2016 resulted in no reports of simulator sickness.

2. The solution provides an extremely high level of immersion for users.

Where hard to specifically quantify, virtually every user commented on the high level of immersion they felt once they goggle in. This appears to be the result of the high brightness and stereo representation provided by the HMD, detail and resolution of the cockpit, and especially the appearance of the virtual hands. The instantaneous field of view of the HMD is approximately 95 degrees horizontal by 95 degrees vertical, which is far less than a human can perceive, yet few commented about the limited instantaneous field of view. This is a major improvement over previous implementation where users often complained they were looking through a straw. Specific comments from WSOs indicated that the VR system was significantly superior to existing TOFT system because they could look over the side of the aircraft at potentially targets as they do in the real world. This is enabled by the head tracking system that provides a full field of view.

Enhanced immersion was also evident with networked operation. Pilots could perform merge maneuvers over real world terrain. In these scenarios, they could communicate over the radio describing their position, airspeed, and direction and other pilots could find them in the virtual environment and merge. During formation flight, pilots became extremely engaged when they could see and react to other aircraft flying in their vicinity. Where a similar effect was seen with entities generated by NGTS, it was evident which aircraft were piloted by human entities verses those generated by artificial intelligence. The image below was taken from the view of one pilot as another aircraft driven by a separate system merged.

Figure 11 - Multiple Player Support - Merge Operation

3. Pilots could rapidly adapt to the VR environment and technology

Pilots could sit and adjust their seat, don and adjust the HMD and be comfortably flying the aircraft within 2-4 minutes in almost every case. More experienced pilots adjusted faster than those less experienced. Adjustment periods were much shorter for repeat users. This is significant as it implies there is almost no learning curve or spin up time associated with the technology. Other training devices and methodologies require much longer periods just to learn how to use the technology before any training can take place.

4. Mixed Results for the Mixed Reality Virtual Crew Station

With input supported both virtually via the Leap Motion sensor and physically with the HOTAS, pilots were readily able to fly the aircraft and cycle through functions supported by the avionics. Based on initial feedback, we feel the virtual crew station concept has great potential to meet a variety of part task training requirements, but the hand tracking must improve. By enabling users to "press" buttons in the virtual domain using bare hands whose movement was detected by the Leap Motion sensor, a myriad of possibilities exist. Since users do not have to wear any special gloves and operate the system with gestures that imitate those done in the real world, muscle memory can be developed with this interface. Blinking lights, color changes, and a clicking sound implemented to indicate contact with the controls was deemed effective by users in letting them know they "touched" a control. However, the hand tracking was inconsistent and was not always accurate, making the process of selecting items slower than in a real cockpit. There was also a limitation as to the gestures one can perform and the inability to turn dials was an issue. Further development and testing is required to enhance the interface. There is also a need to look at different motion capture systems or data gloves that may provide superior results. Finally, additional gestures to turn dials and interact with some of the HOTAS controls should be developed to increase realism and functionality.

5. Display Resolution is the real challenge.

Where we have not yet had a chance to carefully measure it, the Oculus Rift CV1 is reported to provide a resolution of 2160 x 1200 pixels spread across an approximate 95-degree horizontal by 95-degree vertical instantaneous field of view. Since this resolution is far below normal human visual acuity, we expected to hear concerns relative to reading text in the cockpit and detecting and recognizing objects in the scene. As expected, we heard concerns, especially about reading the text on the buttons, MFDs and especially the HUD. Users commented that it was like trying to read a menu without reading glasses or that they simply could not read the text unless they leaned forward, putting their faces within a few inches from the virtual display. At that point, the text was easily readable, but the need to lean forward will likely cause several negative training issues. We implemented several techniques to make the text more readable including drawing the text larger where we could and other cueing methods with excellent success. But despite the range of improvements implemented by the development team, text readability remains a concern and requires additional investigation.

Where software solutions like cueing and scaling may be developed in the short term to compensate for some of the resolution shortfalls, it is projected that in time, resolutions will increase in the headsets. As TVs drive to support 4K resolution, the same will come to HMDs. Custom HMDs are also being developed using multiple numbers the current panels. Therefore, where the current solution is inadequate in field of view and resolution for high-end simulation, it is already well suited for part task applications. With technology giants like Facebook, Goggle, HTC and Sony driving the technology, it will not be long before improvements arrive.

6. The flight model and avionics were simplistic and did not faithfully represent the functionality of the real aircraft.

Since we used a representative flight model for the F-18 along with an avionics simulation for the Australian Super Hornet, we expected this result. Experienced pilots commented that the roll rates were too slow and movement of the stick resulted in a smaller position change than seen in the actual aircraft. There were similar comments on the aircraft pitch performance. The MFDs needed for weapon deployment were slightly different from current versions of the Super Hornet. Both of these issues can be corrected by tuning the models with help from SMEs. The best way to address avionics functionality is to run the actual operational flight program (OFP) integrated with the VR solution. This would guarantee concurrency with the aircraft.

7. Pilots and WSOs prefer an accurate HOTAS.

A replica F-18 HOTAS for the pilot station would have cost $25K, which was an order of magnitude more than the rest of the hardware needed for the entire system. Therefore, we used a $500 A-10 HOATS built by Thrustmaster. Where the major functionality could be replicated with the A-10 device, pilots felt that having a realistic stick and throttle was critical for user acceptance. With the mixed-reality crewstation concept we implemented, where some of the crewstation is real, and much is virtual, having accurate reference points where the pilots primarily put their hands is critical. Therefore, it is important to find an alternate supplier for a replica HOTAS that can produce them more cost-effectively.

The physical position of the stick and throttle relative to the virtual world is also critical. If the physical position of the flight stick does not match what the user is seeing in the virtual world, immersion is broken when the user fumbles around grabbing at the air. However, when the physical position of the HOTAS matches what is seen in the virtual world, pilots immediate connect. The prototype provided no specific way to mount the stick and throttle with proper separation and relationship to the chair. We ended up implementing a reset function which would position the virtual cockpit directly in front of the user at the right distance away which was fairly effective, but a physical jig or mounting assembly for the stick and throttle is significantly important for deployed solutions.

8. A virtual knee board and a way to display checklists was identified as a requirement.

Pilots remarked that they typically wear knee boards where they write all sorts of notes needed to complete their missions. When goggled in, they cannot see a physical knee board they could wear so without lifting off the HMD and breaking immersion, they have no way of taking notes. There are several ways of supporting this requirement where a virtual knee board could be developed and displayed in world. Augmented reality type displays may also be interesting here. Because of the need to write on the board and read the results, using a physical device like an ipad that could sense the writing could be used. In any case, this capability was beyond the scope of the current effort but should be addressed in a follow-on development.

9. Despite a handful of deficiencies, users strongly felt that the solution was a major step forward and that it could support a wide variety of training requirements as it is today.

Where a formal training requirements analysis was beyond the scope of this contract, there are clearly a wide variety of training requirements that can be met with the technology as it is today. If offered as part of a blended learning solution, VR solutions can help to fill gaps between classroom-based instruction and full mission simulation and live training. From basic training tasks including cockpit and checklist familiarization, emergency procedures, weapon deployment, and communication to more complex tasks such as formation flight, crew coordination, and mission rehearsal exercises there is an obvious fit. The exploitation of emerging VR technology can save the US Navy hundreds of millions of dollars by limiting travel for training, avoiding upgrades to existing training systems and limiting the need for some high cost training systems.

6. Conclusions

VR technology has long promised to revolutionize training, but have we moved beyond the hype and arrived at a point where VR technology is viable for military training? Based on the enthusiasm of the significant number of trained pilots who tried out our initial prototype we believe the answer is yes, especially for part task training. There is certainly more work to do to build a complete training system and certain use cases will require further technology advancements. However, in accordance with the feedback received from users, the feasibility study has shown that affordable, highly portable VR technology is deserving of a second look. Where there are still challenges in several areas such as display resolution and sensing, the massive investments from key players including Facebook and Sony will produce rapid technology advances in the next year that are likely to fill the remaining gaps and open yet unimagined capabilities.

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8. References

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