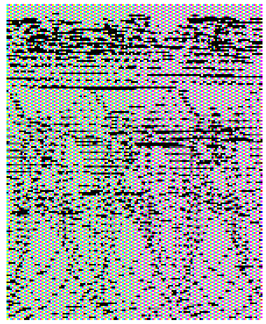

Improving the Management of an Air Campaign with Virtual Reality

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Abstract

This thesis evaluates the near-term military utility of virtual reality (VR) and its component technologies to the battle management of an air campaign. It presumes a large-scale air campaign on the order to that in the Gulf War where air operations were continuous, prolonged, and intense. The author begins with a discussion of VR technology to lay a foundation for understanding its current capabilities, future potential, and limitations. An examination of the prevailing structure and process for air battle management follows. In particular, the flow of information throughout the air operations center (AOC) is revealed and analyzed. The remainder of this thesis looks to mesh the technology of VR with the process of air battle management. Several near-term improvement opportunities are described as a result. The research concludes by assessing the viability and implication of a military decision to invest in a VR-enhanced air battle management system. Recommendations are given for areas in need of further research and development.

About the Author

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Chapter 1

Introduction

One day in the distant future, a young male and an older female of two different species walk into the Holodeck. A simulation is already in progress. They wander through a garden under a beautiful simulated sky, conversing with synthetic actors they encounter. Finally, they find their way to a steaming mud bath. Faster than the blink of a real-time virtual eye, they are soaking in the mud, and deriving great pleasure, and relaxation from the virtual experience.

As a display device the Holodeck is miraculous. Its users have a visual display that produces a 360° field-of-view image. The image has better angular resolution across the entire field of view than either species can resolve. The image is truly stereographic for all users from any viewpoint. All distance cues are present, including focal accommodation. Scene complexity is very high, and is indistinguishable from real world scene complexity. The users do not need to wear HMDs [head or helmet mounted displays] to see the visual images.

Auditory information is spatially localized to the source, with environmental reverberation to improve accuracy. Sound generation, which includes speech and non-speech, is personalized to each individual, even though multiple species with different head and ear structures are present. Again, no equipment needs to be worn in the Holodeck.

The haptic display capabilities are equally amazing. Users have full proprioceptive and somatic feedback consistent with the environment. Interactions with objects in the environment produce appropriate limitations of proprioceptively sensed motion. If you push against a wall, you feel your arm stop as well as see your arm stop. This is accomplished without the use of exoskeletal devices. Somatically sensed stimuli are also consistent with the environment. Pressure and heat from immersion in the hot mud bath are sensed over the entire area of the body immersed in the mud bath. The smell of steam and exotic fragrances permeates the air.

—J. Michael Moshell and Richard Dunn-Roberts
Virtual Reality: An International Directory of Research Projects

In many ways, the above excerpt describes the ultimate state of virtual reality (VR) technology. The user's perceived environment has been completely replaced by a facsimile, indistinguishable from any real-world experience. All of the human senses are hooked into the virtual environment. The mind and body cannot tell the difference between what is real and what is computer generated.

Welcome to the world of virtual reality—a world where reality is artificially created through means of computer interface. VR can be defined as a "world transposed in time or space, either real or imagined, that the user can interact with in real-time."[1] If that transposed world is real, then the user has "telepresence," that is, a virtual presence in a real world that exists someplace else at that point in time. If that transposed world is imagined, then the user is in a world that physically exists nowhere else. Either way, the user is experiencing life in a virtual reality.

The full range of "Holodeck" capabilities as described does not yet exist in total. Computer processing speed and memory are unable to recreate a real-time, interactive virtual environment indistinguishable in all aspects from the real. The input/output (I/O) device technology needed to interact with the virtual environment is not currently sophisticated enough to simulate the entire domain of human sensory perception. While visual and audio stimuli and reception are further along in technological development than haptic sensory capability, they are not without their limitations regarding fidelity, resolution, speed, device size, etc.

The state of VR technology is advancing and its applications are expanding. The Holodeck may not be too far off. The impetus is there for continued research and development into the twenty-first century. Commercial industries such as entertainment, education and training, medicine, manufacturing, and engineering are finding more and more uses for VR. VR applications exist today in telecommunications, air traffic control, molecular modeling, architectural design, fluid mechanics, aerodynamics, and the visualization of numerous scientific microprocesses.[2]

The military is finding uses for VR applications. In fact, although commercial interests are currently pushing VR development, it was the Department of Defense (DOD) which really began the research in the field of VR technology. Military applications exist today primarily for purposes of simulation and training at the tactical level with growing interest and capability in battlefield-level engagements and scenarios. The US armed services already have existing simulation networks for training purposes. The Army has a VR program called *I-Port* which puts real soldiers onto a virtual battlefield.[3] Soldiers wear a VR head monitor in order to take part in the simulation. The Navy is developing the Naval Postgraduate School network vehicle simulation trainer (NPSET) for conducting distributed VR simulations by linking together different locations.[4] The Defense Advanced Research Projects Agency (DARPA), DOD's lead agency for technology research and development, has developed large-scale interactive simulator networking (SIMNET), also a distributed simulation network, where multiusers from all the services can do war gaming from remote locations in near real time.[5] For example, an F-16 pilot from Shaw Air Force Base (AFB), South Carolina, could be tasked with his wingman at Hill AFB, Utah, to attack an armored unit and its air defense systems manned by Army personnel at Fort Irwin, California. The attack could be coordinated with naval air from a carrier deck at either Norfolk, Virginia, or San Diego, California.[6] The entire simulation would take place over and on a virtual battlefield.

A particularly popular, albeit futuristic, Air Force application is an on-board, VR-enhanced fighter aircraft command and control system. The Armstrong Aerospace Medical Research Laboratory at Wright-Patterson

AFB, Ohio, is working toward developing a complete VR cockpit.[7] Their "Super Cockpit" program is striving to reduce the pilot's need for proficiency in mechanical control of the aircraft, in large part, by incorporating an all-aspect, opaque helmet system. With their helmet design in its ultimate form, the pilot's visual and aural cues would be a virtual recreation. The aerodynamic advantages of such an aircraft would be spectacular. With no need for a canopy, the cockpit could be designed for a prone pilot position providing for higher "G-force" tolerance and thus a dramatically more maneuverable aircraft.[8]

But a VR-based super cockpit is many years away from becoming a technical reality. It describes a system of capabilities complete in their development. Additionally, tinkering with the pilot position may proffer Air Force organizational resistances that are just as challenging as the technology. Is there an operational application that takes advantage of the VR capability which exists today or will exist in the near future? Improving air battle management within a theater of operations may be such an opportunity.

American military operations in a wartime environment are occurring at an ever quickening pace. A commander's emphasis on timely and accurate information is a growing premium in a dynamic theater of operations. The after-action reports from Desert Storm bear out this proposition. During the Gulf War air campaign, various operations and intelligence information was not getting to the joint force air component commander (JFACC) in a timely manner or in a consumable form.[9] Information systems for mission planning and targeting were overloaded, resulting in data being ignored, misdirected, or misjudged.[10]

A better way of receiving, processing, and presenting information to an air commander in real-time fashion is needed. VR technology, available within the next decade, may offer a revolutionary improvement to air campaign management. Specifically, this research seeks to discover the viability of a near-term, VR-enhanced theater air battle management capability.

The next chapter explores the technology of VR in order to lay a foundation for its current capabilities and limitations. The subsequent chapter examines the prevailing structure and process for air battle management as it functions currently. The remainder looks to mesh the new technology with the current process of air campaign management to expose opportunities for near-term improvements in air battle management.

Notes

1. Lt Cmdr David Pratt, "A Software Architecture for the Construction and Management of Real-Time Virtual Worlds" (PhD diss., Naval Postgraduate School, 1993), 2.

2. Dr Michael B. McGrath and Dr Mark L. Merickel, "Virtual Reality: The State of the Technology," *Journal of Engineering Technology,* Fall 1993, 10.

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Chapter 2

The Technology of Virtual Reality

A computer interface technology known as virtual reality (VR) has received a great deal of public attention, because it provides a new paradigm for interfacing humans to computer-generated synthetic environments . . . VR immerses the user in a simulated computer environment. The user can then directly manipulate simulated objects, and leave behind limitations of the physical world.

—H. Veron et al.
Exploitation of Virtual Reality Architectures

What is virtual reality? The literature makes it clear that virtual reality means different things to different people. It goes by such cognate terminology as virtual environment, artificial reality, synthetic environment, and cyberspace. Definitions vary as well. An esoteric definition would be "the combination of real-time 3-D computer graphics with shading and texture mapping, high resolution stereoscopic large screen or head mounted displays, along with novel user interface devices."[1] Dr Creve Maples of Sandia National Laboratories defines VR more simply as the coming together of man and machine. In fact, he feels the term *anthropo-cyber-synchronicity* is a more accurate description of the technology than is VR.[2] For purposes of this research, however, the preferred definition for VR is a "world transposed in time or space, either real or imagined, that the user can interact with in real-time."[3] This definition fits best with the goal of the research—to determine if, and how, VR can assist the JFACC in battle management of an air campaign. In this application, the notion of transposing in time and space the ongoings of the actual air situation to the JFACC and his staff is crucial to real-time air battle management. In other words, VR may have the potential to allow the JFACC to experience the air campaign as it unfolds over the battlefield, thereby allowing for better decision making as a result.

VR allows the user to process information more directly through perception in three dimensions instead of two. Various studies have shown that 3-D displays are easier for the mind to process, convey more information more quickly than 2-D displays, and facilitate human memory retention and retrieval.[4] Russel Mikel, a researcher from IIT Research Institute, says, "The primary benefit to be gained from the display of information in three dimensions is that it allows the user to perceive these relationships rather than require [the user] to cognitively translate tabular or two dimensional data into an internal representation with 3-D characteristics."[5] He says the perceptual benefits of 3-D are fourfold: a quicker and more accurate grasp of spatial features, an improved appreciation for the scale of physical attributes such as distance and velocity, a decluttering of graphical and textual information overlaid upon a limited display area, and a greater facility for comprehending graphical representations rather than textual.

Dr Maples relates experiential learning through VR to the John von Neumann wire phenomenon where it's not computer processing unit (CPU) speed, but the limitations of the wire in between the computers which dictate how fast information moves into and out of computer memory.[6] He extends the analogy to the human mind and says the limiting factor for memory retention is not the brain but the computer interface with the user. The challenge then becomes how to increase the "bandwidth" of information moving into and out of the human mind. VR may be a solution. He says experiential learning is parallel learning while cognitive learning is serial. Experiential learning allows the mind to store information subconsciously as well as consciously. In fact, Dr Maples theorizes that of the information the human mind retains for later recall, 97 percent is through the subconscious.[7] A VR human-computer interface (HCI) takes advantage of this circumstance. VR is a revolutionary different form of HCI.

The Human-Computer Interface

VR represents the sixth generation of user-computer interface according to John Walker of Autodesk, Inc.[8] He describes the VR interface as dramatically different than the first five generations of interfaces (table 1).

Table 1

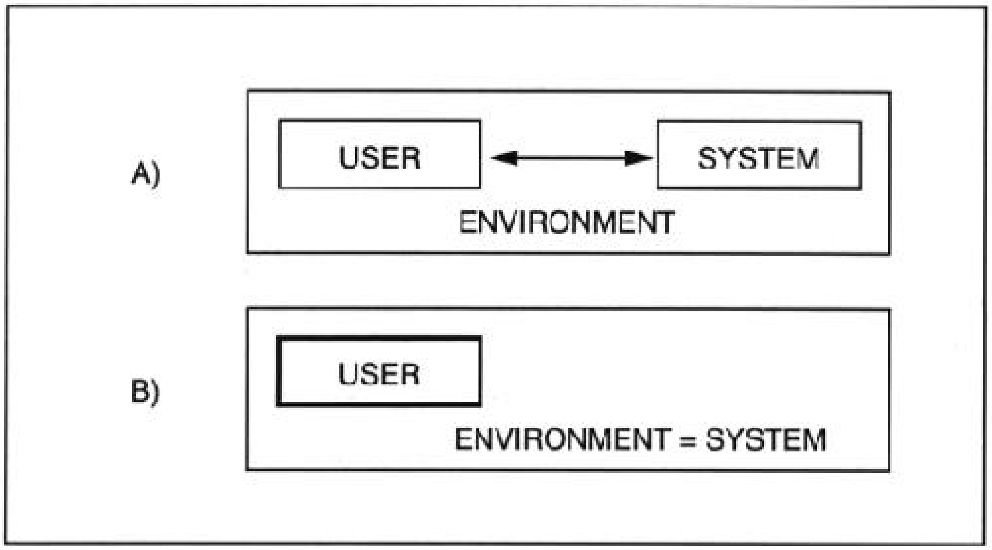
Generations of User Interfaces

Generation	Means of Operation
First	Plug Boards
Second	Punched Cards
Third	Teletype
Fourth	Menu Systems
Fifth	Graphical Controls/Windows
Sixth	***Virtual Reality***

Source: Dr Michael B. McGrath and Dr Mark L. Merickel, "Virtual Reality: The State of the Technology," *Journal of Engineering Technology*, Fall 1993, 10.

Walker states, "Now we are on the threshold of the next revolution of user-computer interaction. A technology which will take the user "through the screen" into the world inside the computer . . . a world in which the user can interact with three-dimensional objects whose fidelity will grow as computing power increases and display technology progresses."[9]

Walker said that VR allows the user to interact with the real world from "inside the computer." The diagram in figure 1 illustrates this relationship.



Source: Jack Grimes, "Virtual Reality 91 Anticipates Future Reality," *IEEE Computer Graphics & Applications*, November 1991, 81.

Figure 1. Conventional (A) versus VR (B) User Interfaces

The generations of HCI prior to VR were of type "A." A VR system removes the distinction between the computer system and the user's environment (type "B"). The system *is* the user's environment. In sum, a true VR system has two essential characteristics: the ability to provide 3-D imagery and, just as important, an HCI which puts the user "inside the computer." Randy Pausch realized this when he said, "The power of VR comes from changing the point of view with respect to the scene much more than it does from presenting stereo imagery. Desktop stereo, or 'through the window' graphics, is like staring into a fish tank; you can perceive depth within a small volume but lack the illusion of being surrounded by fish."[10] This newest form of HCI makes possible different kinds of computer-created realities.

Types of Virtual Realities

VR systems can generate three kinds of virtual realities: telereality, abstract reality, and simulated reality.[11] Telereality, or telepresence, is one where the user is virtually transported to a reality which exists somewhere else. For instance, a VR system which puts the user on Saturn to observe its rings from the planet's surface provides telereality. Abstract reality is the creation of a virtual reality which does not really exist otherwise. The diffusion of heat through a cube can be modeled quite well, but not seen. However, a VR system could create an abstract reality from the output of the heat flow model. A simulated reality is one where the virtual environment is a fabrication of an environment or scenario. VR applications for operational air battle management fall primarily into the first of these three categories as will be shown in chapter 4. The emphasis is to provide the JFACC with a telepresence in an unfolding air situation.

Regardless of the type of virtual environment generated, VR systems can be categorized according to how the user interfaces with that virtual environment. Each category has its own capabilities, advantages, and limitations. Generally, there are three types: immersive, nonimmersive, and overlay. Immersive systems are considered total VR systems because they completely "immerse" the user in the virtual environment. The user's own reality is replaced entirely by a virtual reality through the user's entire field of view. The computer interfaces available to the user are through the virtual environment only. An immersive system is typically obtained through wearing some sort of head- or helmet-mounted display (HMD), where the user's visual cues are entirely virtual.

Nonimmersive systems, also known as "out-the-window" systems, provide the user with a "bird's-eye" of the virtual environment as if the user was looking out the window of a moving vehicle. Nonimmersive systems allow the user to look away from the virtual environment and back to the user's real surroundings as needed. A nonimmersive system typically requires the user to view a special screen or display device to operate in the virtual environment.

Overlay or augmented reality systems are those which portray a virtual image onto the user's view of the real environment. These heads-up display (HUD)-like but 3-D capable systems permit the user to maintain contact with the real environment while simultaneously viewing VR imagery. The annotation of virtual text, or hypertext, upon a real background fits this category.[12] An overlay system typically requires a projection screen device somewhere within the user's operating field of view or the use of a stereoscopic viewing device.

Virtual Reality Component Technologies

Several component technologies comprise a VR system. As with the definition for VR, the component technologies can be categorized variously also. One clear way to identify the enabling technologies is as follows: computer processing and data transfer systems, computer display devices, graphics rendering systems, HCI devices, and the supporting system software.

Computer processing and data transfer technologies are those which address computing speed and data communication rates. VR requires high processing and wide bandwidth communications for graphics imaging and real-time data transfer. CPU speeds are currently at about 0.3 teraflop[13] but are expected to reach 100 teraflop by the year 2000.[14] Massively parallel processing schemes, super workstations, and high-speed, high-volume communications fall into this development area.

Computer display technologies explore various devices to display visual information in 3-D to the user or users. Three-D effects can be achieved with a multitude of systems. Stereoscopic, autostereoscopic, and volumetric systems make up this technology area, as well as particular projection technologies like cathode-ray tubes (CRT), liquid crystal displays (LCD), and various laser beam devices.

Stereoscopic systems create 3-D images by feeding slightly different views of the same object to the left and right eyes independently. The brain then melds the two to create a single 3-D image for the user. These systems require the user to either wear an HMD or goggle-like device, or to use a non-HMD which can be maneuvered in front of the eyes when needed. They replace the user's field of view with a virtual recreation.

Autostereoscopic systems achieve 3-D in the same fashion as stereoscopic, except that no external device (HMD or non-HMD) must be worn by the user. These systems, however, normally have severe line-of-sight limitations. Volumetric systems are fundamentally different from stereo- and autostereoscopic. Stereoscopic systems use two perspective views to mimic a 3-D representation, and volumetric systems use other technologies to create an actual 3-D image. They generally are not immersive. The user must observe a projection device which contains a volumetric reflective surface of some kind. Holographic, spinning helix, and varifocal mirror techniques are of this type.

Graphics rendering technologies are those which deal with how to most efficiently portray visual information to the user. They address primarily the conversion of stored data to 3-D imagery using computing power and memory. The more bits per pixel of frame buffer memory, the greater the performance of the rendering engine. They must be capable of rendering new virtual worldviews with each change of the user's position or orientation, or with a change in the scene being represented. The actual display is created by the assimilation of polygonal approximations drawn on the computer screen. The resolution of the image is limited by the number of polygons that the rendering engine can process. Polygonal approximation techniques and texture mapping are in this area of development.

HCI, or interface devices, are the I/O hardware which permit the user to interact with the virtual environment. They are the gee-whiz devices, along with HMD, normally associated with VR technology. HCI devices include position and orientation tracking systems (to locate the user's head, hands, fingers, and body—whichever is required for the application), haptic systems (to provide the user with the sense of touch, force and pressure feedback), and directional audio systems (for realistic sound replication and 3-D spatial localization) depending on the sophistication of the VR system.

Position and orientation tracking systems are usually of two types: magnetic field and fiber optics. Magnetic field systems use a transmitter and receiver pair to provide position and tracking in six degrees of freedom (x, y, and z coordinates along with rotation about those axes for roll, pitch, and yaw, respectively). The transmitter emits a magnetic signal whereby the receiver pair can calculate location and orientation through triangulation methods. Fiber-optic systems are designed to sense body motion and not necessarily position and orientation in 3-space. Optical fibers, typically located on either a user's glove or even a full bodysuit, work by attenuating the light sent through them. When the fibers are bent, as when bending one's finger or flexing one's limbs in a body suit, the optical signal is attenuated. The degree of attenuation is correlated with amount of flex in the joint. There are, however, optical beam systems as well as newer acoustic technologies which are being considered for tracking user position and orientation.

Haptic sensor technology is not as far along in development as is tracking sensor technology. Current systems require the user to wear some sort of exoskeletal device. This invokes obvious user limitations (mobility, comfort, etc.), the magnitude of which depends upon the application. Directional audio systems deliver localized, 3-D sound to the user. These systems replicate the filtering effects of the outer ear to provide directional and magnitudinal characteristics to the perceived sound. Some examples for all these tracking technologies include data gloves and suits, space balls, 3-D joysticks, and voice command systems.

The supporting system software addresses the broad area of designing software to process, store, and display information efficiently. Emphasis has been on the design of a VR software structure which is modular and versatile so as to be application independent. Particular areas include data compression techniques, the creation of centralized databases, and the fusion of data from multiple sources.

Notice that VR cuts across several defense critical technologies to include high-performance computing, software engineering, simulation and modeling, signal and image processing, and data fusion.[15] Even though the commercial industry is regarded as taking the lead in VR development, the military has recognized several related technologies for increased investment and development.

Technological Challenges

There are technological challenges to the current state of the art for VR. Processing speeds and communication rates, multisource data fusion, and rendering techniques are all critical technologies for making real-time, VR-enhanced air battle management a reality. At the center of the matter is

CPU speed. Insufficient CPU speed forces a trade between rendering satisfactory detail for graphic images and the near instantaneous display of those images. In effect, processor speed compels the user to trade between image resolution and the real-time depiction of those images. Multiuser interfaces and networks slow data transmission rates and create synchronization problems. Technologies are needed which increase the data throughput rate from the source to the user.

The performance of a rendering engine is usually measured by the number of polygonal facets which it can display at some described frame rate (also called refresh or animation rate). Most rendering engines can display approximately 10,000 polygons while ensuring a visually acceptable frame rate of 10-to-20 frames per second.[16] This limits image resolution and fidelity with respect to shadowing and texture mapping which demand that more polygons be rendered. To render more polygons for enhanced image resolution would decrease the frame rate resulting in a jittery effect to the eye. One could trade update rate (down to one or two hertz) to improve display resolution, but the result would be a noticeable lag in display dynamics.[17] A frame rate of 30 frames per second is needed to produce video-quality imagery.[18] A more powerful rendering system is necessary to achieve detailed image resolution with near video quality.

Since the virtual model size and complexity are limited by the number of polygons that rendering engines are capable of processing, more efficient polygonal approximation routines are needed as well as increased CPU speed. Doctors McGrath and Merickel assess the situation as follows, “Although most VR systems are capable of generating reasonable simulations of virtual images, the computing and rendering power required to create real-time virtual worlds, where the user can interact seamlessly with the virtual environment, are currently not available even with the most sophisticated graphics workstations. Major improvements are needed in computing and rendering power before VR technology will reach its full potential.”[19] At the same time, however, they expect that computer processing and graphics rendering technology will improve enough over the next five years to get real-time imaging for VR displays.[20]

Visual display devices also have limitations in terms of their weight and bulk. Currently, producing an HMD under five pounds is not feasible.[21] They also present the user with mobility limitations due to the electrical connections which tether them to their controller hardware. Fields of view for available HMDs are in the range of 100 degrees horizontal and 60 to 75 degrees vertical, both less than that seen through normal human vision.[22] Future HMD must be lighter (six ounces or less) and use technologies which eliminate tethers.[23] They will need a self-contained lightweight power source. They must be able to switch quickly between the virtual environment and the real world, perhaps with a “flip-up” goggle device. “There are great virtues to not having to put a [full] helmet on your head just to accomplish ordinary, everyday tasks.”[24] This will be especially true for air battle management where the mission staff would be working for hours on end.

HCI devices must become more user friendly and not suffer from lag time, interference, or tethers. The tethers for position and orientation trackers limit the range of movement of the user. They also suffer from slow response time which shows up as a lag between the user's actual physical movement and the virtual displayed response. The more common magnetic trackers are easily perturbed by nearby metal objects or stray electrical interferences. Their useful range is restricted to about five feet between the emitter and receiver. On the other hand, light-emitting diode trackers and acoustic sensor devices would be immune to electromagnetic field problems and offer the potential for increased operating ranges. Position sensors must be more accurate, tetherless, longer range, and operate in real time vice any lag.[25] Data gloves, with their internal fiber-optic sensors, have tethering restrictions as well as being insensitive to small gesture movements. Most of these HCI devices must be recalibrated for different users and can be difficult to don and doff.

The software to support VR is limited in the amount of memory it requires to run and its lack of flexibility to support various end uses. Object-oriented programming[26] and modular software design can increase the versatility for VR applications. The Virtual Environment Operating System (VEOS) is such an architecture.[27] VEOS has a body module which takes sensor input combined with an internal human physiological model to create the illusion that the user's body is real. It has a second module which maintains the virtual world's database, through which the virtual body interacts via HCI. Finally, VEOS has a system module which manages its internal communications, processes, and memory.

The severity of the limitations are application dependent. Certain VR applications will require more from the technology than will others. Users must be sensitive to the current technological limitations of VR and explore potential applications with that understanding. Those limitations notwithstanding, this research aims to discern how VR technology might enhance a commander's air battle management capability.

Notes

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17. Andrew Liu et al., "Some of What One Needs to Know About Using Head-Mounted Displays to Improve Teleoperator Performance," *IEEE Transactions on Robotics and Automation* 9, no. 5 (October 1993): 646.
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20. Ibid., 15.
21. Ibid., 12.
22. Ibid.
23. Ibid., 15.
24. J. R. Wilson, "Virtual Reality Benefits May Prove Illusory," *Aerospace World,* April 1993, 34–35.
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Chapter 3

Battle Management of an Air Campaign

The most effective way of organizing air forces to ensure unity of effort and successful conduct of military operations is under a single air commander, exercising command and control through a dedicated command and control system. This role of the ACC [air component commander] has been developed through combat experience, and it is a vital factor in the proper application of the air effort within a theater of operations.

The need for a single air commander is especially critical when resources are limited and the concentrated effort of all available air resources are required to accomplish the mission. The objective of centralized control of the air effort is to achieve mass, surprise, and economy of force through the exploitation of the flexibility and mobility of air forces, and to apply all resources toward the objective set forth by the theater commander.

—Air Combat Command Instruction 13-150

Before looking for VR application opportunities in air battle management, one must first understand the structure and process by which an air campaign is managed at the theater level.[1] In particular, how is the organization put together for command and control, and what are the information products used by the organization? The products must be viewed from a customer perspective, that is, to consider who uses the information and for what purposes. After understanding the manner in which information flows, then potential VR applications for improving the battle management of an air campaign can be contemplated.

Structure and Organization for Theater Air Battle Management

The JFACC concept has its origin in several joint publications.[2] Joint Publication 1-02 states the JFACC derives his authority from the joint force commander (JFC) who has operational authority in the accomplishment of the overall mission. The JFC may assign responsibilities to the JFACC to include planning, coordination, allocation, and tasking of the JFC's air assets. The USAF's *JFACC Primer* states the relationship between the JFC and the JFACC as follows: "The JFACC provides a JFC the means to exploit the capabilities of air power in a theater air campaign."[3] For purposes of this research, it is assumed the JFACC, as assigned by the JFC, has operational and tactical control of all assigned and attached air assets in the theater of operations.[4] His decisions, guidance, and direction drive the planning, controlling, and execution of all air operations. The JFACC also has the additional responsibilities of area air defense and airspace control as delegated by the JFC as well.

The concept for all air operations is embodied in the air campaign plan. From this comes the master attack plan (MAP) and finally the air tasking order (ATO) for mission execution. The JFACC develops an air campaign plan for employing all available theater air and space forces[5] in support of the objectives established by the JFC.[6] Missions include, but are not limited to, counterair and counterspace, strategic attack, interdiction, close air support, surveillance and reconnaissance, airlift, and various specialized missions such as electronic combat, combat search and rescue, and air refueling.[7]

The Theater Air Control System (TACS) is the JFACC's primary tool for employing air assets. It provides the JFACC with the deployable facilities, equipment, and trained personnel necessary for command and control of air warfare operations. The TACS elements may be tailored for large- or small-scale operations, and can be deployed either as a complete system or in segments to augment an existing theater command and control system if one is already present.

The fundamental principle underlying the TACS is centralized control and decentralized execution of air operations. The air operations center (AOC) is the senior operations center of the TACS and the focal point for the command and control of air assets.[8] The AOC manages and preserves centralized control of all air operations. It is the nerve center for maintaining command and control over all operational air forces in-theater, including the coordination of roles and missions among various service aircraft and air defense capabilities. Consequently, the search for VR applications which assist in battle management will take place within and around the AOC. The AOC is under the deputy for commander operations (DO) and organized as depicted in figure 2.[9]

The director, AOC reports to the JFACC/DO and is responsible for the tasking of all offensive and defensive air operations. The Combat Plans Division does the detailed planning, force allocations, and tasking. It produces and disseminates the ATO. Combat Operations Division maintains centralized control of all air operations. It monitors the execution of the missions assigned in the ATO and makes adjustments as necessary during operations. Combat intelligence and the enemy situation correlation element produce, correlate, interpret, and distribute various intelligence information as they receive it for use by the AOC. They work with and receive information from theater and national intelligence organizations. The liaison teams provide service-specific expertise to the AOC with respect to the capabilities of their air assets and assist in development and execution of joint air operations. The air mobility center provides the expertise for the coordination and control of airlift and air refueling resources for both inter- and intra-theater usage.[10]

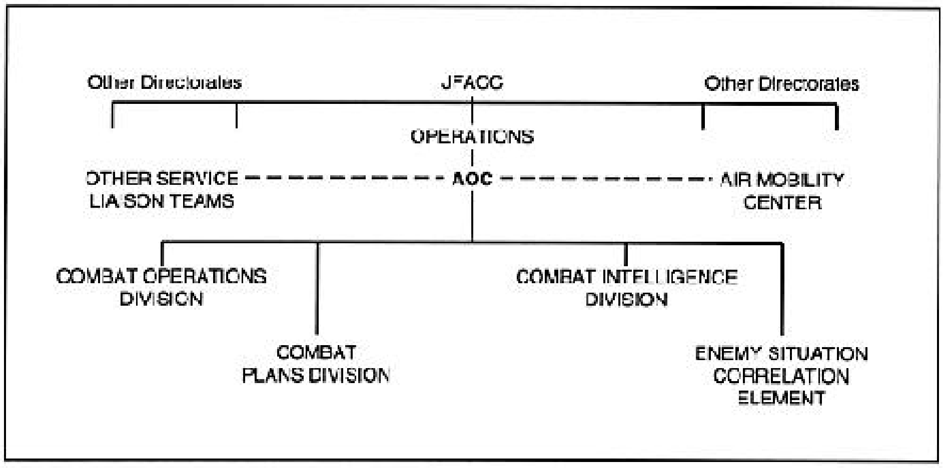


Figure 2. Air Operations Center Organization

Functions of the Air Operations Center

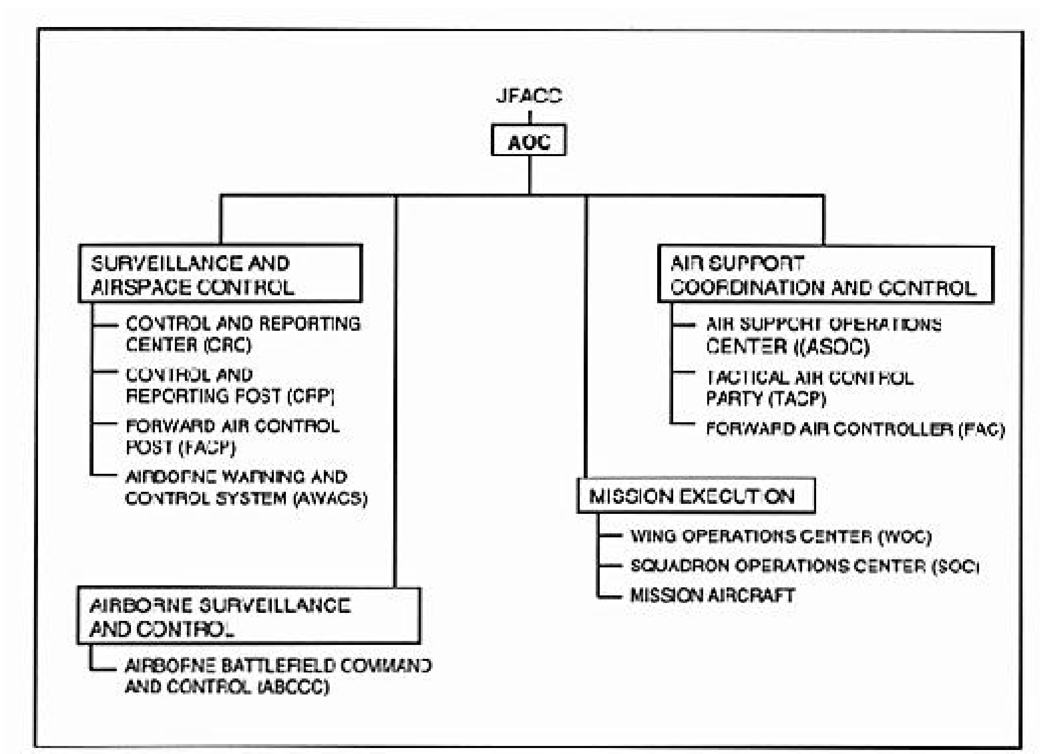
Within the AOC, there are four principal functions which govern the employment of air assets in-theater. They are planning, directing, controlling, and executing.[11] Planning involves the preparation of the MAP and the subsequent ATO. The MAP describes the JFACC's concept of operations for air resources and contains the latest information on the JFACC's assumptions and guidance, assigned missions and tasks, target sets, allocated forces, rules of engagement (ROE), and any other special considerations or constraints. The MAP serves as the driver for the detailed mission planning which occurs during the preparation of the ATO. The ATO contains all the air sortie information necessary for mission execution, including targets and timing. Directing is the process of issuing guidance to lower echelon air components (group, wing, and squadron level) for their tactical planning and execution of assigned air missions. Controlling is the dynamic process whereby the ATO is monitored and adjusted as necessary once execution has begun. Executing begins with sortie generation and concludes with aircraft recovery and the reporting of mission results thereafter.

The result of the entire ATO process is the generation of new ATOs for mission execution. However, it takes generally about three days lead time to generate a given ATO. Consequently, three ATOs will exist simultaneously, each being at a different stage in development. On any given day during an air campaign, there will exist today's ATO ready for mission execution, tomorrow's ATO which is in planning, and the revised MAP from which the ATO for two days hence will come. Significantly, this cycle reveals that the ATO being executed today comes from planning information generated two days ago. Although updates can and do occur within these two days, the process of retasking first depends upon the collection and interpretation of superseding intelligence information from internal or external intelligence organizations and sources. The speed and clarity with which intelligence information came to the tactical air control center (TACC), now called the AOC, in the Gulf War were inadequate.[12] Targeting and mission planning in the TACC suffered from data overload, resulting in data being ignored, misdirected, and misjudged.[13] A better system for handling, incorporating, and presenting intelligence information to the mission planners was sorely needed.

Elements of the Theater Air Control System

As already mentioned, the TACS gives the JFACC the command elements through which his AOC plans, directs, controls, and executes an air campaign. The TACS elements are shown in figure 3.

The elements for surveillance and airspace control are responsible for just that—surveillance and control of theater airspace. Various air and space



Source: Rudolph Zuberbuhler and Larry Pless, *Joint Ops/Intel Analysis,* RL-TR-93-68, vol. 1 (Bedford, Mass.: MEI Technology Corp., May 1993), 9.

Figure 3. Elements of the Theater Air Control System

platforms collect intelligence on the enemy within the theater of operations. Satellites produce imagery through onboard optical, infrared, and/or radar systems. These are national assets normally not under direct control of the JFACC. Likewise, TR-1 and U-2R aircraft collect similar kinds of data with varying resolution and footprint. Rivet Joint (RJ III) aircraft gather electromagnetic emissions produced by the enemy's command, control, and communications (C^3) network. Airborne Warning and Control System (AWACS) and joint surveillance, target attack radar system (JSTARS) platforms have the primary purpose of command and control (C^2) but also collect intelligence through their air-to-air and air-to-ground radars, respectively. Tactical reconnaissance aircraft also gathers intelligence by means of video or other electro-optical (EO) sensors.

The air support coordination and control elements provide for tactical control of air assets within assigned mission areas and the forward battle area. They provide tactical control of air operations in direct support of ground forces. The airborne battlefield command and control (ABCCC) system provides for airborne command, control, and communication between air assets en route and friendly ground defenses and command centers. The ABCCC is the on-scene mission manager for air operations within an area. The mission execution elements execute the missions described in the ATO. They prepare individual mission plans in accordance with the ATO and then report mission results to the AOC's plans, operations, and intelligence divisions.

The significance of the TACS structure for purposes of this study is that it provides the network by which the JFACC, by way of the AOC, receives and disseminates information regarding the air campaign. It lays out the information reporting chains back to the AOC nerve center. But what are the types of information and what are their forms?

Data Required for Air Battle Management

The data needed for battle management of an air campaign can be grouped into four broad categories: plans and objectives data, friendly forces data, environmental data, and enemy forces data.[14] The first three categories are data produced by various C^2 activities. Plans and objectives data provide overall guidance to the AOC. This category of data includes objectives, priorities, forces apportioned, ROEs, special instructions, etc.

Friendly forces data are those which describe the status of friendly forces, to include air resources status, sorties available, tanker and HVAA[15] tracks, aircraft orbits and ingress/egress routes, frequency management, and ground campaign reference points such as the FEBA, FLOT, and FSCL.[16] Environmental data include weather, topographic information, and climatology data for long-range planning.

Information about the enemy is commonly referred to as intelligence data. It is that data produced by the various intelligence organizations which describe the enemy's capabilities, characteristics, and intentions. The intelligence elements at the JFACC level provide the following sorts of information about the enemy:[17]

- enemy command, control, and communications (C^3) network
- intelligence preparation of the battlefield (IPB) data
- threat analysis and assessments
- target nominations
- weaponeering data
- battle damage assessment (BDA) data
- indications and warning data
- reconnaissance and surveillance collection requests and reports
- enemy order of battle (EOB) updates
- all-source intelligence data
- situation awareness
- enemy electronic parametric information

Some of this information is raw and comes directly from sensor assets, but the majority have been culled and put into reports. There are more than 70 kinds of reports and messages which are associated with air operations.[18] Intelligence officers process and interpret the intelligence data and massage it into report form. The more manual preprocessing and culling which occurs, the more time it takes before the information is actually available for use in mission planning and operations. Real-time air battle management is hampered under the current system.

Some of the intelligence reports used by the AOC are in standard United States Message Test Formatting (USMTF) while others are not. The standard reports and messages have the advantage of being read, stored, and manipulated by the Contingency Theater Automated Planning System (CTAPS). Despite this system, however, the automated reports are still textual in form. They may be moved around electronically, but they are printed, reproduced in paper copy, and distributed for use in mission planning and execution. Furthermore, non-USMTF reports, such as BDA which was the single largest intelligence shortcoming in the Gulf War,[19] are disseminated by whatever means possible, to include fax and messenger. CTAPS is a patch to a problem which requires a more innovative approach to correct. It does not offer real-time air battle management capability. Even though some of the information is in standard format, any required preprocessing will still produce some lag before being available to the AOC.

A need exists for a single, real-time, information-fused database at the AOC level.[20] Intelligence information should flow from the collector to the database without unnecessary preprocessing and delay. Mission planners and operators must have an interface which can take advantage of such a database. A VR graphical interface seems ideal. It could handle both imagery and textual information through virtual representations.

Notes

1. The theater or operational level is that level of war concerned with the command and control of all military forces which have been introduced into a geographic area for employment in support of national objectives. The theater level is the highest command level at which the use of military force is managed.

2. Joint Pub 3-0, *Doctrine for Joint Operations,* September 1993, is the primary source for joint doctrine regarding the conduct of joint operations.

3. *JFACC Primer,* DCS for Plans and Operations, Headquarters USAF, 2d ed., February 1994, 1.

4. Operational and tactical control as defined in Joint Pub 1-02.

5. The air campaign includes the use of space forces as well as for the purposes of this research.

6. *JFACC Primer,* 20.

7. AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force,* vol. 1 (Washington, D.C.: Department of the Air Force, March 1992), 7.

8. Air Combat Command Instruction (ACCI) 13-150, *Air Operations Center* (Langley AFB, Va., 7 March 1995), Headquarters ACC/DOY, 11.

9. Rudolph Zuberbuhler and Larry Pless, *Joint Ops/Intel Analysis,* RL-TR-93-68, vol. 1 (Bedford, Mass.: MEI Technology Corp., May 1993), 6.

10. According to ACCI 13-150, the AMC is now the airlift control center (ALCC).

11. Zuberbuhler and Pless, 12.

12. James A. Winnefeld, Preston Niblack, Dana J. Johnson, *A League of Airmen: U.S. Air Power in the Gulf War* (Santa Monica, Calif.: RAND, 1994), 215.

13. Maj Michael R. Macedonia, "Information Technologies in Desert Storm," *Military Review,* October 1992, 36–37.

14. Zuberbuhler and Pless, 19–20.

15. High value air assets or HVAA include those air assets which perform specialized missions and are very limited in overall numbers and AWACS, JSTARS, ABCCC, etc.

16. FEBA, FLOT, and FSCL denote various reference points or lines with regard to the ground battle. The FEBA is the forward edge of battle area. The FLOT is the forward line of troops. The FSCL is the fire support coordination line.

17. Zuberbuhler and Pless, 25.

18. Ibid., A-20, 21.

19. Winnefeld, Niblack, and Johnson, 217.

20. The *C^4I for the Warrior,* Joint Staff, J-6 Directorate, June 1993, defines "fusion" as the process of receiving and integrating multimedia and multiformat information so as to provide the war fighter with "real truth" information.

Chapter 4

Managing an Air Campaign with Virtual Reality

In 1992, TRW began investigating a command and control application when it designed a commander's decision support system. The application was designed to give multiple users, linked on a synthetic local area network, a God's eye view of an operational area of interest. This system would enable commanders in different locations to discuss tactics and improve their coordination. The research and development envisioned users flying through the environment to monitor the theater battlefield. The user would also be able to use the system to determine real-time operational status, pose "what-if" questions, develop courses of action and task resources and assets.

—Joseph A. Viceroy
National Defense

It is quite possible that current VR technology can assist the JFACC in the handling and presentation of information during an air campaign and thus provide for better battle management. This potential application offers both capability enhancements and improved organizational efficiency. A JFACC's capability, through the AOC, is enhanced when more information concerning ongoing air operations is provided in near real time. Immediate information increases the JFACC's ability to stay within the enemy's observe-orient-decide-act (OODA)[1] cycle, resulting in quicker and better informed decisions. The problems experienced in Desert Storm, such as stale and inaccurate bomb/battle damage assessment (BDA) and lengthy ATO planning cycles—30 hours on average[2]—could be markedly reduced. From an efficiency perspective, less personnel would be required for information handling and processing. More information could go directly from source to consumer with less intermediate massaging and manipulating. Better management of these data are critical to improved air battle management. An analysis of VR for this application is overdue.

Two categories of factors pertinent for evaluating VR-enhanced air battle management are operational considerations and technical considerations. Operational considerations are those which improve the operations of the AOC directly. In contrast, technical considerations do not. They consider the maturity of the technology itself and the potential for further research and development in the field.

Improving AOC operations revolves around the need to move deliberately to a more dynamic, near-real-time air battle management capability. The focus must be on acquiring and maintaining a timely, clear, and consistent picture of the theater air situation at all times. The reader will recall that joint doctrine states the JFACC is responsible for planning, directing, controlling, and executing air operations within a theater. VR technology can significantly enhance two of these functions—planning and controlling—in the near term, that is, within the next decade. The relationship between operational versus technical considerations and capability versus efficiency improvements for planning and controlling is shown in table 2.

Table 2

Considerations for VR Enhancements in Air Battle Management

OPERATIONAL		TECHNICAL
Capability	Efficiency	
– greater situational awareness – better decision making – more operational flexibility – better collaborative battle management – quicker mission planning and rehearsal	– reduce manning – noncollocated operations – avoid information overload	– technology maturity – developmental risk – commercial market opportunities

The other two AOC functions—directing and executing—require more from VR technology than do planning and controlling with respect to air battle management. They will be discussed later in the chapter since VR applications for directing and executing have a longer term outlook.

Operational Considerations

Operational considerations are of two types—capability enhancements and efficiency improvements.

Capability Enhancements

Improving the command and control of air operations at the theater level using computer technology is not a new idea. Since the mid-1970s, well before VR had prominence, the need for better command and control in air battle management had been recognized. A 1980 MITRE Corporation study concluded that the battlefield information rate was increasing so rapidly due to modern weapons and sensors that automation would be necessary to maintain adequate command and control.[3]

The MITRE study acknowledged that command and control was not merely a collection of sensors, processors, displays, and data links; but an extension of the basic human decision processes by means of procedures, organization, and equipment.[4] This distinction is ideally suited for a VR user interface. VR would aim to reduce the complexity of the command and control network from the perspective of the user. Aaron Marcus and Andries van Dam, two research engineers, point out, "The purpose of a [VR] user interface is to facilitate user-computer communication by enveloping hardware and software, particularly the semantics of applications in a dialogue. This dialogue hides the structure of I/O [input/output] devices, operating systems, networks, and applications, and lets the user switch applications rapidly, unencumbered by technical mechanisms."[5]

VR-enhanced command and control would increase the AOC's mission effectiveness and air battle management capability in the following ways: provide for greater situational awareness, exploit real-time information for better decision making, increase operational flexibility, and facilitate true collaborative battle management within the AOC.[6]

Rather than rely on static displays of information and written text to ascertain situational awareness, AOC personnel could use stereo displays and hypertext to show the movement of military forces and natural phenomena, like weather, overtime and space. Further, abstract phenomena, like threat envelopes swept out by various radars and air corridors, could be displayed in 3-D.

Decision making within the AOC would be enhanced through VR's ability to exploit real-time information. To act and react quicker than the enemy provides tremendous operational advantage when flexing the military instrument of power.[7] Operational flexibility is extended by reducing mission timelines and allowing for mission redirects and opportunity targeting based upon real-time ATO changes as a result of intelligence updates or unplanned mission events. Reduced mission timelines would achieve a higher mission effectiveness against time critical fixed and mobile targets such as Scuds.[8] True collaborative battle management would be achieved through the creation of a single database from which all AOC personnel operate. The desire would be a seamless flow of information to and from the AOC.[9]

Combining all the above capabilities would allow the JFACC to "fly" through a virtual battlespace, viewing the information collectors' perceptions of enemy units and formations. This real-time, dynamic picture would yield a better understanding of the enemy's immediate movements and capabilities. The JFACC staff could monitor aircraft mission routes, threat zones, and combat air patrol (CAP) orbits, tanker tracks, etc.—all in 3-D and in contrasting color. At the same time, real-time mission update and control functions could assist planners with strike planning and BDA. Mishaps attributed to ROE and IFF protocols, such as the USS *Vincennes* incident[10] and the Gulf War friendly fire accidents, might also be reduced by VR-based systems. In addition, the commander would have the ability to replay or fast forward through time to see major trends during some period of significant operations. There are specific, near-term technology areas which could bring this kind of VR-enhanced command and control capability to the AOC.

The first significant technology area to describe is a real-time, fused database for air operations. Real time means the database is constantly receiving updated information from various sensor platforms and other intelligence sources (discussed in previous chapter) without lag between data receipt and data transmission. Fusion of data indicates that the data from intelligence sources such as radar and photographic imagery, electronic warfare emissions, and intelligence collected by forward reconnaissance teams are sent to and accessible from a single database source. The data would flow to the AOC to be pieced together within the database. As more data are transmitted, they too would be routinely captured by the database from which a VR interface could draw. This fused information warehouse would be the central core of a real-time, real-world battle management system.[11]

The database would certainly contain a terrain library. The library needed for VR-enhanced battle management would include a standard set of objects like tanks, jeeps, trucks, artillery, fighter and bomber aircraft, etc.[12] Also, digital terrain and elevation data (DTED) for the area of operations would be required. The storing, managing, and rendering of terrain data in near real time would be an issue to overcome. Conventional real-world terrain models require massive memory and are difficult to display with acceptable frame rates.

Research is ongoing, however, to make DTED more accessible in real time. For instance, a format developed by K. L. Meissner stores terrain data in a compact configuration which can be converted into rendering structures (i.e., polygons) in real-time fashion.[13] His format outperforms existing commercial formats for storing terrain data, such as MultiGen Flight. The Meissner format decreases memory required and increases frame rate, while maintaining display detail. That is not to say that terrain displays would always require great detail for all applications, especially in air battle management. Required resolution might be higher for close-ups and for panning slowly across an area of interest, but lower for moving over an area of no particular value. The user could tailor his view accordingly.

A second significant technology area necessary for enhancing air battle management through VR is secure high-speed, high-volume data communications. The theater communication network would likely be a combination of air, ground, and satellite transceivers for security and redundancy considerations. Nominally, sensor platforms would transmit their data, such as EO imagery or synthetic aperture radar (SAR) data, near instantaneously to the AOC's central database. Bandwidths for these transmissions would be measured in megabits of information. The military is already working to improve its data link capability. It has established several tactical digital information links (TADIL) to connect various air and ground transceiver stations.[14] Similarly, the Tactical Information Broadcast Service (TIBS) is a satellite network designed for continuous broadcast of tactical data to users.[15] The Joint Tactical Information Distribution System (JTIDS) is a system for distributing tactical information in theater.[16] Finally, the Secure Tactical Data Network (STDN) is a demonstration program designed to improve command, control, communications, and intelligence interoperability between the services.[17] A new commercial communication technology called asynchronous transfer mode (ATM) can deliver throughput rates of 155 megabits per second currently and gigabit speeds in the future.[18]

VR HCI display and rendering technology is the final significant area necessary for improving air battle management within the AOC in the near term. Air battle management requires the command and control of air and surface forces in complex, rapidly changing situations. The quick and accurate portrayal of terrain and sensor data in 3-D is essential.

There are three benefits to stereo imagery in air battle management.[19] First, the image can be decluttered by displaying information at different depth planes. This is particularly important in air space management where data can be voluminous and where multiple moving and overlapping objects must be discernible. The user must be able to zoom and scan through the virtual environment, exposing different depth planes as necessary. Second, abstract and irregularly shaped volumes from radar coverages and other electronic envelopes can be easily depicted in 3-D but not so in 2-D. Third, the display of 3-D imagery through time lets the user perceive time as a fourth dimension. To visualize the relationship between time and space gives the JFACC an accurate and realistic feel for the air situation as it unfolds.

The hardware for 3-D imagery must produce displays with clarity and crispness. Electronic Image Systems (EIS) has developed an autostereoscopic video display (AVD) that can depict any data already in a television-like format, to include real-time computer generated data, live camera images, and sensor collected data.[20] The AVD can provide real-time color "holographic-like" images with full motion parallax and can support multiple users in a collaborative scenario. The system is similar to conventional cathode-ray tube displays and is portable for mobile field use. It builds on raster scan display technology.

Another promising and commercially available display technology is liquid crystal stereoscopic shutter (LCSS).[21] The LCSS mounts to the bezel of a conventional CRT monitor. It synchronizes the video output so that the user, wearing polarizing eyeglasses, sees a flicker-free color stereogram. The LCSS provides the potential to use existing 2-D displays for 3-D imagery.

Super workstations are being developed which are capable of rendering terrain data and other visual information for battle management purposes. The Silicon Graphics IRIS 4D/240GTX, small enough to deploy with an AOC, can render terrain data from the Defense Mapping Agency (DMA), LANDSAT imagery, and radar detection envelopes, as well as haze and shadow effects based on weather, time of day, and season.[22] The system is potentially capable of rendering between 100,000 and 500,000 polygons, depending on the amount of texturing, at an animation rate of 10 Hz to 30 Hz.[23] Continued research and development in parallel multiprocessing and terrain modeling will increase this capability. This fidelity should be adequate for terrain visualization in air battle management.

Some system development work is under way with regard to using VR to enhance air battle management. FORECAST II is an Air Force initiative to develop advanced displays and intelligent interfaces.[24] It is looking at both immersive and nonimmersive environments. FORECAST II will be superseded by the Battle Management Processing and Display Program (BMPDP).[25] The BMPDP will have similar goals to FORECAST II. The Virtual Command Sphere (VCS) program is an Air Force initiative in planning. David Alexander, a writer for *Military Technology*, described the VCS in this way, "In the VCS, autostereoscopic, volumetric and holographic displays would enable a single user (presumably a command level officer) seated in a command chair to access a cyberspatial tactical envelope in which a real-time audiovisual data interface enables the command and control of distributed combat systems."[26] Advanced video displays, which use lasers to excite spinning helixes to generate holographic visuals, are being considered for VCS. The data feed will be real time from multiples sources.

Also planned is the development of an interactive "Data Wall" concept.[27] The Data Wall would be an array of seamlessly tiled, ultra-high resolution, large screen 3-D displays, all connected to one fused core database, from which all AOC personnel could operate. The Data Wall has the advantage of offering true collaborative air battle management and would accommodate multiple users simultaneously whereas the VCS would accommodate a single user at a time.

In addition to enhancing the controlling function of the AOC, VR could also improve the planning function as well. VR 3-D imagery could prove quite valuable in operational mission planning and rehearsal.[28] The mission planner could visually model the mission before actual execution. The planner could take advantage of the greater sense of situational awareness provided by the virtual representation of the air battle space. He could draw upon the multiple sorts of intelligence available in the core database. For example, MITRE's Virtual Environment Architecture Prototype System (VEAS) would permit a mission planner to access the various types of information needed to plan a mission.[29]

Mission planners would likely become more proficient at their jobs due to experiential learning. It was Roger D. Smith, writing for *Signal*, who said, "Just as people remember events from a movie more clearly than those from a book, virtual reality can be used to embed lessons in the human brain more deeply."[30]

VR could reduce the risk for information overload within the AOC.[31] As mentioned previously, the quantity and variety of information flowing into the AOC is on the increase for a dynamic air battle situation. Most of the information flowing through the AOC is textual in the form of standard and nonstandard USMTF reports.[32] VR could render that information stereographically for a more rapid understanding by the user. The potential exists to quicken substantially the ATO generation cycle as well as decreasing the amount of paper reports produced and disseminated.

Efficiency Improvements

VR technology applied to air battle management at the theater level of war could potentially make more efficient the organization of the AOC. The reader will recall that a typical AOC consists of a combat plans, an operations, and an intelligence divisions, as well as an enemy situation correlation element. With VR technology, these divisions could shrink in manning, be noncollocated, and yet operate from the same fused database of information, again substantially increasing JFACC command and control capability of air resources.

The number of intermediate personnel who produce textual reports from the collected intelligence information could diminish. Data interpretation could be made directly from the virtual representations of the data themselves. The mind can process visual data easier and faster than text. Retention and recall of that information is expanded as well. This is not to say that text will disappear. To the contrary, it would be an effective augmentation to graphical representations. Furthermore, the virtual environment could be annotated with the spoken word as well as written text.[33]

It was mentioned earlier that the AOC functions of directing and executing have a longer term outlook with regard to VR assistance than do the planning and controlling aspects of air battle management. Directing and executing air operations through VR begins to creep into the realm of remotely controlled operations and unmanned aerial vehicles (UAV). Although VR technology offers great potential for these applications, the technology to bring them to fruition is farther down the road. But what will it look like when it arrives?

Future UAVs will be theater controlled, multimission capable, and have 24-hour endurance.[34] They will carry payloads like high-resolution radar and electro-optical, visible and infrared, imagery sensors. Their sensor data will be processed and relayed to the AOC in real time via wideband satellite communication links. They will do such missions as reconnaissance, surveillance, target acquisition, BDA, electronic jamming, and even strike and counterair. What will be needed, which VR can provide, is an all-aspect command and control system.

Real-time feedback will give the remote operator a virtual pilot presence. Today, the human perched at the pointy end of the spear is a limiting factor from a physiological viewpoint and a liability strategically and economically.[35] Manned air vehicles are presently designed with crew compartments, life-support systems, and ejection seats, all of which detract from the performance of the platform as well as drive up costs. Fighters are no longer limited by the stress tolerance of their materials but by the physiology of their passengers. Strategically, downed and captured airmen held hostage could severely limit US response and resolve, to say nothing about America's growing intolerance for casualties. And then there are the multimillions spent for pilot training. A serious consideration of VR for UAVs offers a variety of advantages, but a tremendous paradigm shift among airmen is needed.

Technical Considerations

There are relevant technical considerations which also must be assessed when evaluating VR for air battle management. The first is technology maturity and associated developmental risk to the Air Force. Commercial industry is at least involved with and more often leading the development of VR-enabling technologies in almost all areas. Commercial industry has recognized a market for these applications in several business sectors such as entertainment, medicine, manufacturing, modeling, and simulation. With commercial industry already involved in VR component technologies, a partnered investment strategy between industry and government for continued research and development seems very reasonable—even more so given the overlap which already exists with several of the DOD's critical technologies, namely high-performance computing, software engineering, simulation and modeling, signal and image processing, and data fusion.[36]

Spin-on and spin-off opportunities both exist, with more likelihood for the former than the latter.[37] The present commercial industry stake in VR technologies lessens the potential time to develop military applications of VR systems. The lone subarea where the military might have to lead in research and development would be in secure high-speed, high-volume communications. In a future war scenario, numerous sensor platforms would be collecting vast amounts of information and sending it instantaneously to an AOC database for fusion and display. The combination of speed, volume, and security in real-time data communications might not generate an equivalent commercial demand at any given point in time. Consequently, this area might require a good endogenous investment strategy for future development.

Notes

1. Refers to Col John Boyd's (USAF, Retired) observe-orient-decide-act or OODA decision cycle.
2. Rudolph Zuberbuhler and Larry Pless, *Joint Ops/Intel Analysis,* RL-TR-93-68 (Bedford, Mass.: MEI Technology Corp., May 1993), 15.
3. Joseph G. Wohl, *Battle Management Decisions in Air Force Tactical Command and Control,* ESD-TR-80-123 (Bedford, Mass.: MITRE Corp., 8 May 1980), 5.
4. Ibid.
5. Aaron Marcus and Andries van Dam, "User-Interface Developments for the Nineties," *Computer,* September 1991, 49.
6. Richard T. Slavinski, "Advanced Displays and Intelligent Interfaces" (briefing slides provided at Rome Laboratory, N.Y., March 1995); and Mark Storer et al., "Airborne Tactical Information Management System In-Cockpit Mission Replanning and Rehearsal (ATIMS/ICMRR)," *IEEE,* April 1994, 998–99.
7. Maj James E. Haywood, "A Theory for Aerospace Power Application in War" (Unpublished essay, School of Advanced Airpower Studies, Maxwell AFB, Ala., 5 May 1995), 5.
8. Storer et al.
9. Ibid.
10. David Alexander, "Military Applications for Virtual Reality Technologies," *Military Technology,* May 1993, 54.

11. Roger D. Smith, "Virtual Reality Merges with Battle Simulation," *Signal,* July 1993, 52–54.

12. Ibid., 52.

13. Capt Keith L. Meissner, "A Format for Storing and Managing Multiple Levels of Detail Terrain for Simulated Environments" (Master's thesis, Air Force Institue of Technology, March 1994), 1–3.

14. *Theater Air Command and Control Simulation Facility (TACCSF) User Guide,* August 1994, Kirtland AFB, Albuquerque, N. Mex., 1–3.

15. Ibid., 6–14.

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18. Robert Mandeville, "ATM Switches: The Great Unknowns," *Data Communications,* April 1995, 99.

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21. H. Veron et al., *3-D Displays for Battle Management,* RADC-TR-90-46 (Bedford, Mass.: MITRE Corp., April 1990), 3.

22. D. A. Southard, *Superworkstations for Terrain Visualization: A Prospectus,* RL-TR-91-105 (Bedford, Mass.: MITRE Corp., June 1991), ii–vi.

23. Ibid., 7–8, 39.

24. Alexander, 56.

25. Ibid.

26. Ibid.

27. Nicholas P. Negroponte, *Virtual Environments in Command and Control for Ultra-High Definition Displays,* RL-TR-94-24 (Cambridge, Mass.: Massachusetts Institute of Technology, April 1994), 1.

28. Southard, 5.

29. Veron, 64.

30. Smith, 54.

31. Storer, 998–99.

32. Zuberbuhler and Pless, 20.

33. William Ribarsky et al., "Visualization and Analysis Using Virtual Reality," *IEEE Computer Graphics and Applications,* January 1994, 12.

34. John Entzminger, "Acquiring Affordable UAVs," *Journal of Electronic Defense,* January 1995, 36.

35. Haywood, 11.

36. *Critical Technologies Plan,* Table 1, Department of Defense, 1 May 1991, 3.

37. Spin-off is the notion that technology researched and developed under military defense auspices will eventually flow to commercial industry for commercial applications. Spin-on is the reverse phenomenon.

Chapter 5

Conclusion

Although the information processing and distribution capabilities of CTAPS will be tremendously welcome, the structural problems of a command and control system designed to fight tactical war will persist. . . . So without somehow speeding up the entire process of targeting and mission planning, the organizational and structural problem of evaluating reconnaissance information and translating it into targeting objectives will force us to remain outside of the tasking cycle.

—J. Taylor Sink, Lt Col, USAF
Rethinking the Air Operations Center: Air Force Command and Control in Conventional War

A VR system can significantly enhance theater air battle management within the next decade and should be pursued by the US Air Force. During the Gulf War, AOC operations were overloaded with information and a process for the use of real-time intelligence was lacking. The potential exists for further overload as the battlefield information rate is expected to only increase in the future. Future theater war will be rapid paced and information intensive.[1] A system for handling that information flow is needed. The CTAPS is not the answer. It is old thinking that promises only marginal improvements in capability and efficiency. It fails to take advantage of growing computer power and capability. VR, to the contrary, is a way to truly exploit leading edge computer technology. Roger D. Smith, a computer engineer with experience in military applications, calls VR a revolution in human-computer interface.[2] Unlike CTAPS, VR can bring real-time battlespace telepresence to AOC operations.

A VR-enhanced AOC will increase operational mission effectiveness and facilitate organizational efficiencies. It will vastly increase situational awareness, make for remarkably quicker decision making, and increase operational flexibility dramatically within the AOC. At the same time, it will reduce manning and enable genuine collaborative battle management among AOC personnel.

The technologies to bring these capabilities to the JFACC are available now or will be within the next few years. High-speed, high-volume secure data communications will move intelligence information from source to consumer near instantaneously. Information-fused databases will make the same collected data accessible to the entire AOC. VR display and rendering technologies will put the mission planner *into* the battlespace environment.

This real-time, ongoing, dynamic picture will provide a better understanding of the enemy's capabilities, intentions, and ambitions.

Beyond air battle management, VR promises to deliver even more performance once accepted into the operational military. It would perfectly complement future UAVs and unmanned space vehicles by providing an all-aspect command and control capability. Remote operations would occur through a virtual pilot presence.

Enough commercial interest exists to minimize the investment risk for further research and development. Alliances between traditional defense contractors and commercial industry are already forming. For instance, Loral's Advanced Distributed Simulation Division has teamed with Entertainment Systems Corporation to bring real-time interactive simulation to the video games industry. Likewise, Silicon Graphics Incorporated, a major defense supplier of computer graphics technology, has joined with Nintendo Corporation to develop a 3-D, 64-bit VR machine for home use.[3] Both the commercial markets and the military would benefit from continued partnerships.

While VR technology may be available and even more promising for future air operations, the easy acceptance of VR-enhanced air battle management is not likely. Air Force organizational reluctance is anticipated in two areas. The first is a distrust in the technology. The communication data links between the collection platforms and the AOC would be a vulnerability. Nonetheless, security could be maintained by designing a high degree of redundancy into the communications network and by following current frequency protection measures. A further vulnerability would be the electrical power at the AOC. Again, however, planning for redundant power sources would mitigate the problem.

The second area of concern is micromanagement of air operations. There may be fear that a VR-enhanced air battle management system would give too much control to the AOC and thus take away the initiative from the war fighter. But this is a hollow criticism. Execution would still remain with the war fighter. VR in air battle management would only provide for better information handling and presentation at the JFACC level and not be causal to any sort of micromanaged execution. These kinds of organizational resistance can be overcome with persistence and patience. Meanwhile, however, VR technology marches on *virtually*.

Notes

1. *Assessment of the Military-Technical Revolution* (U) (Subject of memorandum for Secretary of Defense, Deputy Secretary of Defense (Secret), 15 July 1992, 22–23. Information extracted is unclassified.

2. Roger D. Smith, "Current Military Simulations and the Integration of Virtual Reality Technologies," *Virtual Reality World*, March-April 1994, 46.

3. Maryann Lawlor, "Firms Take Technology from Battle Simulator to TV Screen," *Signal*, April 1994, 53.

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