NAVAL POSTGRADUATE SCHOOL
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THESIS

VISUAL SIMULATION OF NIGHT VISION GOGGLE IMAGERY IN A CHROMAKEYED, AUGMENTED, VIRTUAL ENVIRONMENT

by

Del L. Beilstein

June 2003

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ABSTRACT (maximum 200 words)

Despite data indicating more human error accidents occur during NVG flight than in any other flight mode, there are very few simulation tools available to aviators at the unit level that aid them in learning or practicing NVG flight tasks. This thesis examines the potential for a Chromakeyed Augmented Virtual Environment (ChrAVE), consisting only of Commercial-Off-The-Shelf (COTS) hardware, to be used as an NVG flight training platform. It also examines whether or not physically-based light calculations are necessary to produce adequate visual representation of simulated NVG imagery. Twelve subjects performed simulated low-level NVG flight navigation tasks in the ChrAVE. Treatments included questionnaires, vision tests, variation of the physics-based component of the NVG imagery, and performance of an evaluation task that compares standard thresholds between day and NVG navigation. Analysis of data and subject feedback indicate that the ChrAVE has potential as an NVG flight training device, and that physically-based calculations may not be necessary to achieve simulated NVG imagery that is adequate for training. The data also supports the existence of a substantial difference in the subjective evaluation standard between navigation performances based on flight condition.

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VISUAL SIMULATION OF NIGHT VISION SYSTEMS IN A CHROMAKEYED, AUGMENTED, VIRTUAL ENVIRONMENT

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Submitted in partial fulfillment of the
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ABSTRACT

As data from the U.S. Army Safety Center supports, a large percentage of Army Aviation human error accidents occur during NVG flight. Despite this fact, there are very few simulation tools available to aviators at the unit level that aid them in learning or practicing NVG flight tasks. This thesis examines the potential for a Chromakeyed Augmented Virtual Environment (ChrAVE), consisting only of Commercial-Off-The-Shelf (COTS) hardware, to be used as an NVG flight training platform. It also examines whether or not physically-based light calculations are necessary to produce adequate visual representation of simulated NVG imagery. Twelve subjects performed simulated low-level NVG flight navigation tasks in the ChrAVE. Treatments included questionnaires, vision tests, variation of the physics-based component of the NVG imagery, and performance of an evaluation task that compares standard thresholds between day and NVG navigation. Analysis of data and subject feedback suggests that the ChrAVE has potential as an NVG flight training device, and that physically-based calculations may not be necessary to achieve simulated NVG imagery that is adequate for training. The data also supports the existence of a substantial difference in the subjective evaluation standard between navigation performances based on flight condition.

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I. INTRODUCTION

A. PROBLEM STATEMENT AND MOTIVATION

Night vision goggles (NVGs) are optical devices that are worn on the head (often mounted to a helmet) that amplify the ambient light that exists in a night environment, allowing increased capability and situational awareness for the user. Performing flight duties while wearing night vision goggles is one of the most challenging and inherently dangerous requirements faced by military rotary-wing aviators. As data from the U.S. Army Safety Center supports, a large percentage of Army Aviation human error accidents occur during NVG flight. Despite this fact, there are very few simulation tools available to aviators that allow them to practice NVG flight tasks in the relative safety of a simulated flight environment. This thesis will examine the viability of using commercial, off-the-shelf (COTS) equipment to construct a chromakeyed augmented virtual environment (ChrAVE) that simulates NVG rotary wing flight for training, and attempt to determine if physics-based electromagnetic energy and material response calculations are required for NVG visual simulation.

1. Characteristics of Existing Simulators

a. Full-Motion Simulators

Most simulation tools in existence for rotary wing aviators today fall into one of two categories: High resolution, full-motion simulators or non-motion, personal computer (PC) based training systems. High resolution, full-motion simulators are very expensive to acquire and maintain, and usually require extensive training or a separate technician to operate. When combined with its support equipment, a planning station, and an operator console, this kind of simulator generally has a rather large footprint, on the order of a dedicated building. The software that drives such a simulator is very complex and expensive to develop, and the associated hardware is proprietary and designed strictly for use as a simulation tool. This kind of simulator is fundamentally non-deployable and despite having high fidelity for instrumented and/or tactical flight, often does not even attempt to support night-vision device training. Further, since the high cost and large footprint of these systems mean that DOD services can afford relatively few of them (relative to the number of aircrew members that need to train on these systems), the amount of time the individual aviator can spend using these systems is

inherently constrained. The need to 'share' such limited resources results in less than desired availability of these systems.

b. Personal Computer (PC) Based Systems

In contrast, low resolution, PC based training systems are becoming ubiquitous throughout the Department of Defense. This type of training device is obviously very deployable and is relatively cheap to acquire and maintain. An added benefit is found in the flexibility of the hardware--since it is PC-based, it can often be used for other day-to-day aviation unit tasks such as word processing or networked communication. While this factor is certainly not the most important aspect of a simulation system and may even be viewed negatively by simulation purists, such flexibility is truly an asset in a severely cost-constrained training arena. The training audience (the pilot or aircrew) is generally the only person(s) required to operate the system, and it has a very small footprint. An example of this type of simulator is the Army's Aviation Survivability Equipment Trainer (ASET), which gives still photo, video and very limited aural stimulations (tones) to the user. Unfortunately, most of these systems do not offer real-time, 3D imagery, thereby limiting the level of immersion experienced by users. Many of these systems (like the ASET) might actually be considered more of a procedural trainer. This type of trainer can definitely play a role in training aviators, but as a rule cannot be effective in training complicated, visually sophisticated tasks such as NVG flight. So while its low cost, availability, and ease of deployment make this kind of simulator attractive at the aviation unit level, it is not very immersive and does little to train complex tasks.

c. Topscene™

One simulation system that tries to bridge this gap is Topscene™. Topscene™, produced by Lockheed Martin, Inc., is already being used by U.S. Navy and Marine communities. Topscene™ uses detailed satellite photography to produce a 3-D scene. Topscene™ consists of integrated flight controls, two screens and a computer that is approximately the same size as a standard desktop monitor, although some Topscene™ imagery can be reproduced on laptops. The Navy currently maintains approximately 300 such systems, and Topscene™ is used primarily as a mission rehearsal tool. Topscene™ is very deployable, and doesn't have a large footprint. It also simulates night vision imagery.

Figure 1. Topscene™ imagery (From Military Brings 3-D Advantage to War Preparation, by David McGuire, The Washington Post, March 17, 2003)

But a recent article in the Washington Post (*Military Brings 3-D Advantage to War Preparation*, by David McGuire, March 17, 2003) identifies several important cost and availability factors that appear to be shortfalls for Topscene™:

> But from the vantage point of Joe the Marine aviator, 3-D mission rehearsal remains something of a luxury for most pilots in the military. Many pilots deployed to the Persian Gulf region come from stateside bases lacking Topscene™ or similar technologies, and even when they are familiarized with the system, they rarely get to use it for longer than five minutes at a stretch, Joe said. The high cost of many of these systems is a factor. While slower PC and laptop-based versions of Topscene™ cost less than $1,000, the fully outfitted Topscene™ racks that are the most useful to combat pilots set the Navy back as much as $300,000 each…'That doesn't include the cost of the satellite images necessary to create the models. We don't have a lot of these out, and a lot of the guys here are not very familiar with it. Guys are coming on board slowly,' he added. 'Most guys can't really hog it. We've got a lot of people here and we've only got one [system].'

2. The Potential Benefits of Using Commercial Off-The-Shelf (COTS) Equipment

As these quotes illustrate, there is still an absence of low-cost, highly available, and easily deployable NVG simulation DOD-wide. A relatively small, deployable NVG flight simulation device that uses COTS equipment could go a long way toward filling this gap. Using COTS components is important for several reasons. It would make the system relatively inexpensive, meaning more systems could be purchased for the same amount of money, making more systems available to aircrews. COTS equipment would also allow for greater flexibility in acquisition, maintenance, and replacement of components. It would allow the system maintainer to upgrade and improve the system as technology improves. This is an extremely important capability that would keep the system from becoming quickly obsolete, given the pace of recent technological advances. For example, if processor speed or graphics card capability improved dramatically over what is currently installed in the system, the system maintainer could simply purchase the improved component locally and replace it. If such a system existed, it would likely proliferate through DOD aviation units rapidly, and could be utilized in several important training roles. Initial NVG qualification training for aviators could incorporate such a training device, allowing aviators to become familiar with the capabilities and limitations of NVG flight in a safe training environment prior to attempting to actually fly with them. Experienced aviators could potentially use such a training device to maintain their skills during times when they are unable to conduct actual NVG flight due to deployment, weather, or aircraft availability.

Aviators could even use the system to practice NVG flight tasks during the day, when mission requirements do not allow them to go on "reverse cycle" (perform their duties during the hours of darkness). The potential of such a system, if it existed and was proven to be an effective NVG training device, could be immense.

3. The ChrAVE's Basic Implementation

The ChrAVE prototype developed by Lennerton would seem to be an obvious candidate to become such a simulation system. The ChrAVE creates the 'look and feel' of a generic cockpit environment, and augments it with a visual representation of virtual terrain displayed from the perspective of being inside the cockpit (in other words, an 'out the window' view).

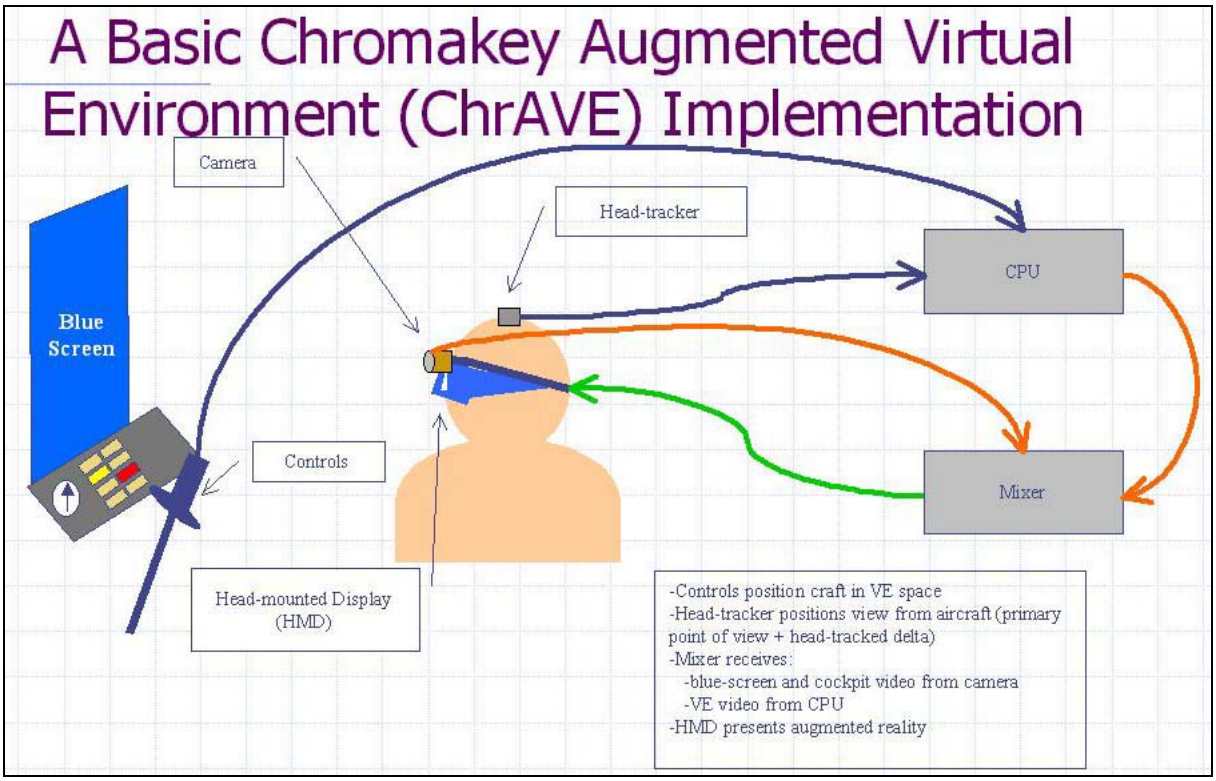

Figure 2. Basic ChrAVE Implementation (From Lennerton, 2002)

The ChrAVE uses chromakey, or 'blue screen' technology to mix the views of the real and virtual worlds so that the user can see himself, his cockpit, and the (virtual) terrain as he would in an actual aircraft. The ChrAVE consists of COTS equipment on a transportable cart, has a relatively small footprint, and is easily maintained and modified. If it can be shown that the ChrAVE is a viable NVG training device, then we are one step closer to the 'perfect' device--

one that is affordable at the aviation unit level, deployable, has a small footprint, and uses non-proprietary, COTS equipment-- described earlier.

B. THESIS OVERVIEW

Initial ChrAVE research (Lennerton, 2002) identified three steps to exploring the potential of a ChrAVE environment for training: "(1) research into the psychology and potential of training via simulators, (2) the production of a fully operational embedded trainer, and (3) verification of the results of using such a trainer." This thesis will continue Lennerton's work in researching the psychology and potential of a ChrAVE environment for training. In order to prove the viability of the ChrAVE prototype for use as an embedded training device, he tested subjects (experienced military helicopter pilots) on their ability to perform a low-level (200 feet above ground level) daytime navigation task. As will be discussed in greater detail later in this thesis, Lennerton showed that the ChrAVE prototype could be useful in training this task under daylight conditions. Implicit in this conclusion is that the ChrAVE's visual representation of a daylight scene at low-level flight altitude is adequately detailed and realistic for training. This thesis will extend that research to try to determine if a ChrAVE environment, using only COTS equipment, can produce a visual simulation of NVG imagery that is adequate for NVG training. It will also try to determine if the ChrAVE can achieve this 'adequate' level of NVG imagery without performing expensive (in terms of software development costs and processor time) physics-based light and material response calculations. In order to examine the ChrAVE prototype's ability to adequately represent NVG imagery, the approach of this thesis will be to obtain the opinions of and evaluate the performances of experienced military helicopter pilots (considered as NVG training subject matter experts (SMEs) based on their experience) while performing a low-level flight navigation task in a simulated NVG environment. The subjects will be asked to perform a series of tasks that are virtually identical to those performed by Lennerton's subjects, using the same prototype ChrAVE originally constructed by Lennerton. Subjects will conduct a pre-flight questionnaire that is designed to gather data on subject (NVG and day) flight, simulator, and virtual environment experiences. The subjects will prepare a map for NVG flight, enter the ChrAVE and attempt to navigate a route in a virtual world similar to that of Lennerton's subjects, but under simulated NVG conditions. Each subject will fly a portion of the route using image rendering software that is physics-based, and another portion that uses rendering techniques that are not physics-based. The performance data collected will

then be used to answer the two primary research questions of this thesis. A within subject group comparison will be made to determine how subject performance changes based on whether NVG imagery was physics-based or not. Additionally, subjects will complete a 'post-flight' questionnaire that will opine the aviators as to any difference in quality or realism of the two visual presentations, the ability of the ChrAVE to be used as an NVG flight training device, and check for any degree of cybersickness.

C. RESEARCH QUESTIONS

As stated previously, there are two primary research questions this thesis will attempt to answer: (1) Can the ChrAVE produce NVG imagery that is adequate for training? (2) Is current COTS physics-based software a requirement for the production of NVG imagery for training? In outlining the scope and relevance of these questions as they pertain to the work of this thesis, two key phrases demand additional definition: 'adequate for training' and 'physics-based software'.

1. Is ChrAVE NVG Imagery Adequate For Training

The term 'adequate for training' refers to the ability of a training system or simulator to impart training transfer to users. For the purposes of this thesis, this term will refer to the potential ability of the ChrAVE to impart training transfer of a low-level navigation task in desert environment under NVG conditions. The opinion of the subjects (as SMEs in the realm of helicopter low-level NVG navigation) as well as their task performance will be used to measure this potential for this research. If the ChrAVE is found to have adequate potential as an NVG flight training device, future research may examine the use of the ChrAVE's effects on actual task performance in an aircraft.

2. Is Physics-Based Software Necessary

This thesis will use the term 'physics-based' to refer to simulation systems with software that attempts to render imagery of a virtual world based by performing physics equations to mathematically define the behavior and effects of light and material response. This is an admittedly subjective definition, since there is software in existence that use physics calculations for only one or two aspects of its imagery presentation, and others that attempt to define virtually all object relationships and effects in terms of physics equations. Performing physics based material response adds complexity to algorithms, uses additional processor cycles, and increases cost and time of software development. Martin and Clark (2000) found that for a visual simulation of NVG imagery to be realistic, it must use physically-based light calculations. It

may well be that some tasks, such as over-land helicopter navigation, do not require the level of detail that is provided by physics-based graphics, and other tasks such as target identification, do require them. This research found that "Realistic luminance, contrast, and resolution are not possible without physics based material response." While this may be true for high resolution NVG simulation devices, it may not be an absolute requirement for training all NVG tasks. There are likely a set of tasks which can be trained in an NVG simulation environment without the added complexity and cost of physics based light calculations. If this task set is large enough, it may be cost effective to produce software that creates NVG imagery adequate for training these tasks by using rendering techniques alone, resulting in software development and acquisition cost reductions for the Department of Defense.

D. THESIS ORGANIZATION

This thesis is organized into the following chapters:

1. Chapter I: Introduction. This chapter includes an introduction to the problem, motivation, and outline for the thesis.

2. Chapter II: Background. This chapter contains pertinent background information including an explanation of how night vision goggle technology works and its limitations, a discussion of how aviators train while using NVGs, information regarding helicopter navigation techniques, summaries of relevant previous work , and a description of chromakey and augmented virtual environments.

3. Chapter III: Implementation. This chapter describes how the system was implemented. It contains descriptions and specifications of the hardware components and software employed in the implementation.

4. Chapter IV: Methodology. This chapter describes experimental setup and execution. It provides necessary information to recreate the experiment.

5. Chapter V: Results. This chapter contains results of the experiment.

6. Chapter VI: Conclusions. This chapter contains conclusions reached from the experimental process.

7. Chapter VII: Future Work. This chapter describes the research and implementation ideas that the author was unable to perform due to time or technology constraints. Additionally, this chapter suggests new research questions generated by this research.

II. BACKGROUND

A. NIGHT VISION GOGGLE TECHNOLOGY

1. NVG Characteristics

Military helicopter aircrews use NVGs extensively during night operations. The use of NVGs provides military helicopter aircrews with greatly enhanced operational capability and significantly improves situational awareness during the hours of darkness. There are some important operational characteristics that are common to virtually all the different models of NVGs currently in use by military aircrews. It is important to have an understanding of the specifications, capabilities and limitations of NVGs in order to understand how they are used by aircrews, as well as how their use should be simulated for training purposes.

NVG image intensification tubes are usually worn mounted to the front of an aircrew member's helmet. The mount normally has a swivel mechanism that allow the tubes to be locked in one of two positions: an 'up' position that keeps the tubes locked in a vertical position and out of the aircrew member's field of view; and a 'down' position that locks the tubes in a position in front of the aircrew member's eyes for viewing.

Figure 3. A pilot wearing NVGs (From http://www.nvl.army.mil/home.html, May, 2003)

Often aircrews will depart on a mission during daylight or dusk conditions with the tubes locked 'up', and then transition the tubes to a 'down' position for use when conditions become too dark for the unaided eye. The image intensifier tubes have several adjustment mechanisms that allow the wearer to configure them for optimal viewing position, viewing resolution, fit, and comfort. The wearer can adjust the vertical position, distance from the eyes, distance between tubes, and 'pitch' angle (fore and aft tilt) of the image intensifier tubes using mechanisms that adapt the tubes to their individual viewing preferences. The objective and eyepiece lenses allow for large and fine adjustments of focal point respectively. The image intensifier tubes normally weigh approximately 1.8 pounds, and their position on the front of the helmet can cause neck muscle strain over time for aircrew members. A weight bag (weighing up to approximately 22 ounces) mounted to the rear of the flight helmet can help to balance the weight of the image intensifier tubes, but also increases the total amount of weight worn on the aviator's head to over three pounds. While aircrew members normally become accustomed to operating with this weight on

their head, it can certainly cause fatigue and should be considered when operating under NVG conditions for extended periods of time.

Most models of NVGs provide a small battery pack that attaches to the back of the flight helmet and connects to the image intensifier tubes via a short cable. The battery pack normally accepts both lithium and 'double A' batteries, though not both types in combination simultaneously. The battery pack usually also provides a receptacle that accepts external power, provided by a cable that attaches from the aircraft. It is important to manage the routing of this cable (along with the audio/communications cable that also attaches to the flight helmet from the aircraft) in order to prevent the cable from restricting head movement or becoming tangled.

2. How NVGs Work

Night Vision Goggles amplify the existing, ambient light energy in a night environment to provide the user enhanced operational capability and increased situational awareness during the hours of darkness. Since NVGs are very complicated electro-optical systems, this thesis will not attempt to provide a thorough technical description of NVG components and how they function. However, a basic description of the major components of NVGs and a high-level overview of how these components work may aid in understanding NVG capabilities and limitations, and are relevant to the visual simulation issues that are the focus of this thesis.

NVGs consist of one or two image intensifier tubes that perform ambient light amplification. Each image intensifier tube contains five major functional components (listed in the order in which light travels): an objective lens, a photocathode, a microchannel plate, a phosphor screen, and an eyepiece lens.

Figure 4. Image Intensification Process (From Martin and Clark, 2000)

Ambient light (electromagnetic energy in the form of photons) from a scene enters the image intensifier tube through the objective lens. The objective lens focuses these photons as an inverted image onto the photocathode. The photocathode then converts the image from photons to electrons by releasing electrons in the pattern of that inverted image, and these electrons are accelerated across a small space to the microchannel plate. The microchannel plate contains millions of microscopic channels, or tubes, which have openings on the front and back of the plate and contain an electrical potential gradient along their length. Electrons flowing from the photocathode enter the individual tubes of the microchannel plate. These electrons 'bounce' through the tubes, and they impact the internal walls of tubes, more electrons are released. With each impact, more electrons are released, and this increased amount of electrons moves through the tubes, continuing to collide with the walls and releasing still more electrons. This electron multiplication process continues until the mass of electrons exit the microchannel plate. After leaving the microchannel plate, the electrons are accelerated across another small gap, striking the phosphor screen. The phosphor screen converts the electrons back to light energy, or photons. At this point the light amplification process is complete, and the luminance of the image produced by the photons from the phosphor screen is many times brighter than that of the image that originally entered the image intensifier through the objective lens. The image from the phosphor screen is then focused via the adjustable eyepiece lens onto the retina of the wearer's eye, where he receives a monochrome green image of the scene. An example of an NVG image is provided in Figure 5.

Figure 5. NVG Imagery

3. NVG Visual Limitations

Night vision goggles in use today are extremely capable and offer outstanding capability for enhancing night operations and increasing situational awareness during the hours of darkness. However, there are still several key limitations that users must be familiar with in order to operate safely and successfully with these devices. A summary comparison of the visual display characteristics of the normal (healthy) human eye, image intensifier tubes, and the ChrAVE (NVG implementation) are provided in Table 1.

Visual Display	Horizontal FOV	Visual Resolution	Color Vision	Peripheral Vision	Type Vision
Eye	200°	20/20	Yes	Yes	Binocular
NVG	40	20/40	No	No	Monocular
ChrAVE	40	Varies	Limited	No	Monocular

Table 1. Summary Comparison of Visual Display Characteristics

a. Limited Field of View

One of the most important limitations of night vision goggles is that the horizontal field of view (FOV) provided by the image intensifier tubes of most NVGs in use by military aircrews today is only 40 degrees, which offers pilots no peripheral vision whatsoever. Arthur (1996) has shown that limited FOVs and the lack of peripheral vision can result in difficulty in depth perception and distance estimation. The ability to correctly judge depth is obviously a critical limitation as it relates to a helicopter pilot recognizing his aircraft's height (altitude) above the ground. Difficulties in estimating distance can result in striking obstacles or other aircraft due to skewed perception of relative positioning. Relatively expensive, limited production models of NVGs exist that are capable of providing a larger FOV (up to 120 degrees horizontal) in an attempt to overcome these limitations, but as of now these models are not available to military pilots as approved aids to visual flight. Aircrews rely upon several techniques or procedures to overcome limited field of view. The most important procedure is

using visual scanning techniques. By simply sweeping the NVGs back and forth across the whole visual search area (by constantly turning his head to the right and left), the aircrew member can give himself the perception of having a larger horizontal field of view. This technique allows the NVG wearer to maintain situational awareness of an area that is larger than that which he can see at any one time by directly viewing a scene. In order to more closely replicate the use of NVGs during this research, the HMD used by subjects was adjusted to provide only a 40 degree horizontal FOV.

b. Monocular Vision

Another important visual limitation of NVGs is that they provide only monocular vision to both eyes, rather than the binocular vision that humans have normally. Binocular vision occurs due to the slightly different point of view between the right and left eyes (Figure 7). Binocular vision allows for depth perception and distance estimation for near objects, -and also provides important cues as to relative motion (motion parallax) and orientation. Motion parallax describes the visual cue that helps humans detect movement rates. It can also be described as relative motion, as during movement near objects appear to move in the opposite direction to your movement at a rate relative to you speed, while objects farther away appear to move much more slowly. A problem that can be encountered due to the lack of binocular cues is undetected aircraft movement, or drift. Undetected aircraft drift can result in a helicopter making contact with obstacles when operating at low altitude or in hovering flight. During flight at any given speed, the ground will appear to move more slowly at higher altitude than it appears to move at lower altitudes. Pilots quickly become accustomed to this visual cue, and use it to help judge their altitude and relative speed. This cue is normally perceived by use of peripheral

vision, which is not available due to the limited FOV of the NVGs.

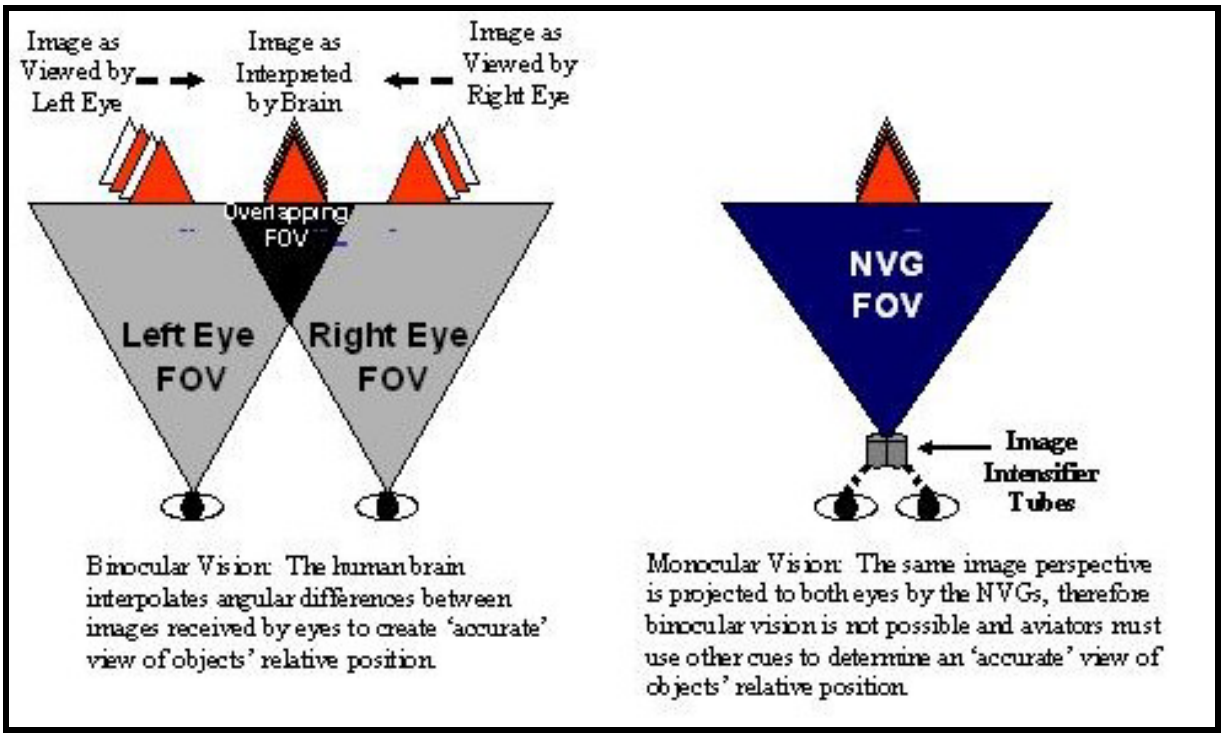

Figure 6. Normal Binocular Vision vs. Monocular Vision Provided by NVGs

Lack of motion parallax when wearing NVGs can result in an obviously undesirable situation where the aircraft is moving without the pilot perceiving it, and also makes it very difficult to judge closure rates during approaches or other low altitude maneuvers. In order to offset this limitation, pilots are taught to use good scanning techniques, constantly turning their heads to the right and left to try to capture the information they would normally get from peripheral vision. In the ChrAVE, the pilot will have a view of the outside world that simulates being in the right side of a 'side by side' cockpit. If 0 degrees is considered to be looking straight ahead while seated in the ChrAVE's pilot station, he will be able to scan the outside world from approximately 330 degrees (slightly to his left/front) to approximately 110 degrees (slightly to his right/rear). This should allow pilots/subjects to use scanning techniques similar to that which they would be able to use in a real cockpit when seated at the right (pilot's station) in a real aircraft.

c. Visual Resolution

Another important limitation of NVGs is the 'less than perfect' visual resolution they provide. NVGs display images with 20/40 'best case' resolution. This means depending on

the ambient light, features and contrast of the scene being viewed, and other factors, aviators may get an image that is significantly worse (as bad as 20/200) in terms of visual resolution. Images and objects appear to be blurred, and shapes may appear ambiguous at a distance. This has obviously dangerous implications for military tasks such as target acquisition and friend or foe identification. The only way for this limitation to be overcome is by gaining experience in viewing NVG imagery. Aviators must become accustomed to viewing objects and scenes at less than optimal resolution and interpreting the imagery displayed by the NVGs.

d. Colors and Textures

NVGs produce a green monochrome view of the night scene. The image displayed is similar to 'black and white' television, only the levels of gray that distinguish between light and dark colors are instead levels of green. Other colors are not displayed, and aviators must rely upon experience as well as scene context in order to gather color cues. Interpreting textures of objects is also an important visual cue that is limited by NVG viewing. Several factors contribute to the difficulty in determining textures while using NVGs including the lack of binocular vision, limited visual resolution, the limited FOV, and the lack of color display. This lack of texture perception is intensified at higher altitudes or greater distances.

e. Visual Noise

NVGs produce some degree of visual noise, and there can be several different causes and types of noise. Scintillation and random temporal noise are present in all NVGs that are currently in use by aviators. These effects are best described as 'sparkles' of varying size and frequency that appear to pass through the image intensifier tubes toward the observer. These effects vary greatly depending on the type of NVG being used and the ambient light conditions. Darker environmental conditions tend to make scintillation and random temporal noise more pronounced, while operating in areas with higher levels of ambient light makes these types of noise less noticeable. Aviators become accustomed to viewing scintillation and random temporal noise as a normal characteristic of NVG displays, so modeling these effects is critical to creating a believable NVG scene. Another type of noise that is common to all NVGs is the effect of light blooming. Light blooming occurs when lights come into the NVG FOV. When viewing lights directly, a glow extends out from the source of the light creating a sort of 'halo' effect. Light blooming varies based on ambient conditions and the color of the light. Higher levels of humidity or particles in the air can create larger or more intense light blooming. Due to

the manner in which wavelengths of different colors of light are received and processed by the NVGs, certain colors of lights are easily viewed while others produce very bright and unviewable effects on the NVG display. Blue or green lights are generally easily viewed by NVGs. These colors are used for illuminating aircraft cockpits because they are easily viewed and do not interfere with NVG operations. Red and yellow lighting (as well as normal white light) can create intensely bright effects on the NVG display, and can render the display unusable. Bright lights can also appear to shut down the image intensifier display if viewed directly, however the tubes do not actually stop functioning. Instead, the automatic gain of the NVGs adjusts itself to the brightness of the light in its FOV, and in doing so renders the rest of the display too dark to view. These effects can be difficult to model, however it is important that they be modeled correctly if the scene is to be realistic. Fixed pattern noise can be caused when there is a problem in the display system of the image intensifier tubes. An example of this type of noise is a 'honeycomb' pattern displayed in one or more areas of the NVG FOV. This pattern could result from misalignment of the microchannel plate. Another example of fixed pattern noise is white or black spots in the image that stay in the same position in the FOV regardless of viewing direction. NVGs that are in good, serviceable condition normally do not display fixed pattern noise. It is not necessary to model this type of noise to create a believable NVG scene.

B. AVIATION TRAINING WITH NIGHT VISION GOGGLES

1. Initial NVG Qualification

Before an Army aviator begins training with NVGs, they are trained in basic day and night visual flight (Visual Flight Rules), and also trained to fly using only instruments (Instrument Flight Rules). Only when they have passed their initial qualifications in these modes of flight do they begin initial NVG qualification. For Army pilots, this initial qualification is done at the Army's flight school at Fort Rucker, Alabama, before these aviators are sent out to tactical units. All flight training is conducted by instructor pilots (IPs) who have gone through extensive training and generally have a great deal of experience in the aircraft in all modes of flight. During this initial day/night and instrument training, simulation tools ranging from computer-based procedural trainers to full-motion instrument simulators are used prior to trainees getting into the aircraft to fly. This is done so that the actual flight training in the aircraft can be done more safely and efficiently. But when the aviator transitions to the NVG portion of

the curriculum, there are no simulation tools that are utilized to prepare them for this mode of flight. Classroom training, videos, and stationary cockpit drills are the only experience trainees get prior to getting into the aircraft and flying with NVGs. If the ChrAVE proves to be a viable NVG training system, it's low-cost and availability might make it an attractive candidate for use in further preparing trainees during their initial NVG qualification training. This would give the trainees invaluable experience with the visual effects and limitations of wearing NVGs in the cockpit prior to exposing them to the dangers of actually flying the aircraft while wearing NVGs.

2. NVG Mission and Continuation Training

Once Army aviators successfully complete initial flight qualification training they are sent to tactical units. Aviators arriving to tactical units from flight school are trained in additional aircraft and mission tasks as required by the unit. Part of this training is 'mission' training, where they are trained to perform individual, crew, and collective tasks that support the unit's war-time mission. These tasks are trained in all conditions, to include flight with NVGs. As there are currently no NVG simulation tools available at the unit level, there are really only three parts of a unit's NVG training curriculum: academic training, 'blind cockpit' drills, and training flights. Academic training is important for expanding the NVG knowledge base of aviators related to such topics as NVG capabilities and limitations, anatomy of the human eye and factors affecting night vision, and NVG tactics, techniques, and procedures. 'Blind cockpit' drills are a teaching method that involves putting the trainee into a static aircraft (on the ground with engines off) during the hours of darkness. Trainees are then drilled on locating the correct switches and controls in a dark cockpit. Academic training continues throughout the aviators' careers, and they are responsible for maintaining the information they are taught. Blind cockpit drills are usually conducted only once. NVG flight training makes up the remainder of the aviators' training regimen. Just as in flight school, there are no NVG training tools that are available to aviation trainees. Their only method of training NVG tasks is to actually fly the aircraft, which means there is little room for error without dangerous, sometimes catastrophic results.

There are four levels of aviator NVG proficiency determined by unit commanders (based on evaluation by IPs) according to the training level and competency of each aviator. These are known as readiness levels or RLs. NVG RL3 indicates an aviator is flight school qualified, but has not shown proficiency to fly with anyone other than IP qualified pilots. NVG RL2 indicates

the aviator has demonstrated proficiency in basic aircraft control and emergency procedures and is undergoing mission training. NVG RL2 aviators can only fly with IPs or NVG Unit Trainers, who are specially designated pilots authorized to assist IPs in conducting mission training. NVG RL1 indicates the aviator has completed mission training, and is able to fly with any NVG Pilot-In-Command (PIC). Finally, NVG PIC indicates that the pilot is capable of flying with any NVG RL1 pilot, and is responsible for the safe and effective operation of the aircraft. After a pilot achieves NVG RL1 designation, they are responsible for flying a minimum amount of NVG flight hours in order to maintain their training level and flight proficiency. This is called continuation training. Unfortunately, due to high unit operational tempo and the challenges related to putting aviators on reverse cycle (reporting for duty at night rather than daytime), aviators often fly only that minimum amount of flight hours.

This is where the ChrAVE, if proven to be a viable NVG training device, could be most valuable. Pilots could augment their flight hours with time spent practicing tasks in the ChrAVE. They could also use the ChrAVE as a mission rehearsal tool, flying their mission in a simulated NVG environment in order to further prepare them for the real flight. It is important to make clear that while the ChrAVE or another NVG simulation device may be able offer a safe, low cost environment where making a mistake is not fatal, no simulation device can take the place of actually flying the aircraft under NVG conditions. It is not the argument of this thesis that training flights should be limited or replaced, but rather augmented. It is the author's position that the best way to become more proficient at flying with NVGs is to get more experience actually flying the aircraft with NVGs. However, there are definitely important roles for a low-cost, always available, NVG simulation device in mission and continuation training at the aviation unit level.

C. SUMMARY OF PREVIOUS RESEARCH

There are two key research documents that helped form the basis for this thesis. Lennerton's "Exploring A Chromakeyed Augmented Virtual Environment for Viability as an Embedded Training System for Military Helicopters" (2002), examined the the ChrAVE's viability as an embedded training system. His research not only showed that the ChrAVE had potential as a trainer, but also set the stage for this thesis as follow-on work. Indeed, much of the software and hardware (including the ChrAVE platform itself) originally created and

implemented by Lennerton was simply modified for use in providing the NVG environment necessary for collecting data for this thesis. "Physics Based Simulation of Night Vision Goggles" by Martin and Clark determined that physics-based calculations of NVG imagery were a requirement for simulation-based training and mission rehearsal to be realistic. The relevance and impact of these research documents dictate their summarization in this thesis.

1. Summary of Lennerton's Research

Lennerton identified the need for a high fidelity aviation training device that could augment the flight training of military helicopter pilots who were deployed aboard naval vessels at sea. His thesis focused on the viability of a ChrAVE which would ultimately be embedded in an actual helicopter, to provide such a capability. His thought was that such a device could help maintain the readiness of aviators during deployments, and possibly delay or prevent the decay of perishable flight skills. There were several key points behind Lennerton's rationale in using a ChrAVE embedded in the actual helicopter to create such a training device, rather than a separate system. First, separate training systems require additional space, which is obviously limited aboard a ship. Second, training systems that are small and deployable (such as PC based systems) do not provide the level of immersion and fidelity that is required to adequately simulate helicopter flight. Lennerton also points out that using the actual helicopter as part of the training system would create the highest level of fidelity of cockpit design and user interface to the system. Using the helicopter would also go a long way toward reducing the need for 'extra' equipment associated with simulation systems requiring additional shipboard space.

To examine the viability of such an embedded system, Lennerton built the ChrAVE prototype that is described in detail in Chapter 3 of this document. For his initial experiment, Lennerton used fifteen male, U.S. Navy and Marine helicopter pilots who were students of the Naval Postgraduate School, and therefore in a non-flying status. Lennerton's treatments included a pre-flight questionnaire, map preparation for a low-level route of flight, a battery of physiology tests prior to virtual ChrAVE flight, a low-level navigation flight, a battery of physiology tests following the virtual flight, and an exit questionnaire. After the entire subject pool had completed their virtual flights, each subject was asked to evaluate the performances of their peers.

The pre-flight questionnaire inquired into the subjects' medical history, flight experience, and subjective parameters for conducting acceptable low-level helicopter navigation. Lennerton

also asked the subjects to evaluate a series of slides which represented fictitious navigation performances. He used this part of the questionnaire as a baseline for the subjective evaluation standards for the subject pool. The subjects then prepared a 1:50,000 map for use in the low-level flight in the ChrAVE. The subjects were told to prepare the map for their use in conducting a low-level navigation flight of a route that was drawn on a satellite photo. There was no time limit associated with this portion of the experiment, and subjects were provided all of the required tools to accomplish this task such as scissors, markers, and tape. At four times throughout the experiment, Lennerton administered a series of physiological test to the subjects. These tests included a visual acuity test, color identification test, Dvorine Pseudo-isochromatic plates, and a hand-eye coordination test. The purpose of these tests was to measure the physiological effects of the ChrAVE over time. These tests were administered before the subjects donned the HMD (baseline un-hooded physiological levels), immediately after donning the hood (baseline hooded physiological levels), after conducting the virtual flight but before taking off the HMD, and immediately after removing the HMD. The subjects performed the virtual land navigation task for 30 minutes, and were instructed to fly as much of the route as they could in that amount of time, as accurately as possible. They were administered a post-flight questionnaire and were debriefed after the virtual flight.

The results of Lennerton's experiment seem to indicate that the ChrAVE does indeed have potential as an embedded flight training system. Although data from the questionnaire showed that the subject pool considered 260 meters to be the maximum deviation from a route of flight for a navigation task to be considered as 'acceptable', only one subject of fifteen was able to average 260 meters or less over the entire route (Table 2). Despite that fact, eleven of the fifteen subjects received at least ten

		Check Points													
		1	2	3	4	5	6	7	8	9	10	11			
	Subject	Course Entry Point	Cemetery Bend	Granite Pass	Whiskey Saddle	Romeo Hill	Hill 1161	Nelson Lake	McLean Lake Feed	Tri-valley Pass	Drinkwater Lake	Course Entry Point	Average Distance **	Proximity Rank	Number Acceptible ***
Min Distance from Flown Path to Checkpoint (Meters)	001	0.0	288.6	528.9	473.3	187.7	183.1	71.0	462.6	969.4	214.7	779.3	375	2	4
	002	0.0	265.1	511.9	71.6	122.1	1008.2	389.3	250.6	598.4	230.3	146.6	383	3	5
	003	0.0	271.0	311.2	1399.3	357.8	882.3	33.6	357.8	4,665.4	3,307.1	3220.2	1287	14	1
	004	0.0	1089.1	183.4	157.9	1,022.6	192.6	144.9	419.1	824.8	4,985.1	5059.5	1002	13	4
	005	0.0	610.0	131.6	1306.7	1,631.8	230.7	252.1	1155.8	501.3	159.1	4186.5	664	10	4
	006	0.0	418.4	36.7	395.4	462.6	941.0	5,345.5	3421.7	2,031.9	275.5	2250.5	1481	15	1
	007	0.0	421.6	504.7	3084.1	1,092.4	412.9	118.6	208.1	534.4	31.3	1723.9	712	12	3
	008	0.0	394.9	1,600.1	639.8	1,751.7	192.0	349.4	572.5	539.8	254.3	32.2	699	11	3
	009	0.0	949.2	204.9	297.5	2,119.6	167.2	211.0	397.4	733.7	251.4	539.5	592	8	4
	010	0.0	461.4	70.9	23.8	309.9	261.9	30.3	242.8	563.9	130.0	456.3	233	1	5
	011	0.0	478.9	59.7	245.0	1,464.7	211.0	209.5	674.1	1,101.9	476.1	283.1	547	5	4
	012	0.0	472.1	240.5	60.7	1,653.0	604.2	253.2	726.4	694.1	75.1	1363.4	531	4	4
	013	0.0	466.0	204.2	129.4	704.2	1598.9	639.9	670.1	334.3	1,122.6	476.7	652	9	2
	014	0.0	711.9	296.7	403.9	2,082.7	280.9	77.3	380.5	835.3	120.1	104.2	577	7	3
	015	0.0	460.0	53.2	380.0	1,218.9	362.6	693.7	726.2	755.5	538.5	1184.7	577	6	1
Average Distance-->		0.0	517.2	329.3	604.6	1,078.8	502.0	587.9	711.0	1,045.6	811.4	1,453.8	688		
Difficulty Ranking*-->		N/A	7	9	5	1	8	6	4	2	3	N/A			
Num Acceptable ***-->		N/A	0	9	6	2	6	10	3	0	9	3	1		

* Note that difficulty ranking was established purely from ranking the average distances. Additionally, checkpoints 1 and 15 were not factored into the checkpoint difficulty ranking because all subjects began at checkpoint 1 and not all subjects were able to complete the route, thereby never attempting to navigate to checkpoint 15.

** Note only checkpoints 2 through 14 were factored into this average because all subjects began at checkpoint 1 and not all subjects were able to complete the route, thereby never attempting to navigate to checkpoint 15 from the previous checkpoint.

*** Number of checkpoints flown within the subject pool's 260 meter threshold as established by question #22 of the questionnaire.

Table 2. Subject Virtual Flight Navigation Results (From Lennerton, 2002)

'acceptable' ratings during the peer evaluation portion of Lennerton's experiment. This illustrates the subjective nature of evaluating a navigation task, and points to the existence of flexible, subjective standards of evaluators.

	Location, Direction, & Proximity Result Averages				Peer Evaluations		
	Position & Orientation Differences		Checkpoint Proximities				
Subject	Distance (Meters)	Heading (Deg)	Min Distance from Flown Path to Checkpoint (Meters)	Number of Acceptable Checkpoint Proximities *4	Average Proximity of Paths Score *1	Average Location Estimation Score *2	Total Acceptable Overall Performance Ratings *3
001	1,124.9	14.4	378.1	4	2.4	1.9	14
002	965.5	21.7	326.7	5	1.8	2.1	14
003	2,543.6	32.9	1346.0	1	6.3	5.5	0
004	2,403.2	30.0	1279.9	4	4.9	4.9	5
005	1,521.1	26.8	924.1	4	3.8	3.5	12
006	4,586.1	28.1	1416.3	1	6.6	6.4	0
007	1,435.5	17.1	739.3	3	3.5	3.4	13
008	1,872.5	18.6	575.2	3	3.4	3.6	14
009	1,132.1	12.1	533.8	4	2.7	2.5	14
010	1,054.9	21.7	231.9	5	1.8	2.2	14
011	1,677.9	19.2	473.1	4	2.3	2.8	14
012	1,133.9	19.4	558.4	4	3.7	3.1	14
013	1,587.6	30.7	576.9	2	4.7	3.8	7
014	880.1	7.1	481.2	3	2.6	2.1	14
015	1,172.2	18.2	579.4	1	4.1	3.5	10
Averages->	1,672.7	21.2	694.7	3.2	3.6	3.4	10.6

*1.The subject's ability to maintain a flight path in acceptable proximity to the intended path.
- Rated using a 1 to 7 scale, '1' indicating highly acceptable while '7' indicates not acceptable.
- This criteria is independent of the following criteria, meaning the proximity to the intended flight path was evaluated independently of whether or not the subject knew where they were.

*2.The subject's ability to correctly estimate their location.
- Rated using a 1 to 7 scale, '1' indicating highly acceptable while '7' indicates not acceptable.
- This criteria is independent of the preceding criteria, meaning the accuracy of the position estimation was to be evaluated independently of whether or not the subjects were on the intended route.

*3.The overall performance.
- Rated the overall performance as acceptable or not acceptable ('A' or 'N')

*4.Number of checkpoints flown within the subject pool's 260 meter threshold as established by question #22 of the questionnaire.

Table 3. Peer Evaluation Results (From Lennerton, 2002)

Lennerton used the term 'vacuously viable' to describe the relationship of his experiment results to the answer of his primary research question. In short, after analyzing his results, Lennerton could not quantitatively prove the ChrAVE was viable due to the lack of actual aviation resources on which to compare his data. But he could also find no evidence proving that the ChrAVE would not be viable as an embedded helicopter training device. He therefore recommended that the ChrAVE continue to be used as a prototype for research until this type of comparison can be made. The research contained in this document is one step in that direction, and attempts to extend Lennerton's base research to determine the ChrAVE's viability in the realm of NVG flight training.

2. Summary of Martin and Clark's Research

Martin and Clark used a series of interviews with experienced users of NVGs from the Air Force, Navy, and Army to derive what they consider to be the nine "core requirements" for NVG simulations across a broad spectrum of missions. These core requirements are:

- Full range of night sky illumination from overcast starlight to full moon
- Effects of light sources
- NVG characteristics
- Accurate surface reflectivity
- Realistic "out the window" night scene
- Shadows
- Weather effects
- Obscurants
- A realistic gaming area

After describing each of these core requirements in detail, the authors give situational evidence as to why each is indeed a requirement for visual simulation of NVG imagery. Martin and Clark proceed to discuss how best to capture these requirements in real time simulation, and specifically whether the best approach is to stimulate actual NVGs to produce the image for the user or to instead simulate the image provided by NVGs using physics-based imagery. They argue that stimulating NVGs is an approach that merely satisfies the commonly assumed

requirement to represent the "form, fit, and function" of NVGs. In their consideration, the stimulate approach does not represent the best method for NVG simulation due to the inability of existing display devices to provide the full, dynamic range of realistic night scenes in order to make the stimulated NVG perform correctly. Instead, Martin and Clark point to physics-based simulation as as the preferred method for generating NVG imagery for training and mission rehearsal. They list four distinct advantages of the physics-based approach: the ability for greater realism due to the ability of a computer to provide greater computational dynamic range than that of a display device used to stimulate NVGs, the inability to display realistic luminance, contrast and resolution without a physics-based material response, the ability to present a more realistic 'out the window' scene when simulating NVGs than when stimulating NVGs, and the significant preparations needed to use real NVGs in a training system (such as creating a "light tight" environment). Martin and Clark do not report any experimental data that supports their arguments, and they do not examine the capabilities of the most current image rendering techniques (without physics-based calculations) to create a simulated NVG environment.

D. CHROMAKEY TECHNOLOGY AND AUGMENTED REALITY

Chromakey technology is used to provide the virtual world of the ChrAVE. In Chromakey technology a key color, often blue or green, that is found in a foreground scene is identified and replaced with the corresponding pixel from a background scene. When the background and foreground scenes are properly mixed, the result is a single, composite scene. This technique is used daily by television weathermen. They stand in front of a large chromakeyed screen, and computer generated map and weather information displayed on the screen behind them. Figure 8 shows an example of the composition of a chromakeyed scene.

Composing a Chromakeyed Scene

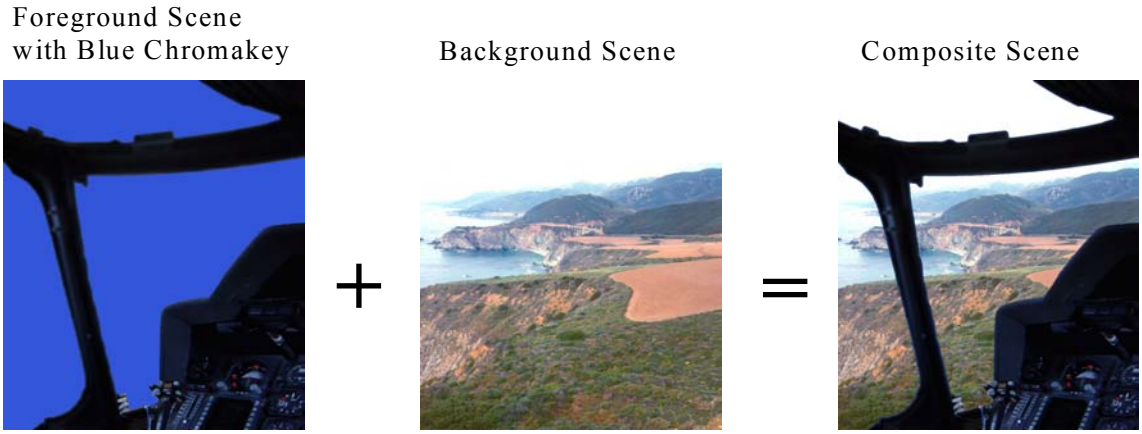

Figure 7. (From www.nps.navy.mil/cs/research/vehelo/Chromakey.htm**, May, 2003)**

The composite scene can also be described as an example of augmented reality. Augmented reality is a combination of a real scene viewed by a user and a virtual scene generated by the computer. In the case of the ChrAVE, the virtual portion of the scene consists of only the virtual desert terrain of the National Training Center at Fort Irwin, California, as viewed through simulated NVG imagery. In short, the ChrAVE uses chromakey technology as a method of achieving augmented reality.

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III. IMPLEMENTATION

A. HARDWARE AND PHYSICAL LAYOUT

The ChrAVE as it exists today is a slightly more advanced version of the original prototype built by Lennerton in 2001. It's purpose remains serving as a laboratory for research into the training potential of certain tasks via simulators. It consists completely of COTS equipment, and purposely contains no custom, one-of-a kind, or specially made components. Several upgrades have been made to the original prototype, and these changes will be discussed in detail in this section. Many more advances and improvements are planned, and the ChrAVE will be continuously refined and tuned as additional research identifies areas for improvement. The basic ChrAVE configuration is still intended to represent the right side of a dual-pilot, side-by-side helicopter cockpit. It can be described as "intentionally generic", since the ChrAVE purposely does not attempt to exactly replicate any one model of helicopter cockpit. This design is intended to support research for the many different types of helicopters in use by the U.S. military today, rather than to focus on specific airframes. Detailed hardware specifications for all ChrAVE components are presented in Appendix E.

1. Platform

The ChrAVE's platform is comprised of a wooden deck, a single pilot's seat, a full set of flight controls (cyclic, collective, and pedals that are not yet implemented for use in actually controlling simulated flight), and is enclosed by materials that attempt to emulate the walls, windscreens, windows, and roof of the cockpit.

a. Seat & Flight Controls

The current implementation of the ChrAVE platform uses a Flight Link Inc. seat and basic helicopter flight controls. When set up for use, these flight controls produce inputs similar to standard multi-axes game port input devices to PCs. As in a real helicopter, the cyclic controls the tilt of the simulated main rotor disk, and therefore affects the pitch and roll attitudes of the aircraft. Similarly the collective controls thrust (power), and the rudder pedals affect yaw and trim. There is also a button on the cyclic that can be given specific assignments. The flight controls were not used by the navigating pilot to control aircraft flight during the experiment. Their purpose was simply to provide an aesthetically realistic illusion of an actual helicopter cockpit environment to subjects.

Figure 8. Seat and Flight Controls (From Flight Link Inc., 2001)

b. Instrument Panel

A generic instrument panel is provided via a separate networked Silicon Graphics computer and 19 inch flat screen monitor. The instrument panel contains indications of airspeed, attitude, altitude, turn and slip, heading, and vertical speed. This instrument panel is mounted to the ChrAVE's wooden platform, and positioned in front of the pilot's station.

Figure 9. ChrAVE Instrument Panel (SGL LCD monitor)

c. Cockpit Structures

The mock cockpit walls, roof and window are intended to provide a 'look and feel' of an actual helicopter cockpit, albeit a limited one. They are also meant to provide realistic obstacles to pilot movement and observation (restrict the line of sight), similar to the obstacles found in a real helicopter airframe. Additionally, the deck was specifically designed and built to allow viewing of the virtual terrain through a mock chin bubble. A chin bubble is a transparent windscreen found in most helicopters just below and forward of the pilot station (pedal area). The chin bubble allows the aircrew to have line of sight directly below the aircraft.

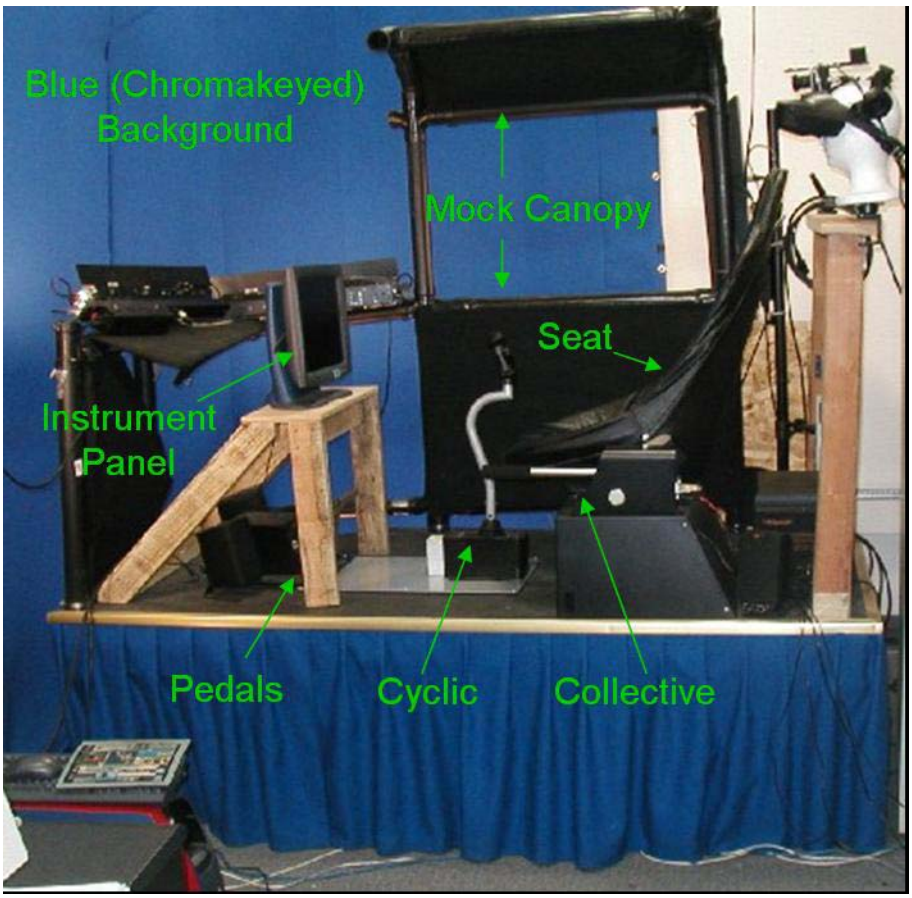

Figure 10. The ChrAVE Platform

2. Chromakey Blue-Screen Matting

A blue chromakey cloth material is used as a backdrop for the front, right portions of the ChrAVE's mock cockpit platform. The material runs from front left of the pilot's station (approximately the pilot's eleven o'clock position) around the front to the right rear (four o'clock

position). This material is used (via chromakey technology) to present an 'out the window' view of the virtual world. Identically colored chromakey blue tape was used to hide the presence of seams in the material.

Figure 11. 2-inch wide chromakey blue tape (From Mole-Richardson Inc., 2001)

3. Lighting

Lighting was the most challenging component of the chromakey technology implementation. In order for the chromakey mixer to correctly perceive the chromakeyed blue backdrop (called the matting), it must be evenly lit and contain no shadows. A number of fluorescent lamps were positioned around the mock cockpit so as to light the matting evenly while not impeding the navigator's view of the matting. This was especially challenging given the large amount of blue matting to be lit. Any uneven lighting or shadows creates undesired visual artifacts on the mixed visual scene. An additional hurdle was ensuring that the lamps did not directly shine into the camera lens or reflect off of the instrument panel or other surfaces. This implementation employed four fluorescent light fixtures that were four feet in length and four fixtures that were two feet long. Each fixture had high output, flicker-free ballast that operated on 120 VAC/60Hz. Each fixture also included a specular reflector, and two lamp barn doors that helped direct the light while preventing unwanted splash-back.

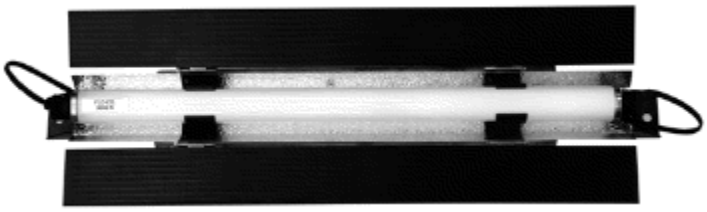

Figure 12. Lighting fixture used in the ChrAVE (From Flo Co, Inc., 2001)

4. Headgear

a. Head Mounted Display

The ChrAVE's Head Mounted Display (HMD) is a Virtual Research Incorporated model V8. The V8 uses an active matrix Liquid Crystal Display (LCD) that has a Video Graphics Array (VGA) pixel resolution of (640x3) x 480. This HMD was chosen for use in the ChrAVE after consideration of cost versus performance. There are several commercial HMDs available with higher resolution, but they were determined to be far too costly for this research. The V8 provides a CRT quality image, and its relatively low cost is in keeping with the overall ChrAVE system goal of affordability, which in turn will make the ChrAVE more available. As technology improves and costs of higher resolution HMDs decline, the ChrAVE will be upgraded. The V8 has several adjustment features that allow the wearer to fit the apparatus comfortably to his head. It also allows for interpupillary distance (IPD) as well as eye relief adjustments. The area below the V8's viewing screens is occluded with a flexible, black, foam rubber material. This blocks line of sight below the viewing screens, and prevents the user from viewing anything except what is presented on the HMD viewing screens. The V8's integrated earphones were not used during this research, and therefore they were rotated above the headband and away from the subjects' ears. Audio was provided by a separate surround sound speaker system detailed later. Audio, video and power inputs and outputs are managed through an external HMD control box. Red Light Emitting Diodes (LED) indicate 'Power On' and 'Stereo' modes. Standard 15 pin VGA connectors accept VGA (640 x 480, 60Hz) inputs, from the ChrAVE's integrated workstation computer.

Figure 13. V8 HMD (From Virtual Research, 2000)

b. Camera

The camera used in this implementation of the ChrAVE was a Panasonic model GP-US532H, with Auto Gain Control (AGC) and Electronic Light Control (ELC) features. This camera was used in conjunction with a Panasonic camera control unit (CCU) model GP-US522CU. The camera system contains three charged couple devices (CCD), one each for the colors red, green, and blue. The camera lens used was a fixed focal length (4mm) lens. It has two adjustment rings which are located along the length of the lens housing. The ring nearest the user is used to adjust aperture f/stop settings. Changing the aperture to lower f/stop settings allows more light to reach the camera sensors, but it reduces the depth of field. The adjustment ring furthest from the user is used to change the focus of the camera lens. Unfortunately, since the focal length of the camera is fixed, viewing objects at varying distances can be difficult. This is a critical limitation regarding the subjects' ability to focus on objects of varying distance from the eye, such as the blue screen background, instrument panel, map, and kneeboard, and will be discussed further in the "Known Artificialities" section.

Figure 14. Panasonic 3CCD Color Camera Head and CCU (From Matsushita Electric Corporation of America, 2002)

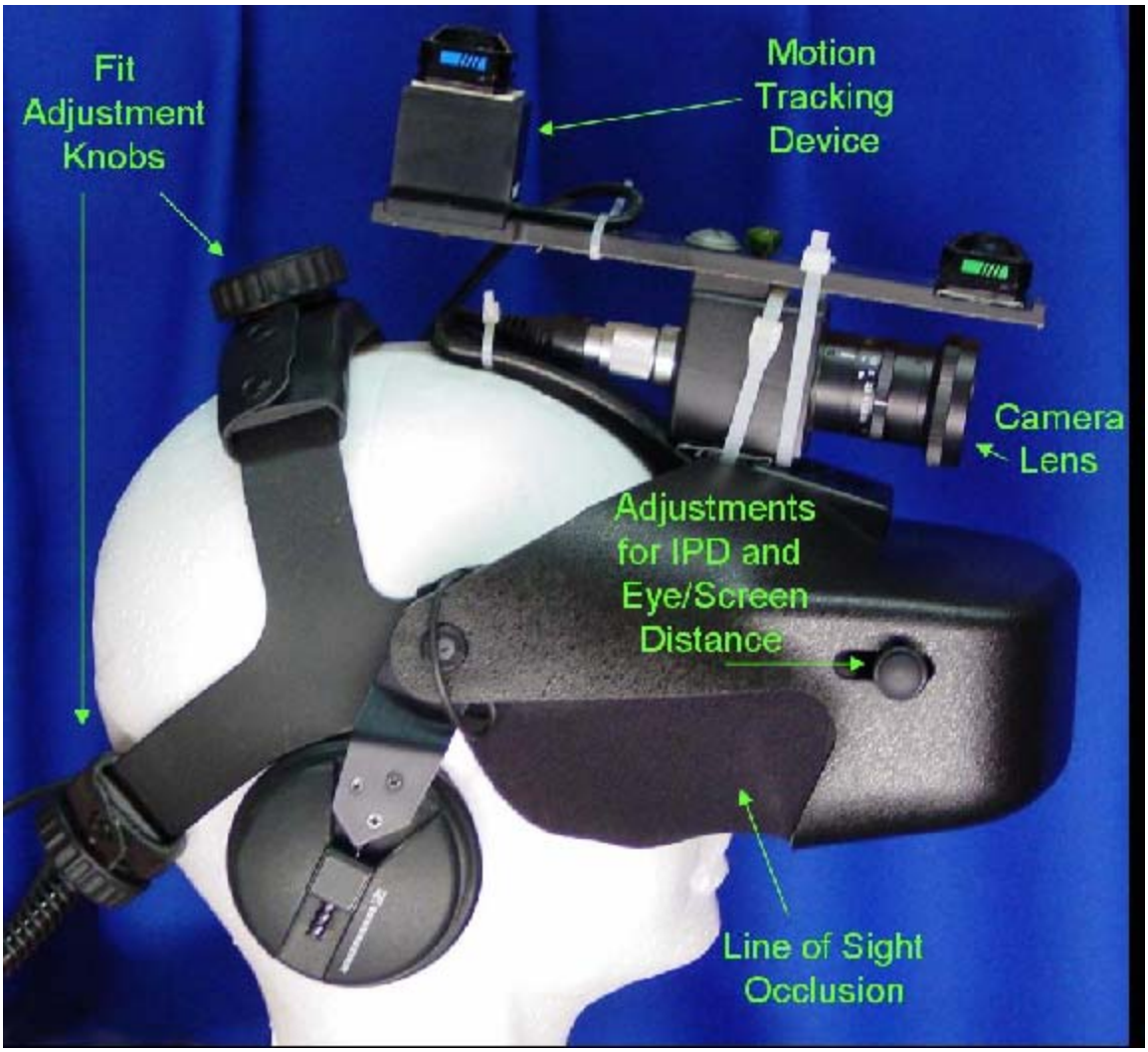

Figure 15. ChrAVE HMD and Camera

c. Motion Tracker

An InterSense, Incorporated IS-300 Pro motion tracking system was used to track subject head movements in this implementation of the ChrAVE. The IS-300 Pro is a motion tracking system that uses inertial sensing technology to provide motion tracking with six degrees of freedom (DOF). The inertial system is comprised of an InertiaCube™ that is strapped to the user's headgear and tethered by wire to the control unit. It is nearly immune from environmental interference. The system provides heading, pitch, and roll information for the user's head position, which is used to determine their gaze direction. The ChrAVE uses this information to determine the proper viewing scene that should be displayed on the HMD's viewing screens.

5. Computers

There are three computers that are used in the ChrAVE. The primary computer drives and coordinates all aspects the virtual environment. This computer runs the application that drives the background imagery, flight simulation, and position tracking features of the ChrAVE. A second computer manages the display of the instrument panel. This computer receives flight parameter information from the primary computer via the network and displays it properly using the generic instrument panel discussed earlier. A third computer receives positioning data from the primary computer, and plots the virtual aircraft's position and route of flight on a map of the terrain database. This provides an overhead, or 'God's eye' view of the navigation performance in real time. This computer also captures and records all flight data so that it can be used for debriefs or after action reviews with the navigator after his flight.

6. Signal Converters, Mixers, and Splitters

The ChrAVE uses a number of signal converters due to the conflicting signal requirements of different components within the image generation portion of the system. The chromakey mixer used in this implementation requires a CCIR-601 digital signal as input. However, the foreground imagery (real world) comes from the camera in an RGB signal format, and the background (virtual world) imagery comes from the CPU in a VGA signal format. Therefore, both the foreground RGB signal and the background VGA signal had to be converted to a CCIR-610 signal for input into the mixer. Then once the foreground and background signals were mixed, the CCIR-610 output signal had to be converted back to a VGA (640X480) signal for the HMD.

ChrAVE Configuration Schematic

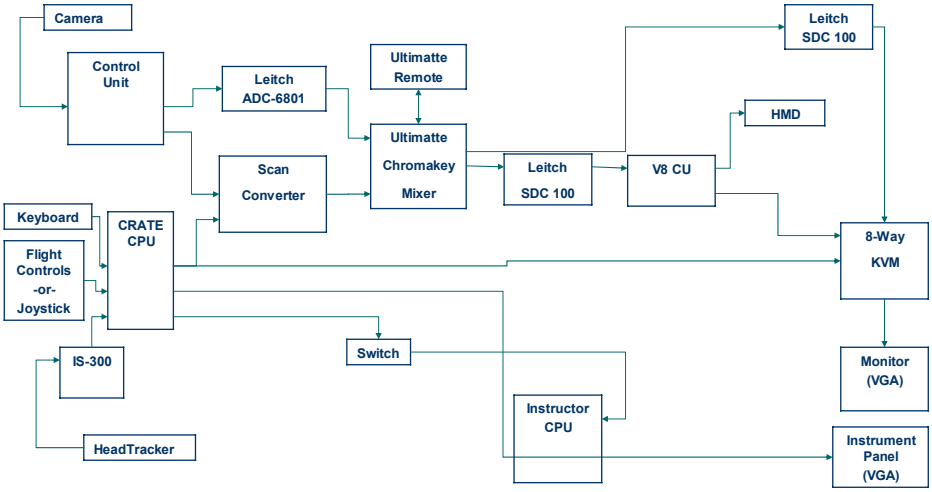

Figure 16. Schematic of the ChrAVE System

a. Camera RGB Signal to Digital 601 Signal Converter

A Leitch ADC 6801 converter was used to convert the RGB signal produced by the HMD-mounted camera into the digital 601 signal that is required by the chromakey mixer.

b. VGA to Digital 601 Signal Converter

An Extron Spectrum Converter was used to convert the VGA signal produced by the primary ChrAVE computer into the digital 601 signal that is required by the chromakey mixer.

c. Chromakey Mixer

The ChrAVE's current configuration uses an Ultimatte 400 Deluxe Chromakey Mixer. The mixer takes in the video signals (now converted to digital 601 format) from the HMD-mounted camera (real world) and the primary ChrAVE computer (virtual environment), mixes them and outputs the augmented reality imagery.

Figure 17. Ultimatte 400 Deluxe (From www.ultimatte.com)

d. Digital 601 to VGA Signal Converter

A Leitch SDC-100 converter was used to convert the digital 601 signal that is produced by the chromakey mixer to the VGA signal that is required for input into the HMD.

Figure 18. ChrAVE in transition to rack-mounted system.

7. ChrAVE Component Rack System

The original configuration of the ChrAVE used a transportable cart to house many of the system's components. The system is currently transitioning to a more space efficient, more

easily transportable, rack system. Some of the components that were used in the original implementation of the ChrAVE system are not 'rack compatible', such as the primary computer, which is a desktop tower. As of the time this thesis was written, the ChrAVE was using components housed both on a rack system as well as the original transportable cart. This is obviously not the most efficient or transportable configuration, but is a temporary state due to the time and cost of acquiring and installing new 'rack compatible' components. The transitional state of the ChrAVE's rack and cart in no way affected the data collected by this research.

B. SOFTWARE

1. Vega™

a. Overview

MultiGen Paradigm's Vega™ software is the scene-graph engine that renders the virtual imagery for the ChrAVE. Vega™ uses a graphical user interface (GUI) application called Lynx™ that allows the user to quickly set up the core components of a virtual scene, such display windows, rendering channels, objects, observers, and motion models. Once these components are initially set up in Lynx™ users can dynamically modify settings and characteristics of the virtual scene by using the application-programming interface (API). This is the same brad of software used to render the ChrAVE environment produced by Lennerton (2002). Vega™ was chosen to render the ChrAVE's NVG environment based on the ease in which a realistic NVG environment could be produced, as well as the ability to easily affect visual parameters dynamically through the API. The two key Vega™ modules involved in creating the ChrAVE's NVG environment were SensorVision™ and SensorWorks™.

b. SensorVision™ and SensorWorks™

Vega™ uses both the physic-based and the non-physics, graphic rendering techniques. It uses two different 'modules', or components to produce the scene imagery. The Vega™ SensorVision™ module performs light and material response calculations, and takes into account the moon position and angle, atmospheric conditions, geographic location (latitude and longitude), and time of day. It uses these factors to make physics-based calculations to determine how the scene should be rendered using an NVG perspective. An example of the SensorVision™ GUI is shown in Figure 19.

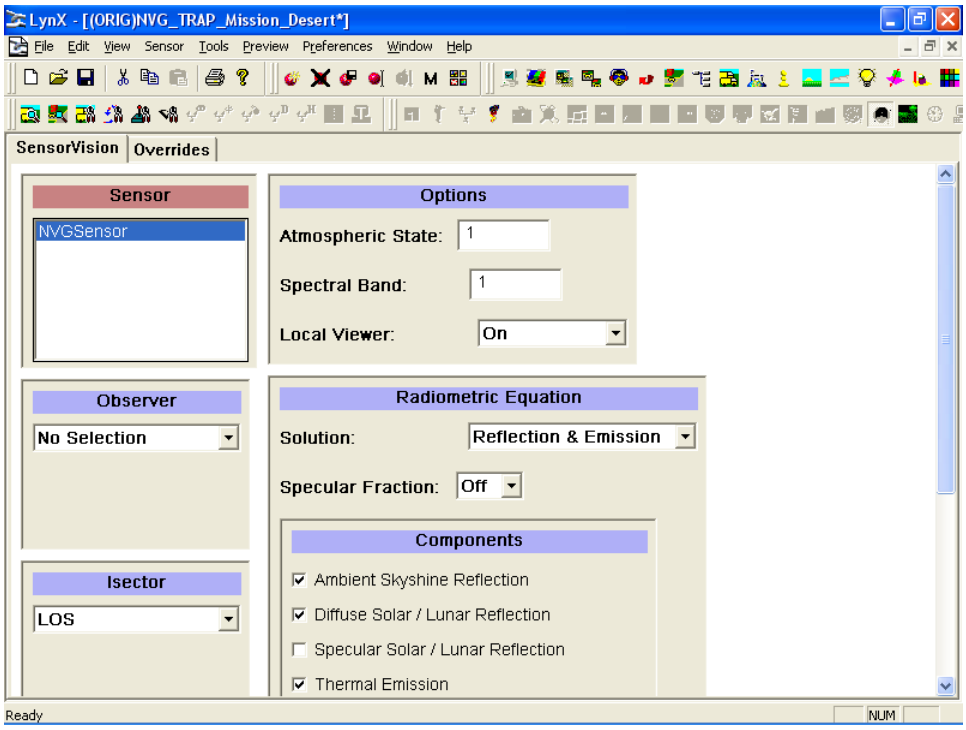

Figure 19. The Vega™ SensorVision™ GUI

The SensorWorks™ module uses non-physics, graphic rendering techniques to produce the details and effects of NVG imagery, such as color, fixed pattern and variable noise, light blooming, obscuration, and scintillation. These two modules work together to create a complete NVG scene. When both SensorVision™ and SensorWorks™ are enabled, the scene imagery produced is physics-based, and when only the SensorWorks™ module is enabled the scene is produced using only graphics rendering techniques. Toggling the SensorVision™ component on and off through the API makes the scene very flexible in terms of the presentation of physics-based imagery to the user. Figure 20 shows an example of the SensorWorks™ GUI.

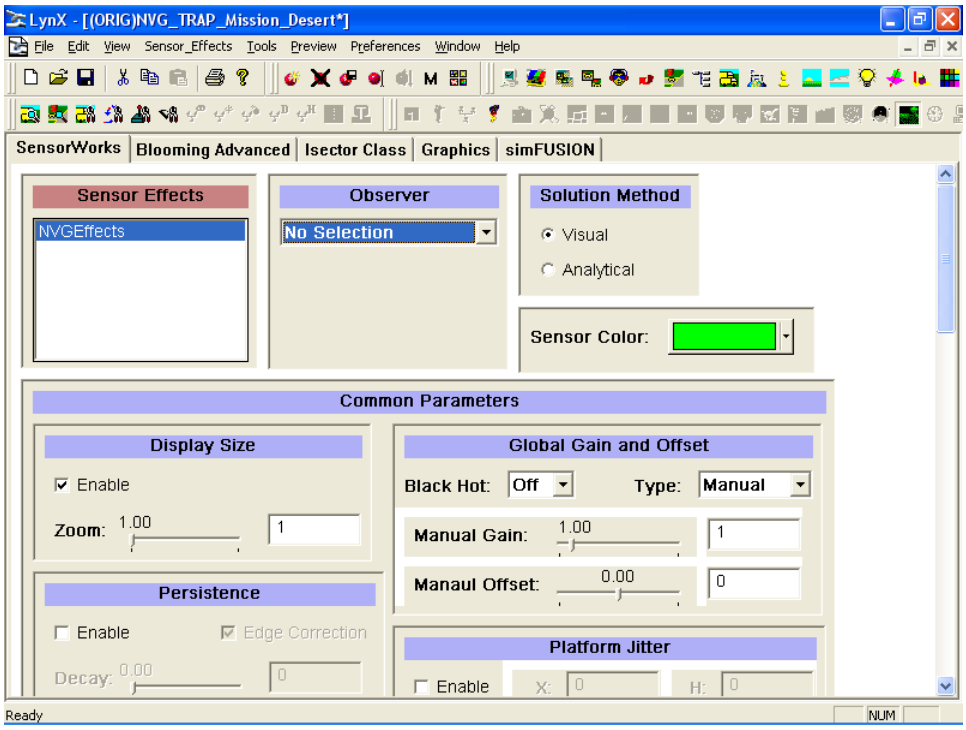

Figure 20. The Vega™ SensorWorks™ GUI

2. C++

C++ was used in conjunction with the Vega™ software to implement the ChrAVE application. A C++ program was written that provides a keyboard interface allowing dynamic, run-time access to Vega™ settings and features. This code allows the 'pilot on the controls' to fly the virtual helicopter based on commands from the navigator, coordinates the virtual scene, and implements the networking code that communicates flight parameters to the computers displaying the instrument panel and overhead view.

3. Open GL

OpenGL was used in Vega™ call-back functions to produce overlay drawings based on recorded navigation performances. This includes producing triangular icons that represent intended, actual, and perceived aircraft locations, intended and actual flights, and a legend schematic.

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IV. METHODOLOGY

A. EXPERIMENTAL DESIGN

1. Subject Pool

The subjects used in this experiment were fifteen male U.S. military officers with ratings as military helicopter pilots. The subjects were students of the Naval Postgraduate School and had spent varying amounts of time in a non-flying status while attending the school. Since all subjects were designated pilots, they meet the expert criteria with regard to the knowledge about the activities of a multitasked helicopter cockpit environment. All subjects had experience flying helicopters while wearing NVGs, as well as experience in over-land helicopter navigation.

2. Treatments

Each subject was asked to complete an entrance questionnaire, followed by map preparation for the low-level, NVG route of flight, a battery of visual tests prior to donning the HMD, a low-level navigation flight, a battery of visual tests following the flight while still wearing the HMD, and an exit questionnaire and debriefing. After all subjects had completed their flights, each subject was asked to evaluate the performances of their peers.

a. Entrance Questionnaire

The questionnaire (Appendix B) asks limited questions regarding subjects' medical backgrounds, overall and NVG flight experience, and tries to determine each subject's opinion of quantitative parameters (in terms of distances from the intended route of flight and navigation checkpoint identification) for conducting acceptable low-level NVG helicopter navigation. A series of slides were shown to each subject which depicted (using green symbology) a portion of a low-level route of flight complete with navigational checkpoints. This represented the intended route of flight. Overlaid on the intended route was an 'actual' flight path (in black or red symbology). This represented the fictional efforts of a pilot attempting to navigate the intended route of flight. Also depicted were fictitious navigator estimations of navigation checkpoint locations. Subjects were told that the flights were records of a daytime flight in excellent weather. Subjects were then asked to rank order the slides from the best navigation performance to the worst. Once the rank ordering was complete, the subjects were asked to identify the last slide that they considered to be representative of an acceptable navigation performance under these conditions. This meant that the subject considered all slides

ranked after the identified slide to be representative of unacceptable, or below standard navigation performances. Once this slide was designated, the subjects were then told to consider that the slides represented flights flown at night while using NVGs (again with excellent weather and illumination conditions). They were asked to once again identify the slide which represented the minimum acceptable navigational performance. This provided a baseline estimation of acceptable performances across all the helicopter communities represented, and attempted to determine the relative difficulty levels of flying with and without NVGs based on the expert opinions of the subjects The evaluation slides used during this portion of the experiment can be found in Appendix C. They were randomly lettered and presented to the subject in no specific order.

b. Tasks

The tasks each subject performed can be found in Appendix B (questionnaire pages 4-5). Some of the tasks (such as monitoring the radio and acknowledging a specific aircraft call sign) are secondary in nature to the primary task of conducting low-level helicopter NVG navigation but performed concurrently with this primary task. Subjects were directed to perform these secondary tasks in order to more closely replicate a realistic cockpit management stress level and workload. Due to the lack of available aviation resources, it is not possible to compare subject ChrAVE navigation performances to navigation performances of actual low-level helicopter NVG flights. However, it would seem reasonable to use the opinions of actual experienced pilots as subject matter experts (SMEs) in partially determining whether a system such as the ChrAVE is viable as a laboratory for continued training in helicopter virtual environment experiments.

c. Map Preparation

The subjects were provided appropriate resources (Appendix B, page 4) including scissors and tape to completely prepare their map for low-level helicopter NVG navigation of the intended route of flight. Aircraft flight parameters were specified (Appendix B, page 4) to allow subjects to correctly prepare their maps with regard to time/distance calculations, as well as to establish a mindset for the tempo of the flight. Subjects were given no time limit to conduct their map reconnaissance and map preparation.

d. Vision Tests

A battery of vision tests were administered twice during the experiment. The unhooded battery was conducted just prior to the subject donning the ChrAVE headgear. This battery provided a baseline measurement of the subjects' normal visual acuity and color vision. The hooded battery was conducted following the flight portion of the experiment, and gives a measure of the degree of degradation of the subjects' visual acuity and color vision while wearing the ChrAVE's headgear.

In each battery there were three vision-related tests. The visual acuity test was the first vision test administered, and was intended to show any apparent degradation in visual acuity while hooded. Subjects were given a simple eye chart (figure 22) created in Microsoft Word consisting of lines of random letters, and asked to read aloud the smallest row of letters they could read. The lines of letters were in courier font and ranged in size from 50 points to 8 points. Subjects were allowed to hold the chart as close to their eyes or the HMD-mounted camera as needed. The second vision test administered was the color identification test, which was intended to reveal any apparent degradation in the ability to correctly perceive colors while hooded. The simple eye chart in figure 22 contains six horizontal, evenly spaced lines of similar length with a width of three points. Each line is colored differently, from top: blue, red, green, orange, purple, and black. Subjects were asked to state the perceived color of each line from top to bottom. Subjects were again allowed to put the chart as close to their eyes or the HMD-mounted camera as desired.

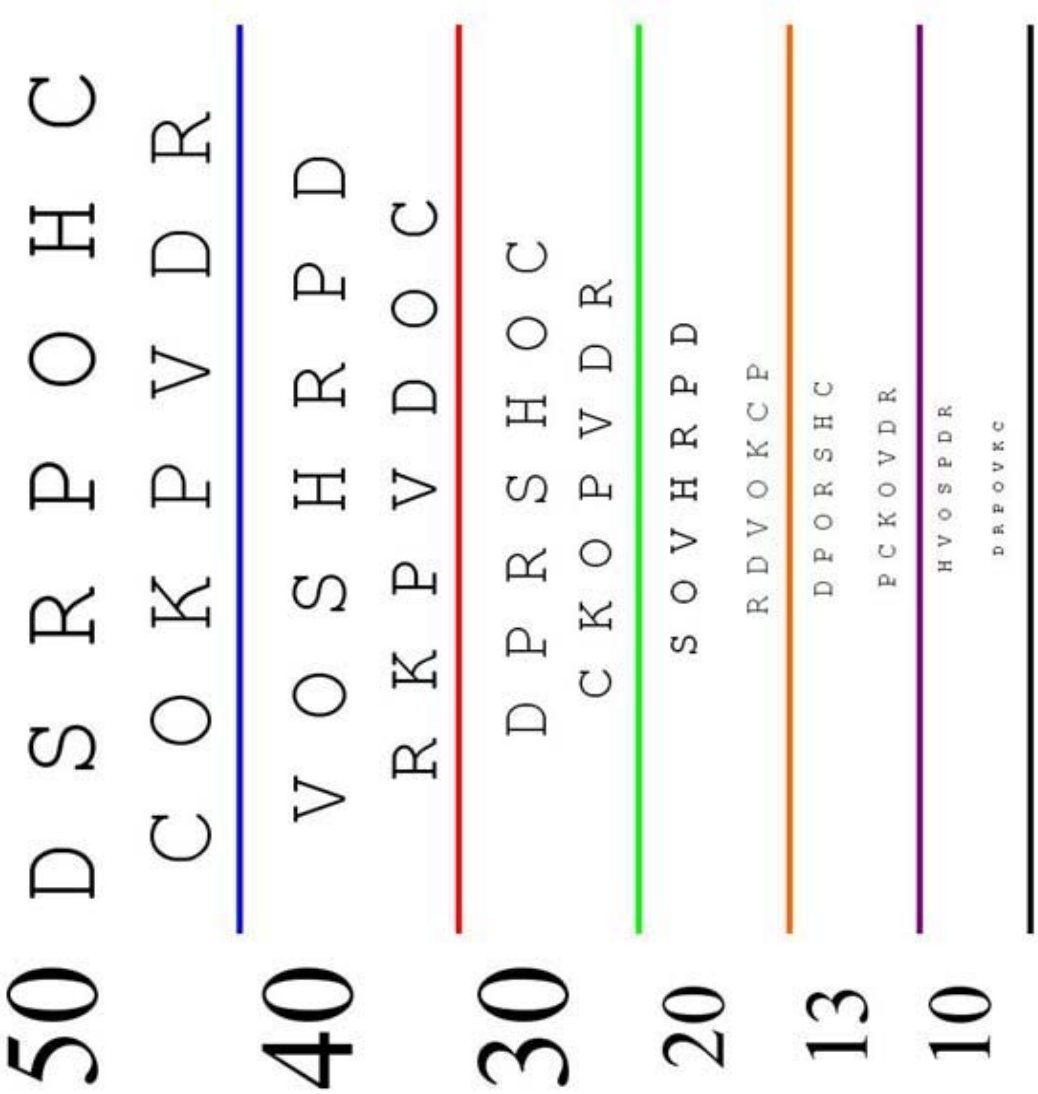

Figure 21. Visual Acuity and Color Identification Chart (Not to scale, From Lennerton, 2002)

	Blue	Red	Green	Orange	Purple	Black
R	0	255	0	255	128	0
G	0	0	255	102	0	0
B	255	0	0	0	128	0

Table 4. R-G-B definitions of the colored lines used in the color identification test (From Lennerton, 2002)

The third and final vision test was the Dvorine Color Vision Test. The *Dvorine Color Vision Test* is a bound set of color plates. Each plate contains a number made up of colored dots against a background of contrasting dots. People with normal color vision have no problem identifying the number contained on the plate, while those with color vision deficiencies often cannot determine the number contained on the plate. The purpose of this test is to determine the extent to which wearing the ChrAVE HMD degrades the color vision of subjects. Subjects were bound set of color plates, and asked to identify the number displayed on each of the first ten plates. Subjects were permitted to put the plates as close to their eyes or camera as needed, however the plates had to remain at a right angle while being viewed. All other established administration procedures (as described by Dvorine, 1963) were enforced. Delays of more than five seconds resulted in an identification failure for that plate.

e. Virtual Navigation

After completing the unhooded vision tests, subjects were seated in the mock cockpit. They were then given a brief tutorial on the cockpit structure, the ChrAVE headgear and how to adjust its fit, and the components of the instrument panel. During the instrument panel portion of the tutorial, the subjects were shown each of the instrument panel's component gauges, as well as how each display was interpreted. This was an important step in their familiarization with the ChrAVE's cockpit, given the generic nature of its construction, and ensured they could correctly extract the information displayed by the instruments. The subjects then donned the ChrAVE headgear and were allowed to become familiar with the viewing the virtual terrain, the instrument panel, and their map and kneeboard. Due to the fixed focal length of the HMD-mounted camera (through which all real and virtual objects were viewed), it was necessary to move their head forward slightly in order to gain proper focus of the instrument panel. Similarly, the map had to be held approximately one foot away from the camera in order to achieve proper focus. Once subjects became comfortable with these characteristics of the ChrAVE, they were given a short familiarization virtual flight. This familiarization flight lasted approximately 3-5 minutes, and was terminated when the subject stated he felt comfortable with the ChrAVE's flight simulation parameters and cockpit procedures. During this familiarization flight, subjects were exposed to turns to the left and right using both standard and half standard rates. The proctor verbally made note of the length of time it took to roll into and out of these turns, as well as the effects each maneuver had on the instrument panel's gauges. Also verbally

noted to the subjects was the large turning radius of the ChrAVE, and the inability to view terrain on the left side of the aircraft. Subjects were randomly started with either a physics-based imagery (SensorVision with SensorWorks modules working together) or a non-physics-based imagery (SensorWorks alone). Approximately two minutes into the familiarization flight, the proctor changed the method of NVG imagery production. The change was made dynamically (without interrupting the virtual flight), and allowed subjects to become familiar with both visual presentations.

Following the familiarization flight, the subject's position in the virtual world was moved to the course entry point for the route of flight for which they had prepared their maps. They were paused at the course entry point and allowed to establish their orientation using the compass, map, and the available views. When the subject was ready, the sound file was cued and the aircraft began to fly. Subjects had to listen for radio calls that were issued to their aircraft call sign amidst other radio traffic contained on the audio file. The proctor noted each radio call that was correctly identified as directed to their aircraft call sign. Approximately every two minutes, a voice on the audio file gave subjects a verbal command to plot their position and orientation. Additionally, subjects had to provide navigational instructions to the proctor.

This flight lasted approximately 20 minutes. In that time, the subject was supposed to negotiate as much of the course as possible, while maintaining the aircraft's position as close to the intended route as possible. Once again each subject was randomly started with either physics-based or non-physics-based imagery, and the imagery was switched dynamically approximately 10 minutes into the flight. Once twenty minutes had expired, the subject was notified that the flight would be paused. After completing the hooded visual tests, the subject was allowed to remove the ChrAVE headgear, and asked if he had to re-adjust to the real world. The subject was then allowed to dismount the ChrAVE and begin the exit questionnaire.

f. Exit Questionnaire

The exit portion of the questionnaire can be found in Appendix B, pages 8-10.

g. Debrief

Upon completion of the questionnaire, the subjects were invited to view their performance on the top-down viewing monitor. The proctor would point out observations and key points during the flight. During the debrief, the proctor made notes of subject comments. These comments often provided valuable insights into the thoughts and opinions of the subjects

related to their ChrAVE experience. The subjects' actual and intended flight paths, as well as the actual, intended, and perceived position plots of each subject's navigational performance are depicted in Appendix D.

h. Subject Peer Evaluations

Once the final subject had completed his virtual flight navigation, each member of the subject pool was presented with the top-down views of the entire subject pool's navigation performances (Appendix D). They were asked to evaluate each navigational performance with the following three instructions:

i. The subject's ability to maintain their actual flight path within an acceptable proximity to the intended path. Evaluate the subject's ability to fly the intended route and hit the intended checkpoints. On the provided overhead views, the intended route and checkpoints are green while the subject's flight path is red. Rate the performance using a 1 to 7 scale, with a '1' indicating highly acceptable while '7' indicates not acceptable. This criterion is independent of the following criteria, meaning the proximity to the intended flight path is to be evaluated independently of whether or not they knew where they were.

ii. The subject's ability to correctly estimate their location. Evaluate the subject's ability to accurately locate and plot his position (including heading) on demand. Aircraft icons of matching color help to pair a subject's estimated and actual locations. Where icons are far apart, white lines are drawn to help identify the pairs of icons. Rate the performance using the same 1 to 7 scale as the previous criterion. This criterion is independent of the preceding criteria, meaning the accuracy of the position estimation is to be evaluated independently of whether or not they were on the intended route.

iii. The overall navigation performance. Rate the overall performance as acceptable ('A') or not acceptable ('N').

i. Day vs. NVG Evaluation Standard Comparison

It would seem intuitive that conducting helicopter low-level navigation is more difficult under NVG conditions than normal daylight conditions. However, there is nothing formally published in Army or Navy standards that changes the standards for navigation performance while using NVGs. The Army's published task standard (Task 1025, Navigate by

Pilotage and Dead Reckoning, TC 1-209 and TC 1-212) for both the OH-58D and UH/EH-60 specifies standards that must be maintained during navigation in terms of maximum distance allowed from intended route of flight (300 meters and 800 meters respectively). These publications address the increased degree of difficulty in performing the same task under night/NVG conditions by making the statement "More detailed flight planning is required when the flight is conducted at night", but do not change the specified allowable distance standards. Despite there being no published change in standard, there may be a *subjective*, de facto change in standard as evaluators compensate for the higher degree of difficulty of navigating under NVGs. Questions 22-24 (Appendix B, pages 2-3) attempt to quantify the existence of such a subjective shift in evaluation standard. Subjects are asked to rank a series of slides that represent portions of recorded helicopter low-level navigation performances in order from best to worst. Each slide depicts an intended route of flight overlaid with an actual route of flight (representing the recorded navigation performance). These slides can be found in Appendix C. Once the subject rank orders the slides, they are asked to identify the slide that represents the minimum acceptable performance if the flight was flown during daylight, good weather conditions. This slide then represents the pass/fail line by that subject's opinion. Keeping the slides in the same, original, rank-order, the subject is then asked to identify the slide that represents the minimum acceptable performance if the flight was flown during NVG, good weather and illumination conditions. If the slide is lower in rank (considered a worse performance in terms of the original rank ordering), then implicitly the subject is stating that the evaluation standards for acceptable performance of helicopter low-level navigation are lower for the task conducted under NVGs than it is under daytime conditions. The degree of the standard shift will be measured by the difference in rank order between the two slides selected as minimum acceptable standards.

B. KNOWN ARTIFICIALITIES

There are several known artificialities associated with performing tasks in the ChrAVE. These artificialities can be described as parts or characteristics of the simulation that are different from what a person would experience while performing the task in the real world, in an actual helicopter. In most cases, these artificialities represent limitations that were met as the prototype was developed, as a result of technological limitations. In other cases they resulted from design decisions related to the ChrAVE system's overall goals of cost effectiveness and component availability (using COTS equipment rather than custom or proprietary components). This

section will identify the major artificialities that have been recognized and accepted for the current implementation. Future ChrAVE implementations will attempt to reduce or eliminate many of these artificialities.

1. Visual Artificialities

There are several visual artificialities encountered when using the ChrAVE with a daytime visual scene, and others that only become apparent when using the ChrAVE with a simulated NVG scene.

a. Color Vision

Most subjects perceive real world color in the ChrAVE with very minor deviations. These color deviations occur along the foreground or real world video pipeline. This pipeline consists of the camera, RGB to digital 601 signal converter, the chromakey mixer, the digital 601 to VGA signal converter, and the HMD. The HMD likely has the most effect on perceived color deviations to the user. The mixed real world and virtual world signal that is displayed by the HMD is also relayed (split) to a monitor for the proctor's use. The image displayed on the monitor has less color deviance than the HMD, indicating that the pipeline prior to the HMD has less of a contribution to color deviation than the display device itself. The monochrome green imagery produced by the simulated NVG imagery tends to make this effect more pronounced, casting a greenish glow to white or lightly colored objects (such as maps) viewed in the foreground. This effect can be lessened by manually adjusting the foreground settings on the chromakey mixer. Future upgrades to the quality of HMD used in the ChrAVE will likely reduce or eliminate this artificiality.

b. Gain Control

The ChrAVE's HMD-mounted camera is equipped with an automatic gain control which automatically adjusts the brightness level of the camera's signal. The HMD display is dramatically affected by these automatic gain adjustments. The user can perceive alternating periods of real world brightness and darkness with rapid head movements that go from repeated head down to head up. This effect is amplified during NVG simulation, and sky illumination can become so bright that the contrast and detail of the virtual terrain becomes difficult to perceive. This effect may be a byproduct of the requirement of the current ChrAVE implementation to ensure the blue chromakey material is highly illuminated. As previously mentioned, the lighting configuration of the ChrAVE is the most temperamental aspect of the system's hardware. This

artificiality is likely caused by the difficulty of ensuring the material is lit adequately for identification as the correct chromakey color, but not so well illuminated as to cause camera gain problems. Future implementations of the ChrAVE may utilize a recently developed back-lit chromakey material, which will likely reduce or eliminate this artificiality.

c. Fixed Focal Range

The ChrAVE's HMD-mounted camera's lens has a fixed focus range that allowed objects within arms reach to be in focus while more distant objects were out of focus. Similarly, focusing the camera on distant objects made near objects difficult to focus on. This artificiality created probably the most dramatic effect on subjects. The ChrAVE's HMD is occluded, meaning it is not possible to view anything except through the HMD's display which is fed by the HMD-mounted camera. As the camera's focus is necessarily set to focus properly on the virtual terrain, viewing near objects became difficult. In order to see near objects in proper focus, subjects were forced to move them within approximately 12-14 inches from the camera lens. Subjects had to lean forward in the seat to properly read instrument panel gauges, and lift the map close in front of the camera to achieve proper focus on terrain features and map markings. Some subjects had a difficult time adjusting to these artificialities, while others adapted rather quickly and without difficulty. It appears the effect of this artificiality is very individual-dependent. Future ChrAVE implementations may experiment with auto-focus cameras, or cameras with lenses that have wider focal range settings in an attempt to alleviate this artificiality.

d. Limited Field of View

The NVG visual simulation application set the FOV at 40 degrees (horizontal), which is what is offered by most NVGs in use by military pilots today. As with real NVGs, such a small FOV does not allow for a peripheral view to be presented to the user. Users commonly compensated for this narrow FOV with extra head movements, this is similar to the NVG scanning techniques taught to military pilots to overcome the limited FOV of NVGs. The aggregate VE FOV was limited to the coverage of the blue screen which was approximately from the user's eleven o'clock to his four o'clock. Some navigators felt that this was too much of a limitation to terrain association since they could not readily see terrain features on the left side of the aircraft. Future ChrAVE configurations may attempt to provide a wider aggregate FOV to eliminate this artificiality.

2. Auditory Artificialities

There are several auditory artificialities associated with the ChrAVE. The ChrAVE produces all audio cues via a set of surround sound speakers with a subwoofer, to include helicopter noise and radio traffic. In an actual cockpit, helicopter (rotor and engine) noise would be ambient (external to the flight helmet), and communications would be heard through the integrated headphones of the flight helmet. Additionally, the volume of the communications cannot be adjusted separately of the helicopter's rotor and engine noise. None of the subjects commented on the audio aspects of the ChrAVE, possibly due to their focus on the visually demanding task of low-level helicopter NVG navigation.

3. Vestibular Artificialities

The ChrAVE is a non-motion visual simulator. The visual perception of movement coupled with the lack of vestibular cues could cause users to experience confusion or simulator sickness, although none of the subjects for this experiment reported such experiences. If the ChrAVE was used shipboard there could also be problems associated with unsynchronized motion, caused by the vestibular perception of the ship's motion not matching the visual cues experienced by using the ChrAVE. Additional research should be conducted to determine the impact of this artificiality on a shipboard environment.

4. Ergonomic Artificialities

a. Cockpit

The intentionally generic design of the cockpit environment may have an impact on pilot performance. As previously mentioned, the ChrAVE prototype's cockpit is intended for use by all branches of the U.S. military, and for pilots who are rated in several different models of aircraft. It must also be said that although the ChrAVE is currently configured to perform as a helicopter training device, it could be re-configured with relative ease to simulate virtually any type of vehicle.

b. Instrument Panel

The size of the instruments, their relative positioning on the instrument panel, their color, and their methods of indicating flight information are again not specific to any one model of helicopter. These differences could make a difference in a pilot's performance by changing or disrupting his scanning pattern. A pilot's scanning pattern is the order, priority and interval in which he visually scans the instruments in order to gain and maintain his situational

awareness. In particular, integrating a clock into the instrument panel should be a priority, as this would eliminate the need to scan a separate area for flight/navigation information. Future implementations of the ChrAVE, should it be shown to be a viable training device, may more closely model individual aircraft instrument panels in order to eliminate this artificiality.

c. NVG / HMD Difference

The current ChrAVE implementation's headgear is somewhat bulky and uncomfortable. Although the visual display offered by the HMD is somewhat similar to what is provided by NVGs (see Visual Artificialities above), the feel of wearing the headgear is not similar to wearing NVGs. Using a modified flight helmet may be a more ergonomically similar method of fitting the necessary devices (camera, HMD, head-tracker) to pilots' heads, but this would present its own set of issues related to audio and communications. The ability to provide a 'look under the goggles' capability for viewing the instrument panel, map, and kneeboard should be a top priority for future ChrAVE implementations.

5. Flight Profile Artificialities

There are several artificial aspects of this implementation of the ChrAVE. The airspeed is kept at a constant rate (in this experiment, 90 knots), and airspeed is exactly equal to groundspeed. Additionally, the view or 'sight picture' of the pilot is adjusted during turns to give visual indications of the aircraft banking, however the pitch attitude of the virtual aircraft never changes from a perfectly level attitude. Finally, the ChrAVE's flight simulation model is artificially limited to either half-standard rate or standard rate turns, and these turns are executed by the software with precisely the same control touch. At this point in the development of the ChrAVE system for use as a helicopter flight training device, the level of flight simulation fidelity was considered less important to the research being conducted than was the visual presentation of the virtual terrain. Once the ChrAVE has been shown to be viable, improvements in the fidelity and realism of the flight dynamics will be explored.

6. Flight Task Artificialities

There would almost never be a situation where a U.S. military pilot was asked to perform NVG low-level helicopter navigation in a single-pilot mode (without a co-pilot). Two or more aircrew members use crew coordination procedures, such as division of duties to perform this type of complex task. While the experiment attempted to limit the navigator's responsibilities to navigation and communication only, it does not account for the additional navigation assistance

that would normally be provided by a co-pilot. Normally the pilot at the controls would assist in identifying terrain or other features that could aid navigation found on his side of the aircraft. As part of normal crew coordination conducted while performing this type of navigational task, the navigator describes what the flying pilot should see; the flying pilot confirms the description or states what he observes. Additionally, a navigator may instruct the pilot at the controls to adjust the aircraft's heading to parallel a road or other linear feature, or to fly directly over a bridge, hilltop, or other terrain feature. These capabilities are lacking in this experiment, partially due to the prototypical state of the ChrAVE, and partially due to the need to isolate the navigator (subject) as he performs this task. Other crew coordination issues include the lack of co-pilot assistance with communications tasks, and the lack of co-pilot assistance with monitoring the instrument panel and status of the aircraft. Monitoring and communicating with radios appears to vary between different helicopter communities, if not from aircrew to aircrew. Experienced navigators may be able to handle the responsibility for answering radio calls in addition to navigational duties. Less experienced navigators are normally allowed to focus strictly on navigating, with other crew members responsible for radio communications. In this experiment, the navigator was given communications responsibility in order to try to simulate the stress and multi-tasking that is normally experienced by aircrew members operating a real helicopter. Assistance with monitoring the status of the aircraft can greatly aid the performance of a navigation task by augmenting the navigator's scan and thereby reducing his workload. For example, a navigator may be looking at the map or outside the cockpit at the terrain while the co-pilot gives periodic heading, altitude, airspeed, or elapsed time updates. To ensure subject navigational performances were not biased by the level of co-pilot assistance, the only co-pilot feedback they were given was confirmation of the flight commands they issued to the pilot on the controls.

C. DATA COLLECTION

Data was collected via the questionnaire, recorded flight data, subjects' maps, debriefs, and subjects' peer evaluations.

1. Questionnaire

Questionnaire data was manually recorded onto Microsoft Excel™ spreadsheets for statistical analysis.

2. Recorded Flight Data

The ChrAVE automatically saves all flight parameter data to a text file. This file can then be used in a separate application to produce an overhead view of the route of flight for debriefing subjects, as well as for importing into a Microsoft Excel ™ spreadsheet for statistical analysis. This data was used to compare actual versus subject perceived locations and average distances from the intended route of flight and checkpoints. This data was also used to compare the differences in performances for physics-based and non-physics based visual presentations of the NVG imagery.

3. Subjects' Maps

Subject maps were used to obtain their plotted position data. These plotted positions represented the subjects' best determination of their location at the exact time they were asked to do plot their position on their maps. These positions can then be compared for accuracy to their actual positions using the recorded flight data.

4. Debriefs

Detailed notes recorded the opinions and statements of subjects gathered verbally immediately following their participation in the experiment.

5. Subjects' Peer Evaluations

Subjective peer evaluations were recorded for statistical analysis using a Microsoft Excel ™ spreadsheet. This data was used for comparison with stated navigation evaluation standards.

V. RESULTS

There were four major phases of data collection used in the experiment conducted to support this research: a pre-flight portion of the questionnaire, performance of a virtual flight, a post-flight portion of the questionnaire, and a peer evaluation task. This chapter is organized by data collection phase in order to give structure to the results.

A. QUESTIONNAIRE

The pre-flight portions of the questionnaires provided some interesting insight into the backgrounds, opinions, and subjective standards of the aviators who participated in this experiment. The post-flight portions (including subject verbal debriefs) yielded subject opinions of the ChrAVE as an NVG training system, comparisons of the ChrAVE versus Topscene™, the realism of the tasks performed in the ChrAVE, and the realism of the NVG imagery presented to them.

1. Pre-flight Portion of the Questionnaire

The U.S. military helicopter pilots who participated in this experiment averaged 1506.25 flight hours (minimum 700, maximum 3150, standard deviation 874.78), and 306.67 NVG flight hours (minimum 40, maximum 700, standard deviation 194.20). Seven of the pilots were Marines, three were from the Army, one from the Navy, and one from the Air Force.

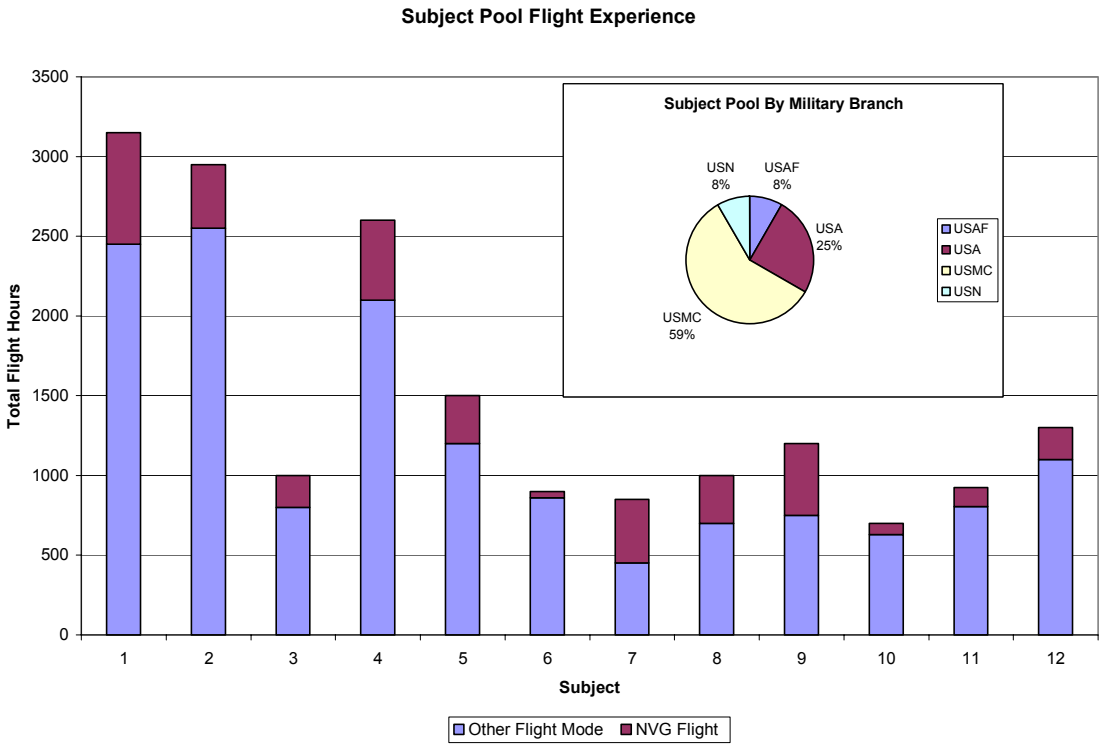

Figure 22. Subject Pool Experience

Another important factor related to the subject pool is the issue of currency. A pilot is considered to be 'current' if they have flown their aircraft within a certain amount of time (specified by each branch of the service), and 'not current' if they have exceeded that amount of time. Each service has its own currency time limits defined by regulations. The currency clock starts the day after the pilot performs aircrew duties, and is not re-set until he flies again. Pilots who become 'not current' (by exceeding the allowable time between flights) are normally required to receive a currency evaluation flight with an instructor pilot in order to restore his currency (reset his clock). By U.S. Army Aviation standards (Training Circular 1-210), a pilot must have at least one hour of flight time within a consecutive 60 day period in order to be considered as 'current' in their aircraft, and within a 45 day period in order to be considered as 'current' for flying NVGs. Since the subject pool for this experiment was drawn from an academic environment where all of them are in a temporary non-flying status, only one of the pilots who participated in the experiment could be considered to be 'current' flying NVGs. The average time since the last flight with NVGs for the subject pool was 13 months (minimum 1 month, maximum 29 months). Additionally, U.S. Army standards (TC1-210) require pilots who

exceed 180 days between NVG flights to undergo extensive retraining. Because the skills required to fly while wearing NVGs is recognized as being so technically difficult and perishable (skills deteriorate quickly if not practiced), a pilot who exceeds 180 days between NVG flights gets the same level of retraining that a pilot reporting into a unit for the first time from flight school would receive. According to these rules, all but one of the pilots used in this study have exceeded 180 days since their last NVG flight, and would therefore require re-training.

2. Evaluation Standards Task

The questionnaire asked several questions directed at defining subjects' individual evaluation standards related to low-level helicopter navigation, and subjects were also tasked to evaluate a set of fictitious navigational performances. Figure 24 shows the data from questions 18 and 19. Question 18 asks how far (in meters) a navigator can stray from his intended route of flight and still be considered acceptable. Question 19 asks how far (in meters) a navigator can be from specific checkpoints along the route and still be considered acceptable.

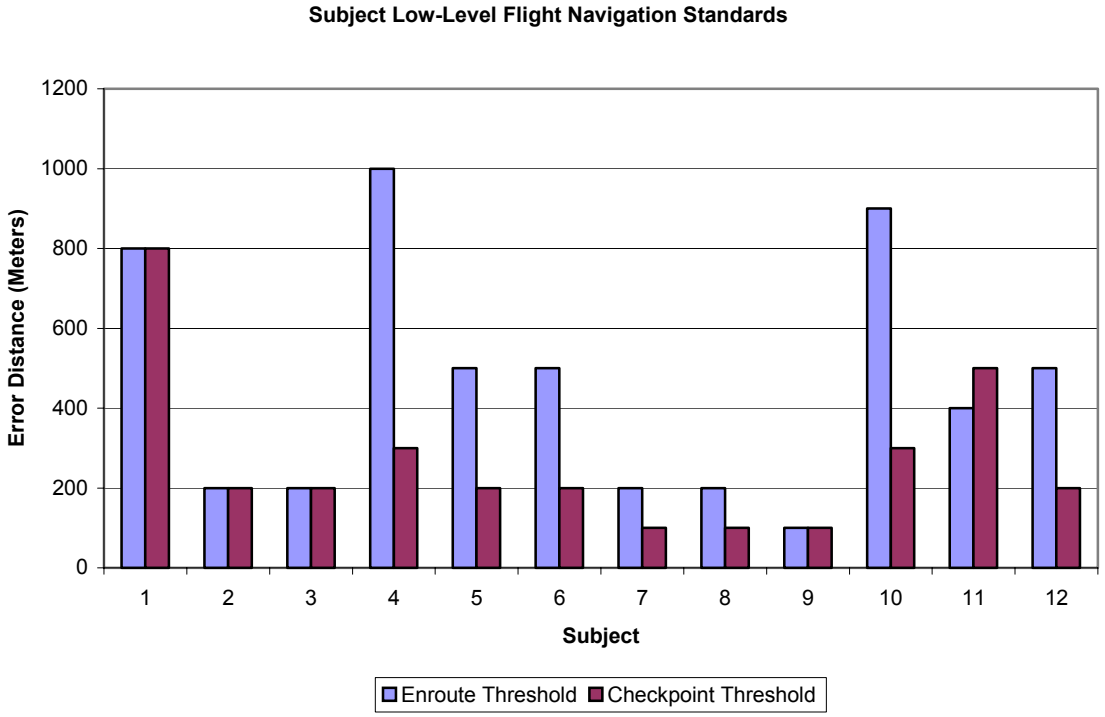

Figure 23. Subject Low-Level Flight Navigation Standards

The average standard threshold for enroute navigation accuracy was 458.33 meters (maximum 1000, minimum 100, standard deviation 302.89). The average standard threshold for checkpoint accuracy was reduced to 266.67 (maximum 800, minimum 100,

standard deviation 201.51). These questions do not specify flight mode (day, night, NVG), and are intended to obtain the subjects' navigational standards without regard to flight condition. The subjects consistently (with the exception of Subject 11) indicated that there was less tolerance for navigational error at checkpoints than at other points along the route of flight.

Question number 21 asked subjects to rank seven criteria in order of their importance to evaluating navigation performance. Figure 25 compares the responses to this question across the subject pool. A score of '1' indicates that the subject ranked the question as the most important (shortest bars), while a score of '7' represents the least importance (longest bars). The criteria the subjects considered to be most important is knowing location by means of dominant terrain feature, while they considered being off the intended route of flight but correcting to hold the least amount of importance in evaluating a navigation performance. This seems to validate using knowledge of one's current location as the primary consideration for evaluating navigational performance, which is the criteria used in this thesis for evaluating subject ChrAVE navigation performances.

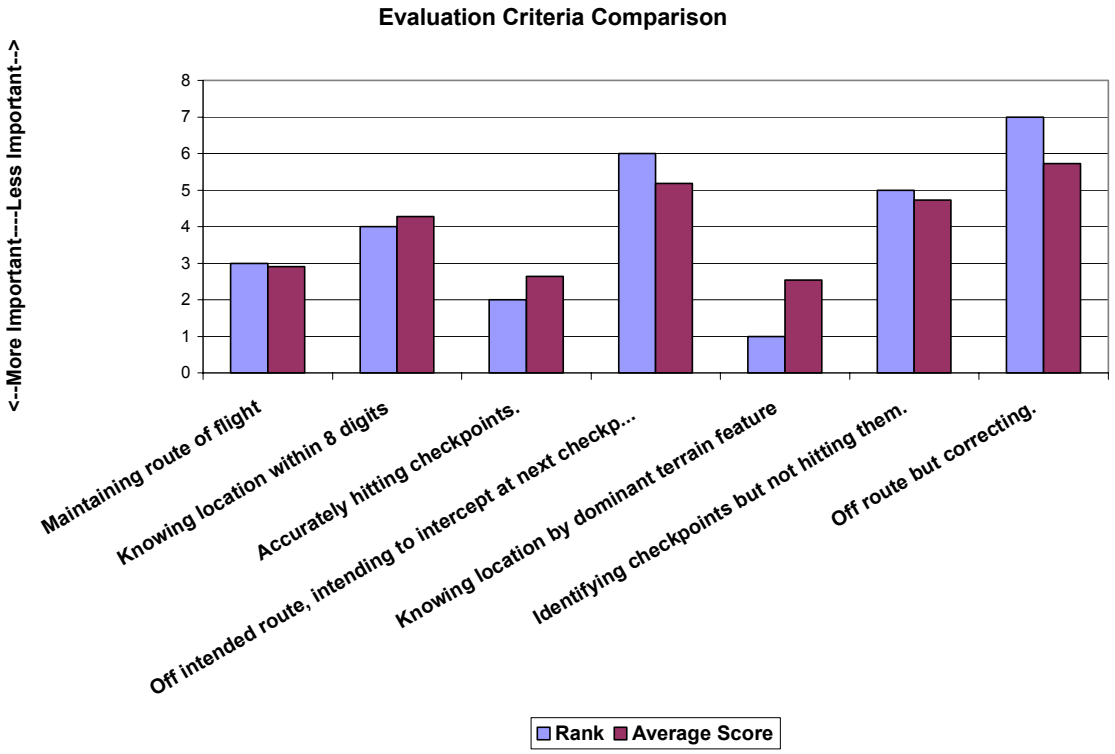

Figure 24. Evaluation Criteria Comparison

The standard evaluation task performed by subjects asked them to rank order 15 slides containing portions of fictitious navigational performances. These slides are lettered for identification, and are located in Appendix C. Once the slides were rank ordered, subjects were asked to identify the slide that represented what they consider to be the minimum acceptable performance, beyond which they would consider all performances to be unacceptable, for a daytime low-level flight with good weather. Keeping the slides in the same rank order, subjects were then asked to designate the slide they considered to be the minimum acceptable performance, beyond which they would consider all performances to be unacceptable, for an NVG flight with good weather and illumination conditions. Figure 26 shows the results of this evaluation task. The primary purpose of this evaluation task was to capture the degree of shift of the threshold between conditions. In other words, how much of a difference is there in the subjective standards of experienced aviators?

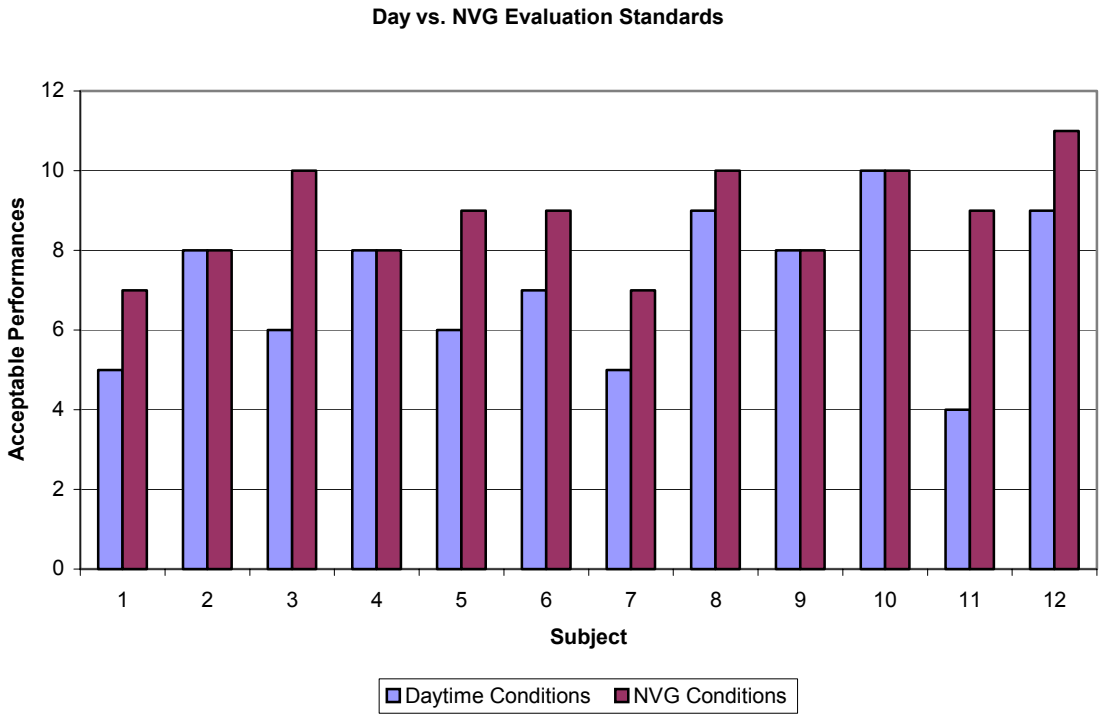

Figure 25. Day vs. NVG Evaluation Standards

The results of this evaluation task clearly indicate that most of the subjects tolerate more error for navigation performances if they consider that the task was conducted while using NVGs. The average amount of evaluation standard shift (measured in number of

slides rated as acceptable) was 1.75 (standard deviation 1.66) for the subject pool as a whole, indicating that on average the subject pool would allow two (out of 15) more performances to be considered as acceptable if flown with NVGs versus daytime conditions. That is an average standard shift of twelve percent. A third of the subjects (4 out of 12) maintained the same standards for acceptable performance of the navigation task regardless of flight condition. Of the subjects who shifted their evaluation standard, two thirds (8 out of 12) averaged 2.63 more NVG performances (maximum 5, minimum 1, standard deviation 1.30) considered as acceptable than during daytime conditions. That is an average standard shift of 18 percent. None of the subjects considered more performances acceptable for daytime conditions than for NVG conditions, indicating a consensus opinion that navigating with NVGs is at least as difficult as daytime navigation.

3. Post-Flight Review of ChrAVE Performance

The final portion of the questionnaire was administered to subjects after they had finished performing their low-level NVG navigation flight task in the ChrAVE. This part of the questionnaire was intended to gather data on the subjects' opinion of the realism and validity of the tasks (comparing the tasks conducted in the ChrAVE to those same tasks as conducted in the actual aircraft), and the quality and realism of the visual representation of NVG imagery. This portion of the questionnaire also attempted to draw out subject opinions of any differences between the realism of the NVG imagery produced by physically-based means and that of the imagery produced by non-physically-based techniques.

a. Task Realism

Question number 25 asked subjects if the navigation task as performed in the ChrAVE was realistic. Seven subjects agreed that it was realistic (58.3 percent), four disagreed (33.3 percent), and one strongly disagreed (8.3 percent). Of those that disagreed, most pointed to factors discussed in the 'Known Artificialities' section of this thesis, specifically the lack of a co-pilot assisting with navigation information and the difficulty associated with viewing near objects through the camera. Other questions attempting to draw comparisons to real world task performance were fairly inconclusive in their results, with widely scattered responses that averaged to an opinion of 'neither agree nor disagree'. These questions included whether or not the ChrAVE performed as well as other visual simulators they had used in the past, if the cockpit

management skills required of the ChrAVE were similar to those required in real aircraft, and if the HMD felt similar to what was experienced when flying with NVGs. When asked if using the the ChrAVE would be beneficial to trainees undergoing initial NVG qualification training, three of the subjects responded with 'strongly agree' versus one subject who strongly disagreed, but again the average response was only slightly more positive than 'neither agree nor disagree'. Subjects' opinions of the ChrAVE's potential as an NVG training device that could assist experienced crews in maintaining their NVG flight skills when unable to actually fly the aircraft had exactly the same average result of slightly higher than 'neither agree nor disagree', with only one subject who strongly agreed and none who strongly disagreed.

b. Comparison with Topscene™

Of the 12 subjects who participated in this research, only five were familiar with Topscene™. This fact also speaks to the availability of Topscene™ at the user level, given that less than 50% of the subject pool were familiar with this simulation tool. Interestingly, four out of those five felt that the ChrAVE's NVG imagery was more realistic than that of Topscene™'s, with the fifth stating he neither agreed nor disagreed. Despite the extremely small sample size, this statistic is especially surprising considering that the ChrAVE uses only COTS equipment, rather than the proprietary, custom architecture found with Topscene™. Question number 39 asked subjects to rate the realism of eight different portions of the ChrAVE's flight task on a 1 to 5 scale, with a rating of 1 indicating strong disagreement that a task was realistic, and a rating of 5 indicating strong agreement that a task was realistic. Subject responses seemed to agree that the tasks of preparing the map, maintaining awareness of their location, terrain association, navigation, and monitoring the radio calls were fairly realistic. Subject responses averaged 'neither agree nor disagree' that the other tasks performed in the ChrAVE were realistic. The subject pool's average responses are displayed in Figure 26.

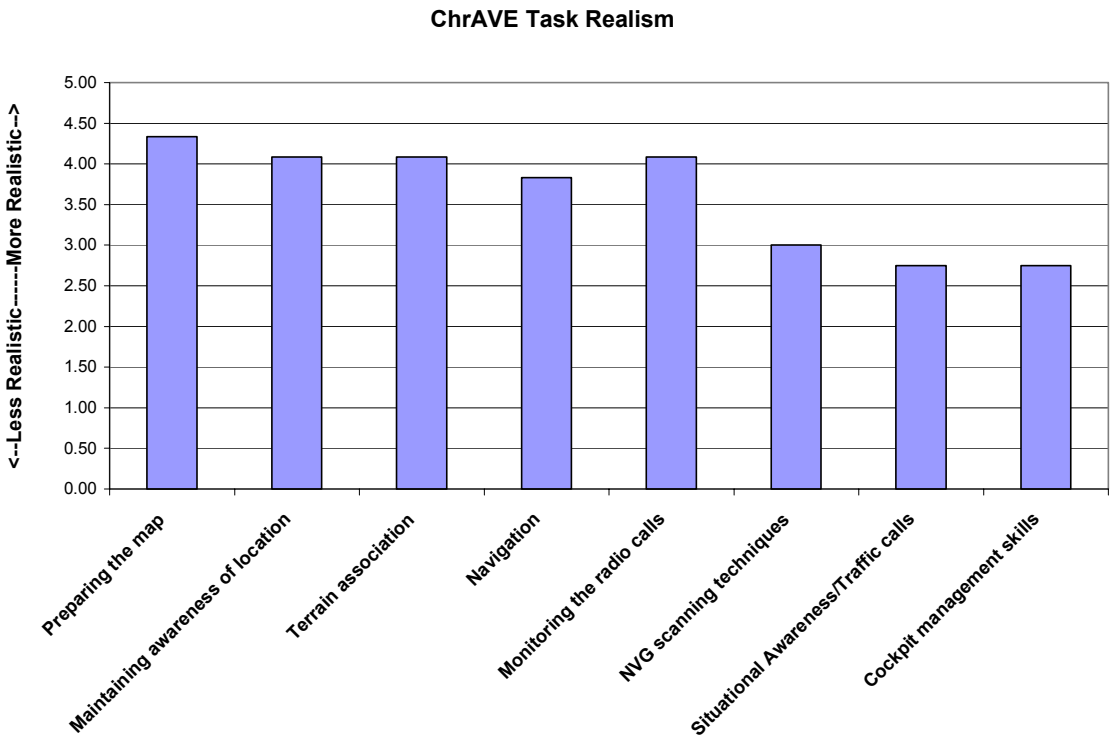

Figure 26. Subject Opinions of ChrAVE Task Realism

c. Physics-based Versus Non-physics Based Imagery

Questions 27 and 28 asked subjects the degree to which each of the two types of imagery was realistic. Again the scale for subject responses was from '1' to '5', with a '1' indicating strong disagreement that the imagery was realistic, and a '5' indicating strong agreement that the imagery was realistic. Figure 27 shows a comparison of subject opinions of the two types of NVG imagery overall. There was no recognizably consistent difference in how realistic the subjects considered either method of NVG imagery production. The average rating for non-physically based imagery was 3.58 (standard deviation 0.79), which correlates to a subject pool average opinion that is slightly closer to 'agree' than 'neither agree nor disagree' that the imagery was realistic. The average rating for physically based imagery was 3.67 (standard deviation 0.85), which has a similar interpretation of subject opinion, although slightly more positive.

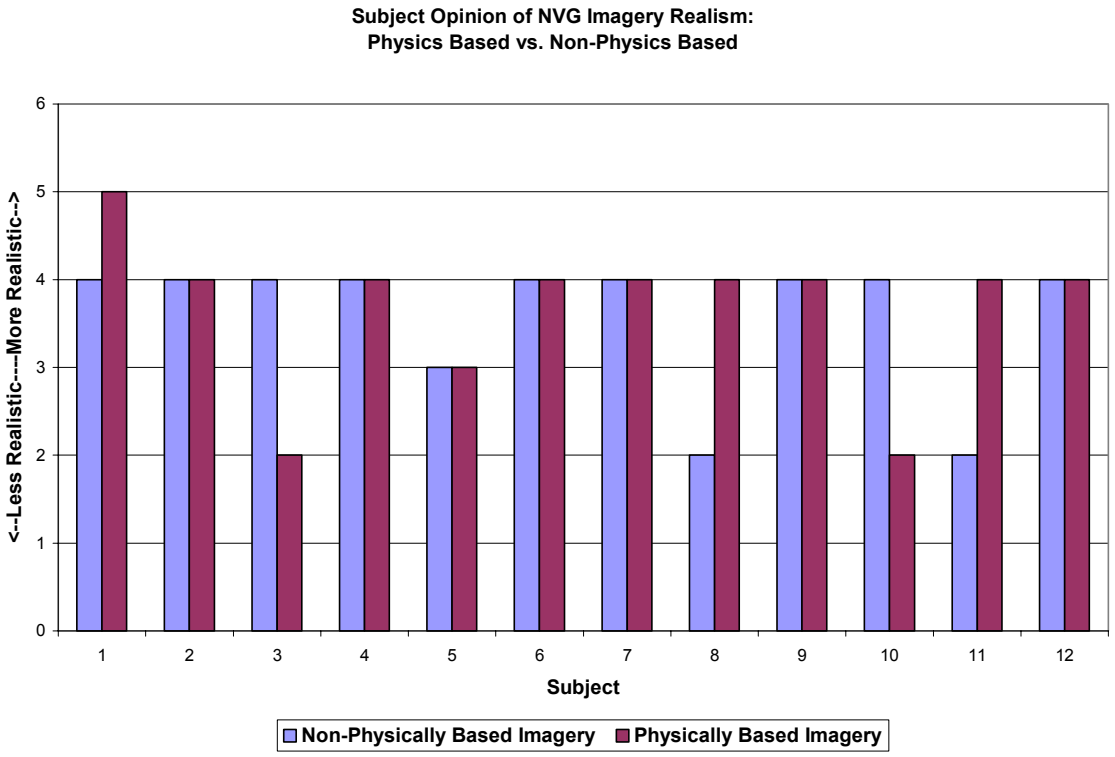

Figure 27. Subject Opinion of NVG Imagery Realism

The navigation performance data for each subject is drawn from only the first portion of flight, in order to ensure independence of the flight performance data between visual production treatments (physics based versus non-physics based imagery). In order to more closely link subject opinion of imagery realism during the performance evaluation portion of each subject's flight, Figure 28 displays the subject pool's opinion of non-physics based imagery realism for only the first portion of flight, while Figure 29 displays the subject pool opinion of physics-based imagery realism for only the first portion of the flight.

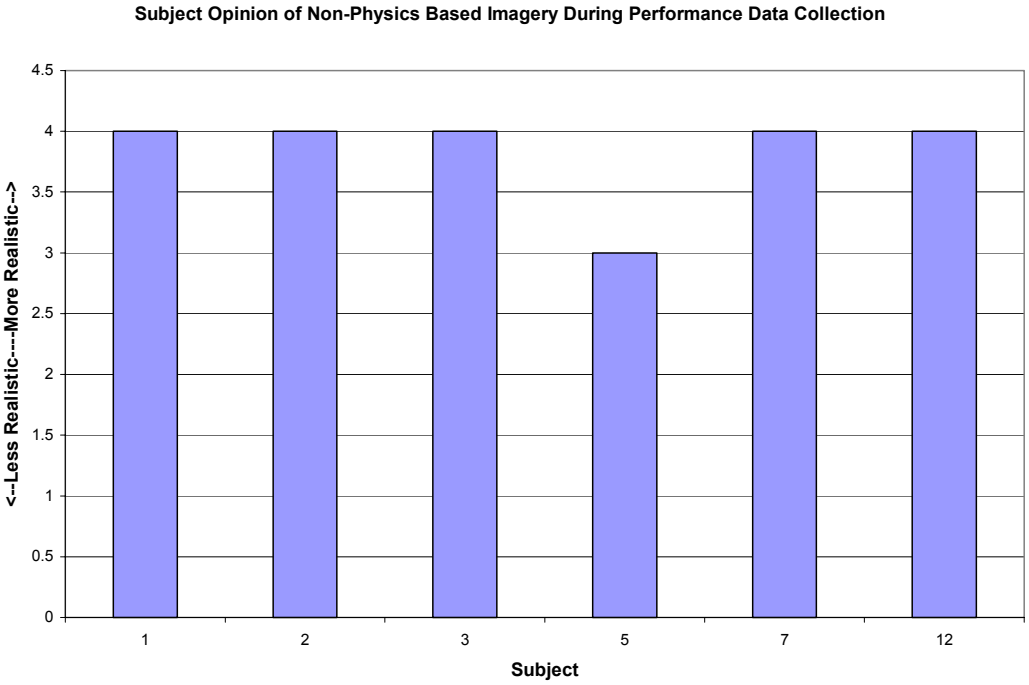

Figure 28. Subject Opinion of Non-Physics Based Imagery Realism

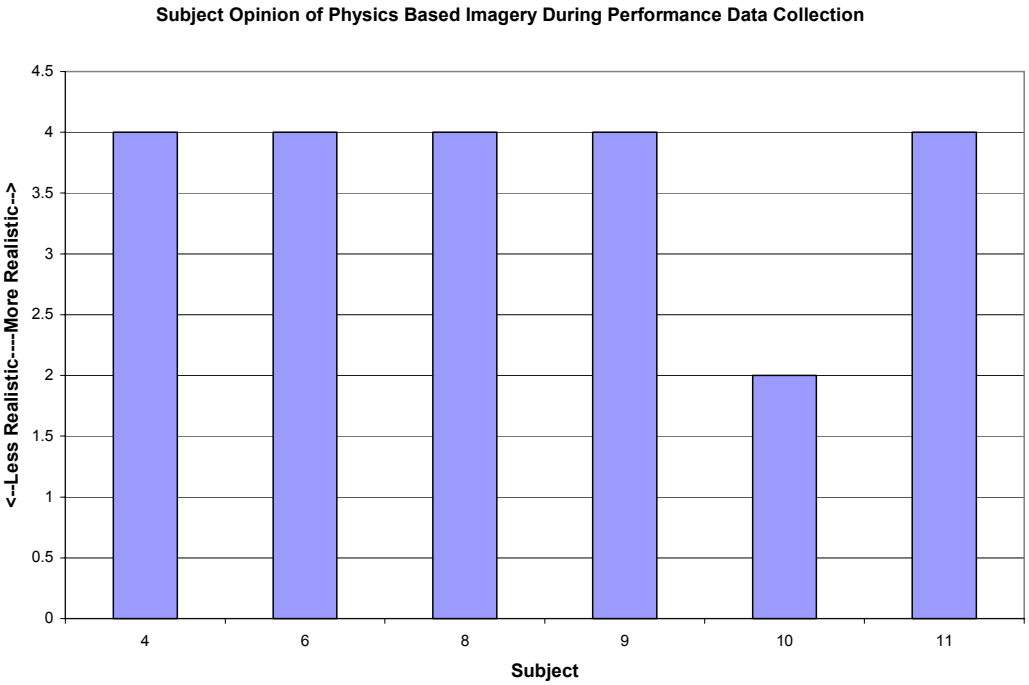

Figure 29. Subject Opinion of Physics-Based Imagery Realism

In both cases, five out of six subjects agreed that the imagery was realistic. One subject responded that he 'neither agreed nor disagreed' that the non-physics based imagery was realistic, while one subject disagreed that the physics based imagery was realistic. The difference in subject opinion of realism between these two methods of imagery production is statistically insignificant.

As described in Chapter II of this document, the existence of visual noise is an important characteristic of NVG imagery. Question number 36 asks subjects if the visual noise characteristics of the NVG scene were modeled accurately. Since the same visual noise effects were used for both methods of imagery production, this question was asked without regard to type of imagery or reference to individual portions of flights. Nine out of twelve subjects indicated that the visual noise effects were realistic, two disagreed, and one declined to respond due to his perceived lack of adequate experience to make a judgment on this issue. The final two questions on the questionnaire asked subjects to compare the ChrAVE's level of cockpit workload and stress to the levels they've experienced in a real aircraft. Five of the subjects felt the ChrAVE's cockpit workload was less than found in a real cockpit, four felt it was greater than in a real cockpit, and three responded that the levels were about the same. Details gathered during subject debriefs indicated that for those who felt the workload was greater in the ChrAVE, the major reasons were the lack of co-pilot assistance and the inability to look under the HMD to view near objects. Six of the subjects felt that the stress level of the ChrAVE was less than that found in a real cockpit, while five felt it was about the same, and one felt the stress was greater in the ChrAVE.

B. SUBJECT PERFORMANCE DATA

1. Evaluation Criterion

One of the most challenging aspects of conducting this experiment was determining what criteria to use to evaluate subject navigation performances. When pilots perform navigational tasks in the aircraft, a great deal of information is exchanged between the navigator and the instructor pilot (who is also the pilot on the controls) that cannot be captured by simply recording flight data. For instance, a navigator may demonstrate verbally to the instructor pilot that he knows exactly where he is despite being off the intended route of flight. Similarly, an instructor pilot may know that a navigator is disoriented due to statements or actions inside the cockpit, and

yet the aircraft may still be on its intended course or over a checkpoint with little or no error. Identifying a checkpoint or distinct terrain feature is often done by the navigator simply pointing it out to the instructor pilot. It is impossible (at least at this point in the system's development) to accurately capture this kind of information in the ChrAVE. If the navigator is wildly off course and not correcting, it is probably safe to judge him as disoriented, however this will most often not be the case, especially given the relatively short amount of time subjects spend navigating in the ChrAVE. It is easy to determine in the ChrAVE whether or not the 'aircraft' is off the intended route of flight; it is difficult to know if the subject is off course but knows where he is, is off course and does not know where he is, is on course and knows where he is, or is on course but still doesn't know his position. In an attempt to overcome this lack of information and still gain a snapshot of navigator perception of position, navigators were asked to plot their position on the map with a pencil at approximately two-minute intervals. Their navigation performance will be primarily evaluated by the difference between these plotted positions and their actual position in the virtual world as recorded by the ChrAVE system. Data presented earlier in this chapter (Figure 24) supports using this criterion as a measure of effectiveness; since it corresponds to the criterion the subjects themselves felt most important (knowing one's location by dominant terrain feature) when evaluating a navigation performance. It is important to note that there is an unknown amount of error in the accuracy of the subjects' plotted positions. When plotting their position, their mental and visual scanning is interrupted, and they may have induced plotting error by trying to rush to re-establish their scanning patterns. Error may also be produced if attempting to plot their positions during turns or maneuvers of the virtual aircraft.

2. Raw performance data

Each subject was directed to plot his position on the map five times during the first ten minutes of his flight, and Table 5 compares the differences between each subject's actual position and their perceived position.

Subject Pool Overall--Both Types of Imagery							
Self-Location Error (in meters)							
Subject	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Average	Physics
1	3158	1631	5167	7133	5178	4453	No
2	541	3959	768	3929	5316	2903	No
3	952	566	1204	275	492	698	No
4	1315	7840	7572	9734	9016	7095	Yes
5	3598	2489	530	4161	7440	3644	No
6	2755	3356	3104	6440	12638	5659	Yes
7	1355	1071	918	379	257	796	No
8	823	1400	4921	7692	5947	4157	Yes
9	1115	1556	2389	2247	4375	2336	Yes
10	578	4212	5548	11280	14490	7221	Yes
11	2155	4074	4299	7983	7509	5204	Yes
12	1594	2265	1389	824	1611	1537	No
Average	1662	2868	3151	5173	6189	3809	

Table 5. Subject Self-Location Error by Imagery Type

Figure 30 separates the subject pool performances based on the type of imagery (physics-based or non-physics- based) they were presented, in terms of the amount of error (in meters) between subjects' real and estimated positions in the virtual world.

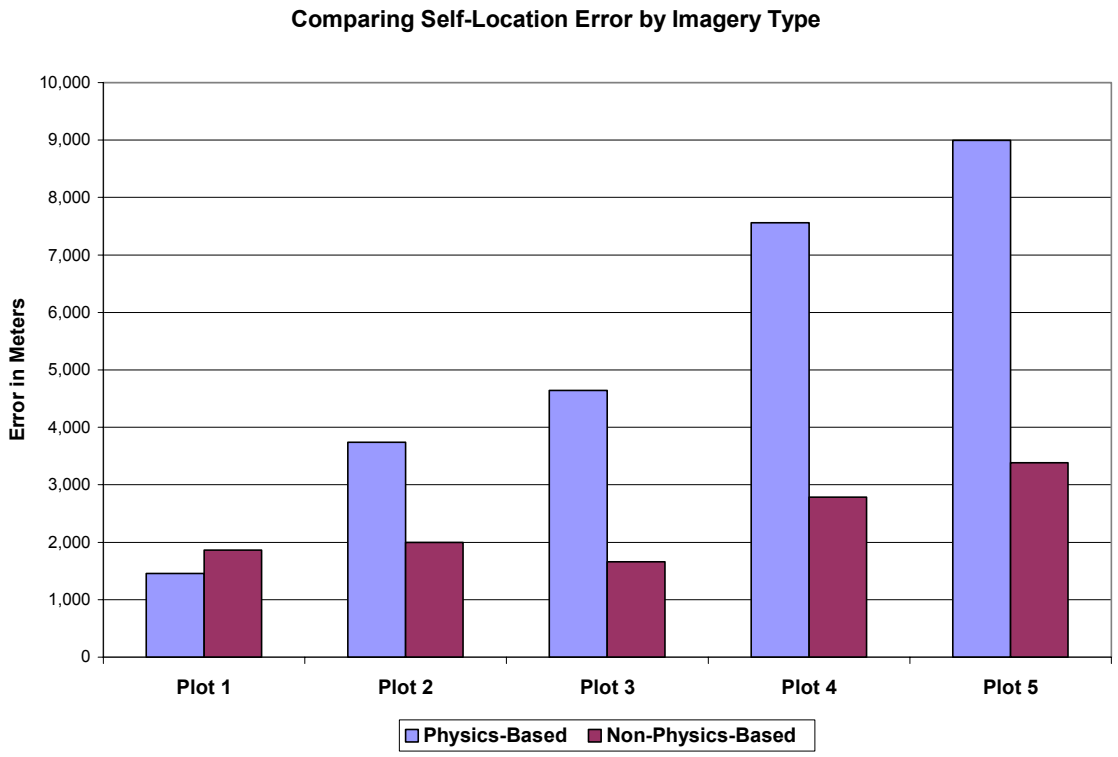

Figure 30. Comparison of Subject Self-Location Error by Imagery Type

Based on the small sample size of this data, a Wilcoxon Rank-Sum test was performed on the results to determine if there is statistical evidence that there is a difference between performances based on type of imagery presented. The test returned a p-value of 0.0931, indicating that at a 10% level of significance, there is weak of a difference. It does appear that the average errors separate over time. Wilcoxon Rank-Sum tests were performed on the subject errors for Plot 1 and Plot 5 separately. There is no evidence of a difference at Plot 1 (p-value 0.59), but significant difference at Plot 5 (p-value .026). This may mean that if the navigation task had been performed over a longer period of time, a difference would be seen. The implication of the higher rate of error over time of the physics-based group is that over time they tend to get further off course faster than the non-physics based group. One explanation for this higher error rate could be the continuous, cumulative nature of navigation. Each point along a navigation route is inherently dependent on earlier route decisions, headings, and speeds. It may be that the physics-based group may not be getting the visual cues they need to perform the navigation task, and over time the lack of these visual cues may be accumulating, and thereby increasing the amount

of error of their self-location knowledge. Figure 31 shows the difference between subject group self-location errors over time.

Figure 31. Subject sub-group error plotted over time

One factor that must also be considered when examining the performance error found between the imagery treatment groups is the difference in experience level of the two groups. The subjects were randomly divided into two groups, which determined whether they were first presented the physics or non-physics imagery treatment. This random division was done prior to the subject providing any background data, other than own verbal confirmation as to their status as a helicopter pilot with NVG over-land terrain navigation experience. It is apparent that there is a difference in the flight and NVG experience levels of the two groups, and this may influence the amount of error between the two groups. Figure 32 shows the flight and NVG experience levels of the two subject groups.

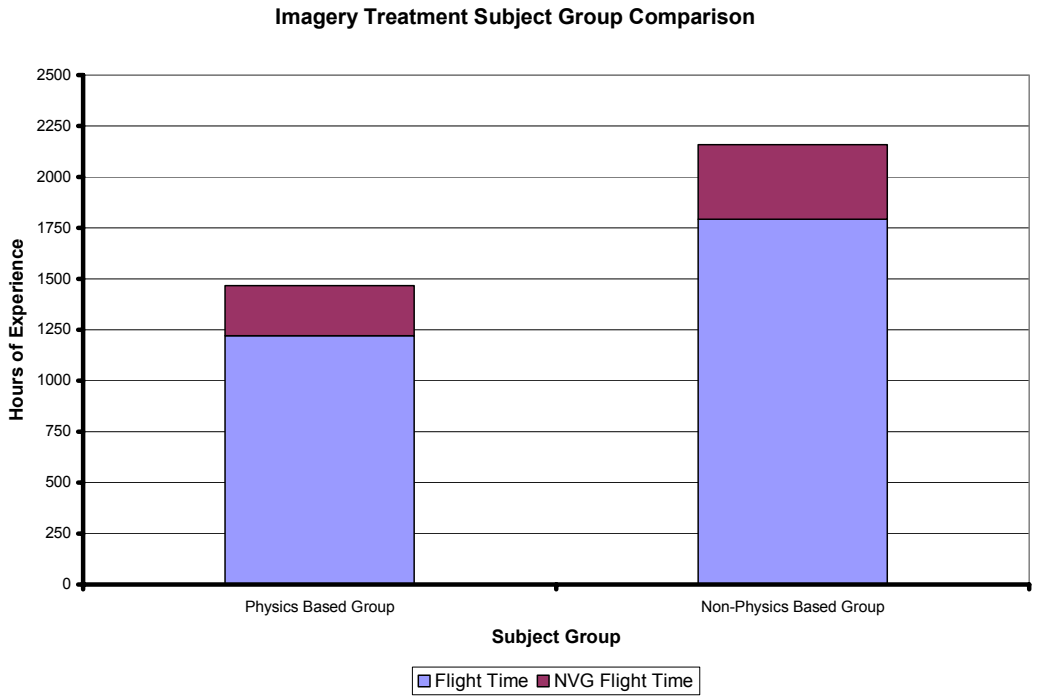

Figure 32. Comparison of Subject Sub-Group Experience Levels

Another important factor that may influence the difference between these two treatment groups is the branch of service of the subjects. In order to obtain the most subjects possible for this experiment, all military helicopter pilots in attendance at the Naval Postgraduate School were asked to participate, and the four major branches of service are represented in the subject pool. After ranking the flights in order of the most accurate to least accurate self-location plots during the navigation flight, the three Army pilots ranked first, second, and fourth. The top two performances (both Army) were also familiar with the National Training Center at Fort Irwin (an Army training facility from which the terrain database used in the virtual flight was drawn) and had also actually flown there. Most Army pilots spend virtually all of their NVG flight time at terrain flight altitudes over land, so the task most closely paralleled the normal mission profile of this portion of the subject pool. It would make sense that these subjects would have an advantage over other subjects based on the task chosen for evaluation. Although this factor reduces the ability to draw objective statistical conclusions from the data, it also points to the realism of the task as performed in the ChrAVE. The subjects with the most experience in performing the task in the real world were the most successful in the virtual representation of this task.

3. Peer Evaluation

		OVERALL PERFORMANCE EVALUATIONS											
EVALUATORS	Subject Number	001	002	003	004	005	006	007	008	009	010	011	012
	Subject 001		A	A	N	N	N	A	A	A	N	N	A
	Subject 002	N		A	N	N	N	A	N	A	N	N	A
	Subject 003	N	A		N	A	N	A	A	A	N	N	A
	Subject 004	N	A	A		N	N	A	N	A	N	N	A
	Subject 005	N	N	A	N		N	A	N	A	N	N	A
	Subject 006	N	A	A	N	N		A	N	A	N	N	A
	Subject 007	N	A	A	N	A	N		N	A	N	N	A
	Subject 008	N	N	A	N	N	N	A		A	N	N	A
	Subject 009	N	N	A	N	N	N	A	N		N	N	A
	Subject 010	N	A	A	N	N	N	A	A	A		N	A
	Subject 011	N	A	A	N	N	N	A	N	A	N		A
	Subject 012	N	A	A	N	N	N	A	N	A	N	N	

Table 6. Peer Evaluation Results

Table 6 shows a summary of the peer evaluation results. Each subject's rating of his own performance was thrown out, as indicated by the diagonal row of blackened cells. It is interesting that each performance was almost unanimously evaluated as either acceptable (A), or not acceptable (N) by all of the other subjects independently. In fact, only the performances of Subject 2, Subject 5, and Subject 8 had other than unanimous evaluations. This seems to indicate that although there is subjectivity in evaluation of this task, the subject pool overall agrees as to where that subjective standard threshold exists. This is especially interesting considering the diverse backgrounds, service components, and mission profile of the subject pool.

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VI. CONCLUSIONS

By looking at the data provided by this experiment at face value, it appears that the ChrAVE does produce simulated NVG imagery that has adequate realism and image quality to have potential for use in NVG aviation training. Overall, eighty percent of the subjects considered the ChrAVE's representation of NVG imagery to be realistic. That same number of subjects indicated that the modeling of the visual noise associated with NVG imagery was modeled accurately. Bearing in mind that the subjects are SMEs with an average of 1506 total flight hours and 306 NVG flight hours, these statistics would seem to validate ChrAVE's NVG imagery as having potential for use in a training role. Continuing ChrAVE development as COTS technology continues to improve will likely make the NVG image quality even more realistic. In the two years since the ChrAVE prototype was built there have already been significant advances in the image quality (resolution) and available horizontal FOV of COTS HMDs alone, not to mention the improvements of COTS graphics cards and CPU chip speed that have exceeded Moore's Law. As the COTS components that contribute to the ChrAVE's capability improve, so should the degree of its viability as a NVG training device.

The navigation performances of the subject pool also seem to indicate that the ChrAVE has potential for use as an NVG training device. Although several of the subjects became disoriented very quickly, that is not out of line with what would likely happen in a real aircraft to pilots with such a long period of time since their last NVG terrain navigation flight. None of the subjects were able to maintain the average minimum acceptable distance from the intended route of flight of 458 meters, and yet peer evaluations of the subject pool show that the pool was amazingly consistent in their evaluations of acceptable and unacceptable performances. Given (as already stated) that there is a subjective shift in evaluation standards from day to NVG flight conditions, this may indicate that the subjects have also shifted their evaluation standards to account for the artificialities associated with the ChrAVE's current configuration. To some degree, this also validates the ChrAVE as a viable NVG training device because the peer evaluation results are so consistent.

Unfortunately, the large amount of variance and small sample size of the available subject pool used for this experiment makes drawing statistically significant conclusions based on their performances impossible. Similar research conducted with a subject pool containing less varied backgrounds, flight experience, and NVG experience may yield more statistically definitive data with which to answer the research questions posed in this thesis in a more quantitative manner.

VII. FUTURE WORK

There are several interesting and important research questions that were either untenable due to technological limitations in existence when the experiment was conducted, or simply beyond the scope of this thesis. The results of this thesis can accurately be described as a "stake in the ground" for NVG work in the ChrAVE. It will serve as a baseline for later studies and research. Even as this study was unfolding, there were several new ideas and different products released that may lead to additional research and progress in developing the ChrAVE as an NVG training device. This list of future research question only scratches the surface of the work yet to be done in this area, but will hopefully spur the next round of investigation and analysis on the ChrAVE's potential for NVG training.

One of the major complaints registered by subjects during debriefs was the difficulty they had adapting to viewing near objects through the head-mounted camera. When using actual NVGs in a real helicopter, pilots simply look under the image intensifier tubes with their unaided eyes into the dark cockpit to view near objects. They usually use supplemental lighting to illuminate unlit objects such as paper maps or kneeboard material. This supplemental lighting is normally a very small, NVG compatible light, such as a lip-light mounted to their flight helmet's microphone boom. The light is actuated by pressing against a small pressure sensitive switch. Viewing the instrument panel is also done by looking under the goggles, with the gauges and switches either backlit or otherwise illuminated by NVG compatible cockpit lighting. Some subjects had no problem adjusting their scanning techniques to viewing these objects through the camera; others felt it dominated their performance in a negative manner. At the time of this study, there was no viable method to create a dark cockpit that would allow a realistic 'look under' capability while still allowing adequate lighting of the blue chromakey material required for camera registration. Recently however, a product has been developed that will allow for back-lighting the chromakey material. Further research should be conducted into the viability and effects of using a backlit ChrAVE implementation that would allow pilots to use their normal scanning techniques to view objects inside the cockpit. This would remove one of the chief artificialities encountered by subjects, lending higher fidelity to the ChrAVE's NVG simulation capability as well as greater insight into its NVG training potential.

Another interesting area to investigate is the level of detail at which the ChrAVE's NVG imagery becomes inadequate--at what point does the NVG scene provided by COTS software and hardware become unacceptable or unrealistic? The virtual world used in this experiment was intentionally non-descript, containing only dessert terrain with no man-made items, vegetation, or other features. The intent was to create a baseline acceptable NVG imagery in order to prove initial viability of the ChrAVE as an NVG training device. Future work could use a more varied, interesting terrain database, or add additional objects such as vehicles, buildings, or vegetation to attempt to define the limitations of the ChrAVE's NVG imagery. Another way to try to define these limitations might be to vary the altitude in the virtual world. This experiment used a constant altitude of 200 feet above ground level. Tactical helicopter flight normally requires operating at much lower altitudes. Operating at lower virtual flight altitudes would create a need for greatly increased levels of detail in order to produce NVG imagery with fidelity, and it would be important to determine if an altitude threshold exists, beyond which the ChrAVE's NVG scene is unacceptable.

Preliminary work has now been done to show the ChrAVE's viability for both daytime and NVG flight conditions. A logical progression will eventually require testing of the ChrAVE against actual pilot performances in aircraft. If the resources can be coordinated, this would be the ultimate test for the ChrAVE, and could make great progress in answering many questions regarding the ChrAVE's potential as a training device.

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APPENDIX A. COGNITIVE TASK ANALYSIS FOR TACTICAL OVERLAND FLIGHT TO OBJECTIVE

COGNITIVE TASK ANALYSIS
FOR
TACTICAL OVERLAND FLIGHT TO OBJECTIVE

Version 1.1
2 December 2002

Prepared by:
The MOVES Institute, Naval Postgraduate School

INTRODUCTION

This document contains a cognitive task analysis (CTA) of rotary wing tactical overland flight to objective in support of the VEHELO implementation of VIRTE Demonstration 1. The intended use statement indicates that this is the general task that we wish to train as it fits inside more complex tasks such as Non-combatant Evacuation Operations (NEO), Combat Search and Rescue (CSAR), Tactical Recovery of Aircraft and Personnel (TRAP), Downed Aircrew Recovery Procedure (DARP), and Special Operations Insert/Extract (INFIL/EXFIL). The CTA has been encoded using a variant of conventional GOMS (Goals, Operators, Methods, and Selections) notation. There are also several cue inventories that are specific to certain points in the CTA where critical decisions are to be made.

The document is presented in four primary parts. We begin with a narrative description of a specific TRAP mission for context of the overall objectives of the training system. This is followed by a GOMS representation of a generic TRAP mission. This is a high level representation intended to give context to the underlying task of rotary wing tactical overland flight to objective. TRAP is only one of several mission profiles that fits the intended use of the VEHELO training system. Figure 1 illustrates how Tactical Overland Flight to Objective is a common element of several mission profiles which is in part, why it was selected as the training objective for VEHELO.

The third section is the high level task analysis indicating the fundamental high level task blocks that must be executed for successful task completion. The first part of this representation is a TRAP scenario showing how Tactical Overland Flight to Objective fits into the full mission profile. The second part is a high-level view isolating the navigation portion of the task. In both cases, these representations purposely eliminate detail in order to provide context for the final task analysis section.

The next section is the detailed CTA notation describing all goals and sub-goals inherent to the task. Where multiple methods may be used to accomplish a goal, a SELECT statement indicates what the choices are. To the left of the GOMS notation are comments describing the element or decision criteria. Lastly, critical decision points are further described in terms of a cue inventory which lists what cues are essential for the task and how those cues are used in the decision making process.

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Contributors

This document was prepared by a number of experienced rotary wing pilots. The TRAP analysis was completed by Captain Robert List, USMC. Captain List is a CH-46 pilot. The TRAP scenario was written by Major Mark Lennerton, USMC. Major Lennerton is a CH-53D pilot. The overland flight analysis was completed by Commander Joe Sullivan, USN. Commander Sullivan is an H-60 pilot. The night vision goggle extension of this document was written by Captain Del Beilstein, USA. Captain Beilstein is an OH-58D pilot. Rudy Darken encoded the GOMS notation and confirmed consistency of representation. He is not an experienced rotary wing pilot.

TACTICAL RECOVERY OF AIRCRAFT AND PERSONNEL MISSION SCENARIO DESCRIPTION

This section will describe in narrative form, what a TRAP mission entails in order to set context for the CTA to follow. The example is very simple and does not include contingencies as would likely be the case in an actual mission. We assume here that there is little to no enemy resistance so that we can focus on the elements of the TRAP. The scenario employs many possible features for such a training simulation system. The scenario refers in detail to the figure.

The key aspects of a TRAP mission include:

- Mission planning: This includes all intelligence briefings, weather and illumination forecast and analysis, map preparation, night vision goggle (NVG)

operational checks, and aircraft preparation. We assume in this document that standard mission planning tools such as N-PFPS or JMPS are available.

- Tactical Overland Flight: This is the in-flight task of moving overland to the objective area using available navigation tools such as map, aircraft gauges, clock, etc.
- Recon/TRAP team insertions: Assuming that the helicopter is unable to land in the immediate vicinity of the downed crew, it must insert the TRAP team nearby.
- Ground movement to friendly contact. After insertion, the ground-based TRAP team must then navigate overland on foot to the objective point.
- Authentication and recovery. On arriving at the objective point, the downed crew must authenticate itself to avoid placing the TRAP team in danger. Then the recovery can take place.
- Ground movement for extraction. The ground TRAP team must now move back to the landing zone for extraction.
- Employ CFF (call for fire) / CAS (close air support) to delay the enemy. If there is resistance or if the ground team needs to delay the enemy to allow for the extraction to take place, a CFF may be utilized.
- TRAP/Recon team extraction. The ground TRAP team and downed crew are recovered by the helicopter and are returned safely.

Background

A TRAP mission has been ordered as a result of a Marine Corps AH-1W Cobra crashing into the territory of a known enemy warlord. The Cobra traveled several miles after receiving small arms fire before being forced to ditch. The downed pilots[2] were able to communicate with the other aircraft in the flight, a UH-1N Huey. The Huey was unable to land or provide direct assistance due to the terrain. The crash site is located in a dense, triple canopy jungle. Visibility is extremely limited. It appears the Cobra came to rest in the trees. One pilot appears to have escaped with minor injuries while the other may have a broken back. There is no fire or smoke at the crash site.

The closest suitable landing zone (LZ) is approximately three nautical miles (NM) east of the crash site. Another LZ is approximately 8 NM southwest of the crash site. A suitable observation post exists four NM to the Northeast. Due to the density of the jungle and the enemy's present location to the north, the enemy is not expected to converge on the crash site for eighteen hours (This time estimate assumes the enemy knows the location of the crash site.).

Scheme of Maneuver

- A reconnaissance team will be inserted into LZ Falcon via landing or fast rope (as terrain/vegetation allows), move to OP Eagle and report any enemy movement or contact. In addition, the team will coordinate any close air support (CAS) as needed.
- The TRAP team will be inserted into LZ Falcon via landing or fast rope (as terrain/vegetation allows), move to the crash site, and extract the pilots.
- If a medevac is necessary, it shall occur at the crash site, via a jungle canopy penetrating hoist.

- The Sparrow Hawk team shall return to LZ Falcon for extraction via landing or SPIE rig. (special personnel insert/extract)
- The recon stay team shall return to LZ Falcon for extraction via landing or SPIE rig.

Reconnaissance team: 6 Pax—requires one CH-46E aircraft (Pax = passengers) TRAP team: 18 Pax—requires two CH-46E aircraft

Other aircraft required will be on 15 minute strip alert on ARG (amphibious readiness group) shipping and will include two sections of Harriers for CAS, one hoist capable SH-60 for medevac, and a section of AH-1W Cobras for both escort and CAS.

TACTICAL RECOVERY OF AIRCRAFT AND PERSONNEL COGNITIVE TASK ANALYSIS

Assumptions

- Analysis begins at walking to aircraft and ends when aircraft lands back aboard ship.
- Mission originates and terminates on shipping.
- Delayed, planned TRAP vice an immediate internal TRAP.
- Written from a CH-46E perspective.
- Helicopter flight consists of CH-46E assault helicopters and AH-1W attack helicopters.
- This is an aircrew recovery TRAP mission vice aircraft recovery.

Acronyms

ABCCC – Airborne Battlefield Command and Control Center
ISOPREP – Isolated Personnel Report
OSC – On Scene Commander
RADALT – Radar Altimeter
TACAN – Tactical Air Navigation
ALE – Expendable Countermeasures
APR – Radar Detector
ALQ – Infrared Countermeasures
LZ – Landing Zone
ITG – Initial Terminal Guidance

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Capt Joseph B. Woods, USMC, Instructor, Marine Aviation Weapons and Tactics Squadron One

GOAL: Execute-TRAP ; TRAP mission will be ordered

GOAL: Review-ISOPREP-data ; Isolated Personnel Report – used to authenticate the aircrew after they have been located

Review-ISOPREP

GOAL: Launch-aircraft

GOAL: Start-up
Execute-checklist
GOAL: Radio-checks
Uncovered ; check radios in plain (non-secure) mode
Covered ; check radios in secure (encrypted) mode

GOAL: Check-survivability-equipment
MODE-IV ; secure IFF (identification, friend or foe)
ALQ ; component of aircraft survivability equipment (ASE) – infrared jammer
APR ; component of ASE – missile radar detection device
ALE ; component of ASE – countermeasure dispensing system

GOAL: Meet-go/nogo-criteria
[SELECT: Continue-method
Call-troubleshooter-method
Go-to-backup-method]

GOAL: Verify-NVG-function-checks ; check image quality and proper focus, also check for no-go faults

[SELECT: Continue-method
Adjust-NVG-settings-method
Replace-NVG-method]

GOAL: Load-TRAP-team ; non-aircrew embark after rotor engagement and systems checks.

Load-team
Radio-for-clearance
Take-off

GOAL: Rendezvous ; aircraft in the same flight may not take off from adjacent spots on the ship
Linkup-flight

GOAL: Controlling-agency-check-in
Check-out-tower

Check-in-center
Check-in-air-defense
Check-in-ABCCC

GOAL: Inbound-routing
[SELECT: Primary-route-method
Alternate-route-method]

GOAL: Penetration-checks ; checks to ensure aircraft is configured for flight in hostile territory.

Testfire ; ensure weapons operative
Lights-off ; to avoid beaconing enemy
RADALT-off ; active source of radar energy
TACAN-receive-only ; active source of electromagnetic energy

ALQ-high-power
APR-on
ALE-armed

GOAL: Avoid-enemy-fire
Return-fire
Evade
Call-escorts
Call-combat-air-patrol

GOAL: Check-in-OSC
Radio-OSC

GOAL: Escorts-push-ahead
Escort-push

GOAL: Locate-aircrew
[SELECT: Radio-method
Visual-signal-method]

GOAL: Authenticate-aircrew ; ensure enemy is not spoofing calls as crew.

[SELECT: ISOPREP-method
Code-letter-method
Code-word-method

Code-color-method
Visual-signal-method]

GOAL: LZ-go/no-go-criteria
[SELECT: Go-method
No-go-method
[SELECT: Escorts-engage-method
All-for-reinforcement-method
Abort-method]]

GOAL: Assault-helo-inbound
Assault-IP-inbound

GOAL: Land-in-LZ
Find-LZ
Wind
ITG
[SELECT: Land-method
Wave-off-method]

GOAL: Recover-downed-crew ; based on the mobility of the crew being recovered and terrain, choose the most expedient method

[SELECT: Crew-mobile-&-location-known-method
Keep-TRAP-team-method
Board-aircrew-method
Crew-immobile-or-location-unknown-method
Deploy-TRAP-team
Launch-helos
Hold-in-holding-area
TRAP-team-contacts-crew
Helos-back-to-LZ
Board-team-&-crew]

GOAL: Depart-LZ
Launch-helos

GOAL: Outbound-routing
[SELECT: Primary-route-method
Alternate-route-method]

GOAL: Depenetration-checklist ; return aircraft configuration appropriate for flight in friendly territory

Secure-weapons
Lights-on
RADALT-on
TACAN-on
Secure-ALQ
Secure-APR
Secure-ALE

GOAL: Agency-radio-calls
ABCCC
Air-defense
Center
Tower

GOAL: Recover-aircraft
Coordinate-landing-with-tower
Land-aircraft

HIGH-LEVEL COGNITIVE TASK ANALYSIS OF ROTARY WING TACTICAL OVERLAND FLIGHT TO OBJECTIVE

This is the high-level representation only. Details of each component within this representation can be found in the following sections. Each of the primary sub-goals represented here: Complete-flight-planning-operations, Complete-pre-flight-operations, and Complete-in-flight-navigation-procedures is described in its own section to follow.

GOAL: Complete-rotary-wing-tactical-overland-flight-to-objective ; generic task description to include TRAP/CSAR/NEO/INFIL/EXFIL

GOAL: Complete-flight-planning-operations ; typically ready-room activities; navigation component of detailed mission planning, including time enroute, anticipated track and fuel required

GOAL: Acquire-navigation-materials ; often available digitally using JMPS

GOAL: Conduct-map-study
GOAL: Conduct-map-preparation ; annotate maps with route and timing information

GOAL: Conduct-NVG-pre-operational-checks ; using NVG operator's manual

GOAL: Complete-pre-flight-operations
GOAL: Configure-cockpit-for-navigation ; arrange maps and kneeboard checklist to facilitate rapid scan and effective navigation.
GOAL: Configure-aircraft-for-dual-ship- NVG-flight
GOAL: Conduct-preflight-navigation-system-initialization

GOAL: Complete-in-flight-navigation-procedures
GOAL: Navigate-to-initial-point
GOAL: Navigate-to-next-waypoint ; at each checkpoint, perform cockpit maintenance duties including a check of planned versus actual timelines.
GOAL: Maintain-orientation ; this is the basic default method, in absence of any higher priority task, PNAC attempts the best possible update of plotted position
GOAL: Adjust-speed-for-arrival-time
GOAL: Adjust-course-if-required
GOAL: Execute-Magellan-procedures ; procedures for lost aircraft, may involve mission abort
Repeat-until-complete

PLANNING PHASE COGNITIVE TASK ANALYSIS
Overland <TRAP/CSAR/NEO/INFIL/EXFIL> Mission

Assume the pilot has been given specific mission objectives and constraints to include aircraft configuration, crew load, area of operation, and mission support.

First primary objective is to complete the planning phase of the task. This involves acquiring maps, aerial photos, intelligence data, etc. that will be used for planning flight paths, spider routes, and assumed accuracy and location of assumed threats.

GOAL: Acquire-navigation-materials

SELECT: Map-study-method
Acquire-correct-map ; multiple scales if available
Aerial-photo-method
Acquire-aerial-photo
Satellite-photo-method
Acquire-satellite-photo
Combined-method ; preferred method assuming all are available
Acquire-all-available-assets ; either paper or JMPS

GOAL: Conduct-map-study

GOAL: Conduct-legend-study ; study the legend for all specifics to be used in next phase
Determine-horizontal-scale
Determine-elevation-scale
Determine-units ; in meters, feet. etc.
Calculate-conversion ; to bring into aircraft units
Determine-contour-interval
Determine-vegetation-types
Determine-cultural-features
Determine-populous-areas ; high intensity lighting makes NVG use difficult in vicinity of populous areas
Determine-magnetic-variation

GOAL: Conduct-detail-map-study ; pre-route planning activity
Locate-threats ; based on current intelligence (JMPS)
Plot-threats
Locate-area-of-interest ; e.g. landing zone
Plot-area-of-interest
Locate-current-flight-hazards ; e.g. power lines, (JMPS/ECHUM)
Plot-current-flight-hazards
Determine-SAFE-areas
Plot-SAFE-areas
Compute-threat-areas ; JMPS

GOAL: Analyze-threat-envelopes
Rotary-wing-threat-envelope
Fixed-wing-threat-envelope

GOAL: Analyze-terrain-features ; based on what is available
SELECT: Prominent-recognizable-checkpoints-method
Prominent-limiting-features-method
Prominent-guiding-features-method
Combination-method ; always the preferred method

GOAL: Analyze-NVG-flight-considerations ; if the mission will/could be flown under NVG conditions
Checkpoint-analysis ; ensure key features can be identified under NVG/low lighting conditions
Avoid-flying-directly-toward-light-sources ; use doglegs to avoid flying directly at high intensity lighting (i.e. cities, moon)
Analyze-moon-position-and-angle ; consider effects of shadows

GOAL: Select-navigation-points-for-primary-ingress-route ; navigation fixes (turn points along route) are selected from cue list
Calculate-distance-of-ingress-route
Calculate-time-of-ingress-route
Calculate-fuel-for-ingress-route

GOAL: Annotate-map-&-kneeboard-card
Anticipated-track
Anticipated-progress-interval-marks ;'tick' marks to be used in flight to judge progress along track; useful for estimating terrain features that should be in view at any particular time along route
User-specific-navigation-aids ;e.g. highlighting specific contour intervals
Doghouse-information ;for each leg, maps are normally annotated using a doghouse shaped box for each route leg. This information includes heading to next checkpoint, groundspeed,

fuel ladder information and time to next checkpoint,

GOAL: Select-navigation-points-for-secondary-ingress-route

Calculate-distance-of-ingress-route

Calculate-time-of-ingress-route

Calculate-fuel-for-ingress-route

GOAL: Annotate-map-&-kneeboard-card

Anticipated-track

Anticipated-progress-interval-marks

User-specific-navigation-aids

Doghouse-information

GOAL: Select-navigation-points-for-primary-egress-route

; egress route will normally be different from ingress route to minimize the likelihood the enemy forces alerted during ingress will have an opportunity to respond

Calculate-distance-of-egress-route

Calculate-time-of-egress-route

Calculate-fuel-for-egress-route

GOAL: Annotate-map-&-kneeboard-card

Anticipated-track

Anticipated-progress-interval-marks

User-specific-navigation-aids

Doghouse-information

GOAL: Select-navigation-points-for-secondary-egress-route

Calculate-distance-of-egress-route

Calculate-time-of-egress-route

Calculate-fuel-for-egress-route

GOAL: Annotate-map-&-kneeboard-card

Anticipated-track

Anticipated-progress-interval-marks

User-specific-navigation-aids

Doghouse-information

Calculate-mission-timeline ;mission timeline generally uses the longest anticipated ingress and egress routes, any loiter time, and time to complete mission (e.g. land and pick up troops.)

Calculate-total-fuel-required-for-mission

GOAL: Compare-required-fuel-with-maximum-gross-weight ;required fuel includes NATOPS, typewing, airwing and squadron mandated reserves

Adjust-mission-configuration ;if the mission requires more fuel than can be carried due to gross weight constraints, either the navigation route (and fuel requirements) must be reduced, or the aircraft configuration (ordnance and crew) must be adjusted.

GOAL: Account-for-fuel-in-route ;if the mission can not be completed with adequate fuel reserves the navigation route or mission requirements must be updated.

Adjust-navigation-route

Adjust-mission-configuration

GOAL: Prepare-in-flight-guides

GOAL: Prepare-kneeboard-cards ; possibly generated by JMPS

Prepare-communication-cards

Prepare-brevity-code-words

Prepare-strip-charts ; possibly generated by JMPS

GOAL: Prepare-annotated-maps

Load-data-points-in-tactical-navigation-computer-mission-data-loader ;PFPS has the capability of loading a set of waypoints directly into a Mission Data Loader

PRE-FLIGHT PREPARATION PHASE
(AIRCRAFT CONFIGURATION TO TAKE-OFF)
Overland <TRAP/CSAR/NEO/INFIL/EXFIL> Mission

Assume successful completion of planning phase tasks and all associated objectives. Second primary objective is to prepare the cockpit for the actual flight. This begins with the pre-flight preparation, and concludes with the aircraft in the air beginning the overland navigation component.

GOAL: Configure-cockpit-for-navigation	; required inflight reference material (maps and kneeboard cards) must be readily accessible
Configure-maps	; e.g. fold correctly
Configure-kneeboard-cards	
GOAL: Configure-aircraft-for-dual-ship-NVG-flight	
Check-external-lighting	
Attach-chem-lights-to-aircraft	; aircraft not configured with external NVG compatible lighting may use chem lights
GOAL: Conduct-preflight-navigation-system-initialization	
GOAL: Conduct-preflight-checks	
Check-navigation-computer	
Check-GPS	
Check-TACAN	; Tactical Air Navigation
Check-Doppler	; Inertial navigation system
Check-INS	
Check-RADALT	; Radar altimeter
Check-transponder	
Check-search-light	; for NVG
Check-cockpit-lighting	; for NVG
Check-compass-system	
Load-waypoints-in-navigation-computer	
Select-waypoints-to-create-primary-ingress-route	
Select-waypoints-to-create-secondary-ingress-route	
Enter-magnetic-variation-information-in-tactical-navigation-computer	

GOAL: Conduct-final-NVG-function-check ; verify adequate image quality and proper focus

GOAL: Conduct-post-takeoff-systems-checks
- Verify-navigation-equipment-operational ; from list above. Additionally, verify and align compass systems.
- Conduct-navigation-to-initial-point
  - Identify-ingress-point-on-map
  - Identify-feature-to-aid-identifying-initial-point ; a nearby prominent landmark
  - Scan-field-of-view-for-navigation-aid
  - Locate-navigation-aid
  - Positively-identify-initial-point
  - Estimate-arrival-time-at-initial-point
  - Adjust-speed-to-arrive-at-ingress-point-on-time
  - Adjust-course-to-overfly-initial-point
  - Adjust-speed-to-arrive-at-ingress-point-according-to-timeline
  - Use-visual-aids-to-identify-ingress-point
  - Verify-ingress-point-with-cockpit-navigation-aids
- Select-waypoint-from-tactical-navigation-computer
- Execute-navigate-to-next-waypoint

EXECUTION PHASE
(IN-FLIGHT EXECUTION OF ROUTE)
Overland <TRAP/CSAR/NEO/INFIL/EXFIL> Mission

Assume successful completion of all preceding tasks and associated objectives. The last primary objective is the actual in-flight navigation component. Because we make no assumptions as to the length and duration of the flight, nor do we assume anything about the terrain in question, we assume a simple repeated procedure for each pre-planned leg of the flight. For each leg, the navigating pilot will conduct a number of sub-tasks involving orientation to the environment and self-location. Communication to the PAC (pilot-at-controls) is included. If disorientation occurs (or even if it is believed to have occurred), the sub-goal Execute-Magellan-procedure is entered which involves re-orienting and getting back on route.

GOAL: Navigate-to-next-waypoint
- Start-leg-timing

GOAL: Direct-flying-pilot-to-predetermined-heading ;the method is selected based on time available and visual cues present. If there are fewer non-ambiguous landmark features in view, one of the more time consuming methods may be required. Additionally, if the PNAC cannot quickly identify and communicate a unique landmark feature, a more time consuming method may be required.

SELECT: Use-landmark-method ;e.g 'saddle to the right of the peak at your two o'clock'. This method has the advantage that it allows the flying pilot flexibility on *how* to get to the specified location. The flying pilot can proceed at his discretion with little further assistance; thus providing the pilot not at controls (PNAC) more time to devote to comparing terrain features to map representation.

Identify-discernable-feature

Direct-PAC-to-feature ; PAC=Pilot at controls

Use-clock-position-method ;turns are relayed to the PAC using clock position calls (rather than heading) to minimize the inside scan requirements of the flying pilot.

Specify-heading-by-clock-position ;this method places higher demand on the PNAC than the landmark method. After the initial turn, the PNAC will need to update the PAC quickly. It gives the flying pilot little flexibility in controlling the route of flight.

Using-turn-&-rollout-calls-method ;this is the most demanding method for the non-flying pilot since in general it demands complete attention for the duration of the turn. Additionally, the information it provides to the PAC has the shortest duration. The PAC will require further guidance quickly.

Specify-series-of-specific-actions

Adjust-navigation-needle-to-new-course ;the navigation needle is often used to provide both pilots a backup of the intended heading between fixes.

Check-timing ;at each checkpoint, the PAC should compare the anticipated time enroute with the actual time enroute

Record-deviation-in-timing

GOAL: Adjust-timing

SELECT: Late-arrival-method ; i.e. time has passed and you're not there yet

SELECT: Low-confidence-in-navigation-solution-method

Defer-adjusting-speed ; you might be lost

High-confidence-in-navigation-solution-method

Estimate-initial-increment-in-speed-required ; fix timing and proceed

Direct-PAC-to-adjust-IAS ; IAS Indicated Airspeed

Early-arrival-method ; already over checkpoint before specified time

Estimate-initial-decrement-in-speed-required

Direct-PAC-to-adjust-IAS

Verify-PAC-proceeding-correctly ;after directing a change in speed, the PNAC needs to follow up to ensure the correct change has been applied

GOAL: Check-ground-speed

Scan-cockpit-gauges

SELECT: No-Correction-Method

No-action-required

Correction-method

Direct-PAC-to-adjust-speed

GOAL: Check-on-track-progress ; actual vs. planned

SELECT: Within-limits-method

No-action-required

Outside-limits-method

Estimate-required-change-in-ground-speed-(delta-GS) ; to minimize inside scan requirements, the PNAC directs the PAC using indicated airspeed. The calculations for adjusting timing are based on ground speed.

GOAL: Calculate-new-IAS
Scan-current-IAS
Add-delta-GS-as-to-IAS
Direct-PAC-to-new-adjusted-speed

GOAL: Verify-heading-is-correct ;this is a two-part correction. The PNAC estimates (or, if available, scans cockpit instrumentation to acquire) the heading required to maintain track. The PNAC must first determine if the PAC is flying the intended heading, and then verify that the resultant track is correct.
Scan-gauges
SELECT: On-heading-method
No-action-required
Off-heading-method

GOAL: Correct-heading
Direct-PAC-turn
SELECT: Use-landmark-method ;refer to previous discussion concerning preferred method and resultant PNAC workload.
Identify-discernable-feature
Direct-PAC-to-feature
Use-clock-position-method
Specify-heading-by-clock-position
Using-turn-&-rollout-calls-method
Specify-series-of-specific-actions

GOAL: Verify-track-is-correct
Scan-gauges
SELECT: On-track-method
No-action-required
Off-track-method

GOAL: Correct-heading

Direct-PAC-turn

SELECT: Use-landmark-method

Identify-discernable-feature

Direct-PAC-to-feature

Use-clock-position-method

Specify-heading-by-clock-position

Using-turn-&-rollout-calls-method

Specify-series-of-specific-actions

GOAL: Determine-aircraft-position

Scan-heading-&-track

Align-map-with-aircraft-track

Analyze-terrain-within-field-of-view

SELECT: salient-navigation-cues-in-view-method ;see cue list for details on 'salient' cues

GOAL: Match-navigation-feature-with-map-representation

Estimate-map-representation-of-salient-navigation-cues

Compare-estimated-map-representation-of-features-in-view-with-map

Locate-potential-match-on-map

Compare-map-with-feature-to-verify ;this may involve scanning from world to map multiple times. If feature goes out of view, procedures starts over with determine-aircraft-position

SELECT: positive-match-method

Estimate-distance-&-bearing-to-feature

Estimate-position-on-map-based-on-distance-&-bearing-to-feature

Update-position-on-map

Ambiguous-match-method

Analyze-terrain-for- ;a possibly ambiguous feature that

correlating-feature because of it's spatial relationship with other features may be used to definitively locate aircraft position

SELECT: possible-correlating-feature-in-view-method

Estimate-map-representation-of-correlating-feature

Compare-estimated-representation-of-feature-with-map

Compare-map-with-feature-to-verify

SELECT: positive-match-of-correlating-feature-method

Estimate-distance-&-bearing-to-feature

Estimate-position-on-map-based-on-distance-&-bearing-to-feature

Update-position-on-map

No-positive-match-of-correlating-feature-method

Fly-time-distance-heading

Update-aircraft-position-on-map-based-on-time-distance-heading

Continue-analyzing-and-comparing-until-found-or-lost

No-possible-correlating-feature-in-view-method

Fly-time-distance-heading

Update-aircraft-position-on-map-based-on-time-distance-heading

Continue-analyzing-and-comparing-until-found-or-lost

Candidate-feature-positively-classified-as-misidentified ;based on further analysis, the feature selected from field of view is determined NOT to be the feature originally

selected on the map

GOAL: determine-if-any-positive-match-can-be-made ;one of three cases will apply:

SELECT: feature-on-map-identified-elsewhere-in-field-of-view-method

Estimate-distance-&-bearing-to-feature

Estimate-position-on-map-based-on-distance-&-bearing-to-feature

Update-position-on-map

Feature-in-field-of-view-positively-identified-elsewhere-on-map-method

Estimate-distance-&-bearing-to-feature

Estimate-position-on-map-based-on-distance-&-bearing-to-feature

Update-position-on-map

No-match-found

Fly-time-distance-heading

Update-aircraft-position-on-map-based-on-time-distance-heading

Continue-analyzing-and-comparing-until-found-or-lost

GOAL: determine-if-lost

Update-expected-position-on-map-using-time-distance-heading

Align-map-with-aircraft-track

Analyze-map-for-prominent-feature-within-expected-field-of-view

Analyze-terrain-for-possible-match-with-prominent-feature

SELECT: match-found-method

Estimate-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
Plot-current-position
Determine-navigation-correction-required
SELECT: major-deviation-method
Determine-new-course-to-route
Treat-current-position-as-new-waypoint
Execute-navigate-to-waypoint
Minor-deviation-method
Execute-correct-track-error
No-match-found-method
Query-crew-for-salient-cues
SELECT: no-cue-provided-method
Execute-Magellan-procedure
Cue-provided-method
Query-crew-for-description-of-cue
SELECT: match-found-method
Query-crew-for-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
No-match-found-method
Execute-

Magellan-procedure
Query-wingman-for-salient-cues
SELECT: no-cue-provided-method
Execute-Magellan-procedure
Cue-provided-method
Query-wingman-for-description-of-cue
SELECT: match-found-method
Query-wingman-for-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
No-match-found-method
Execute-Magellan-procedure
Maintain-orientation

GOAL: Scan-for-next-navigation-point ; see cue inventory
SELECT: Follow-hand-rail-method ; usually a linear terrain feature
Positively-identify-hand-rail-feature
Direct-PAC-to-follow-hand-rail
GOAL: Update-on-track-progress
Select-on-track-landmark
Evaluate-track-deviation
Visible-intermediate-navigation-point-method ; only if you see the point
Direct-PAC-to-navigation-point
Verify-PAC-proceeding-to-correct-feature
SELECT: PAC-proceeding-to-correct-feature-method
Continue-to-navigation-point
PAC-not-proceeding-to-correct-

feature-method

Inform-PAC

Direct-PAC-to-correct-navigation-point

Continue-to-navigation-point

Proceed-through-ambiguous-area-method ; no useful immediate cues, so fly on until this changes

Update-expected-position-on-map-using-time-distance-heading

Align-map-with-aircraft-track

Analyze-map-for-prominent-feature-within-expected-field-of-view

Analyze-terrain-for-possible-match-with-prominent-feature

Continue-until-match-found-or-lost

Time-distance-heading-method ; always available, use dead-reckoning. PAC responsible for maintaining mean track, subject to error.

Update-expected-position-on-map-using-time-distance-heading

Align-map-with-aircraft-track

Analyze-map-for-prominent-feature-within-expected-field-of-view

Analyze-terrain-for-possible-match-with-prominent-feature

Continue-until-match-found-or-lost

Execute-determine-accurate-current-location-steps ; essentially, 'determine-accurate-current-location' becomes a default action

Update-current-position-mark-on-map ; successful outcome of 'determine-accurate-current-location' is new position mark on map

Check-time-enroute

Compare-time-en-route-with-progress-tick-mark-on-map

Compare-position-on-map-with-plotted-track

Estimate-horizontal-deviation ; locate yourself on the map and mark it

Estimate-impact-on-navigation-and-timing

Estimate-impact-on-exposure

SELECT: Course-correction-required-method

GOAL: Correct-heading
Direct-PAC-turn
SELECT: Use-landmark-method
Identify-discernable-feature
Direct-PAC-to-feature
Use-clock-position-method
Specify-heading-by-clock-position
Using-turn-&-rollout-calls-method
Specify-series-of-specific-actions
Speed-correction-required-method
Direct-PAC-to-adjust-speed

GOAL: Execute-Magellan-procedures ;the option to select will depend on following factors:
Analyze-current-terrain-for-threat ;how close are enemy forces presumed to be and what is the level of confidence in troop location information
Analyze-current-terrain-for-exposure ;if it is possible to climb without increasing exposure, increased altitude will afford more opportunity to find recognizable landmark
Analyze-current-terrain-for-signature ;hovering may not be an option if based on power required and fuel constraints signature will beacon enemy.
Analyze-timing-for-ahead
Analyze-timing-for-behind
Analyze-fuel-on-board-compared-to-estimated-fuel-required ;if fuel is near limits, landing will use less fuel. Since this will likely reduce terrain features in view, landing is only practical if help is available
Analyze-degree-of-confidence
Analyze-potential-assistance-with-navigation ;is RESCORT/RESCAP available to help
SELECT: Confess-method
SELECT: Wingman-method ; if wingman is available, is he disoriented also?
Initiate-radio-call
RESCORT/RESCAP-method
Initiate-radio-call
Orbit-method
Provide-orienting-feature-for-PAC

Attempt-to-match-terrain-feature-with-map-representation
SELECT: feature-recognized-method
Estimate-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
Plot-current-position
Determine-navigation-correction-required
SELECT: major-deviation-method
Determine-new-course-to-route
Treat-current-position-as-new-waypoint
Execute-navigate-to-waypoint
Minor-deviation-method
Execute-correct-track-error
No-feature-recognized-method
Attempt-to-recognize-prominent-feature
Continue-until-abort-criteria-met-or-match-found
NOE-method
Provide-area-for-NOE-to-PAC
Attempt-to-match-terrain-feature-with-map-representation
SELECT: feature-recognized-method
Estimate-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
Plot-current-position
Determine-navigation-correction-required
SELECT: major-deviation-method
Determine-new-course-to-route
Treat-current-position-as-new-waypoint
Execute-navigate-to-waypoint
Minor-deviation-method

Execute-correct-track-error
No-feature-recognized-method
Attempt-to-recognize-prominent-feature
Continue-until-abort-criteria-met-or-match-found
Hover-method
Provide-direction-to-hover-area-to-PAC
Attempt-to-match-terrain-feature-with-map-representation
SELECT: feature-recognized-method
Estimate-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
Plot-current-position
Determine-navigation-correction-required
SELECT: major-deviation-method
Determine-new-course-to-route
Treat-current-position-as-new-waypoint
Execute-navigate-to-waypoint
Minor-deviation-method
Execute-correct-track-error
No-feature-recognized-method
Attempt-to-recognize-prominent-feature
Continue-until-abort-criteria-met-or-match-found
Land-method
Determine-appropriate-LZ ;see cue chart for LZ evaluation criteria
Direct-PAC-to-LZ
Attempt-to-match-terrain-feature-with-map-representation
SELECT: feature-recognized-method
Estimate-distance-&-bearing-to-feature
Estimate-position-on-map-based-

on-distance-&-bearing-to-feature
Update-position-on-map
Plot-current-position
Determine-navigation-correction-required
SELECT: major-deviation-method
Determine-new-course-to-route
Treat-current-position-as-new-waypoint
Execute-navigate-to-waypoint
Minor-deviation-method
Execute-correct-track-error
No-feature-recognized-method
Attempt-to-recognize-prominent-feature
Continue-until-abort-criteria-met-or-match-found
Climb-method ; nap of the Earth
Direct-PAC-to-new-altitude
Attempt-to-match-terrain-feature-with-map-representation
SELECT: feature-recognized-method
Estimate-distance-&-bearing-to-feature
Estimate-position-on-map-based-on-distance-&-bearing-to-feature
Update-position-on-map
Plot-current-position
Determine-navigation-correction-required
SELECT: major-deviation-method
Determine-new-course-to-route
Treat-current-position-as-new-waypoint
Execute-navigate-to-waypoint
Minor-deviation-method
Execute-correct-track-error
No-feature-recognized-method
Attempt-to-recognize-prominent-feature
Continue-until-abort-criteria-met

CUE INVENTORIES

Environmental Cues

Identify unique features to correlate expected position with actual position -- scan outside, query crew. These are used in a repeated fashion throughout the flight, but are particularly triggered in re-orienting and map-correlation sub-tasks.

CUE	DESCRIPTION
Unique, distinguishable terrain feature based on three-dimensional shape and orientation. (Three dimensional shape infers use of altitude as correlating feature.)	A key characteristic of a terrain feature to be used as a navigation checkpoint is that it is uniquely identifiable. Navigation routes are planned such that, when practical, such a terrain feature is always in view.
Unique, distinguishable cultural feature	Cultural features are considered secondary navigation aids. Flying in close proximity to cultural features generally increases the exposure to enemy forces. Distant cultural features visible from long ranges and low altitudes (i.e. poles for power lines, water towers) are more commonly used than terrain features that would be associated with dense population areas (towns, highways and rivers.) The accuracy of depicted cultural features often relates to the likelihood of exposure to enemy forces. (Compare jeep trails with hardball roads.)
Distinguishable location based on relation and orientation of two or more non-distinct terrain features	If a single unique terrain feature cannot be selected, position may be determined by using the spatial relationship (distance and orientation) of more than one non-distinct terrain feature. This is considered a lower priority since it relies on keeping multiple features within the field of view (or coordinating with crewmembers.) Given cockpit visibility constraints, usually the time when multiple features are in view will be considerably less than the time a single feature is in view.
Any discernible difference of terrain along selected navigation route from surrounding terrain	In areas with little terrain relief, navigation may rely on subtle variations in the terrain selected for the navigation route. For example in desert terrain, it may be appropriate to navigate along a dry creek bed or wash.

CUE	DESCRIPTION
Any charted and discernible difference of vegetation along selected navigation route.	Lacking other navigational cues, vegetation can sometimes be used as a cue. For example, in areas with little terrain relief but ample coverage by vegetation, waterways will often be visible based on the difference in vegetation along the waterway.

Cockpit Cues

These are cues specific to inside the cockpit to include gauges and controls.

CUE	DESCRIPTION
Altitude above mean sea level (MSL) – barometric altitude	Elevation of terrain features is used as an identifying characteristic. Current altitude must be known to do this. Additionally, pilots will need to judge height of terrain relative to aircraft. (I.e. peak at aircraft ten o'clock is 200 feet above aircraft. Aircraft is at 1400' MSL. Peak is approximately 1600' MSL.)
Altitude above ground level altitude (AGL) – radar altitude.	Pilot will use current altitude to judge distance to objects.
Heading	Magnetic heading, also depending on the aircraft, true heading information may be available. Aircraft may also have a selectable navigation marker ('bug') that can be dialed to heading to fly. If the aircraft is equipped with a navigation computer a needle pointing to the next selected waypoint may also be available.
Track	If available in the aircraft, a track needle should be available to verify aircraft is on correct heading to maintain planned track.
Clock	Used to track total time enroute as well as individual navigation leg timing. Essential for time/distance/heading mode.
Ground speed	Required for PNAC to calculate maintenance of and correction to timeline.
Indicated airspeed (IAS)	Primary scan for PAC. Required for PAC to maintain airspeed to aid time/distance/heading calculations.
Attitude indicator	Improve situational awareness and facilitates rapid scanning for PNAC. For example, PNAC can initiate a turn and then track progress of turn while checking cockpit gauges or map.

CUE	DESCRIPTION
Current fuel onboard	If too much fuel is used on route or expected delay times are exceeded, the navigation route may need to be changed. Additionally, the procedures to follow if pilot is lost depend on fuel.
Turn rate	Useful for judging time required to complete a turn.

Landing Zone Cues

These are cues specific to a landing zone. These should be considered in addition to the Environmental Cues listed earlier.

CUE	DESCRIPTION
Size	Pilot must be able to determine if aircraft will be able to safely land and takeoff
Slope	Pilot must be able to determine (or approximate) if the slope of the terrain is within aircraft landing limits.
Suitability	Factors such as muddy or badly rutted landing areas and foreign object damage (FOD) hazards may make landing impractical.
Wind	Pilot must be able to determine wind direction. This can be done with cockpit instrumentation (comparing airspeed and groundspeed) or visual aids (direction of dust and smoke, movement of vegetation). Pilot must also be able to judge the effect of surrounding obstacles on wind (turbulence and loss of effect.)
Escape routes	Pilots must judge if an approach and departure path based on current winds can be safely executed with an acceptable margin of error and preserving a waveoff capability.
Elevation	Pressure and density altitude are required to determine if adequate power margin exists to safely conduct and approach, landing and takeoff after troop embarkation.

NVG Considerations

It is significantly more difficult to conduct the Tactical Overland Flight to Objective task while wearing NVGs than during daytime conditions. This is due to the inherent limitations and characteristics of the NVGs.

Characteristic/Limitation	DESCRIPTION
Limited Field of View	The limited fields of view provided by NVGs require pilots to continuously scan in order to get the visual cues necessary to determine self-location and relative motion.
Reduced Visual Acuity	The reduced visual acuity pilots get from NVGs makes identification of key features much more difficult.
Monocular Vision	The most important effect of monocular vision is the loss of motion parallax, which makes the determination of relative motion difficult. Monocular vision also makes it more difficult to determine the size, shape and depth of objects.
Weight of NVGs	The physical weight of the NVGs causes a degree of fatigue, which can make pilots less effective.
Shift of Focus	Pilots fly with their NVGs manually adjusted to an infinite focal point. This means they must look under the lenses of the NVGs in order to see maps, kneeboards, or aircraft instruments including the compass.
Loss of Detail/Texture	The image displayed by the NVGs offers less visual acuity (40/20 best case) than unaided viewing. This can make terrain feature recognition challenging.

APPENDIX B. QUESTIONNAIRE

***Please read first*:** The following experiment and questionnaire are completely confidential. Nothing you do or answer will be related back to you in any manner. Thank you for your assistance. Please begin below the solid line and hand to the proctor when you reach "Stop Here". You may ask questions at any time.

Subject Number _____ (proctor use only)

Preliminary questions:

1. Do you have any history of epilepsy? Yes / No

2. Are you prone to simulator sickness? Yes / No

3. Do you require corrective lenses? Yes / No

4. What is your vision uncorrected?

5. Do you have any other history of eye disease or injury?

6. How often do you use a computer on a daily basis? (Check one.)
   ❍ 0-2 hours ❍ 2-4 hours ❍ 4-6 hours ❍ 6-8 hours ❍ greater than 8 hours

7. Have you ever used virtual environment for training or entertainment? Yes / No

8. If yes, did you use a head-mounted display (HMD)? Yes / No

9. As a designated aviator, how would you rate your low level helicopter navigational skills? (Check one.)
   ❍ novice ❍ average ❍ advanced ❍ navigation instructor ❍ expert

10. List all type, model, series aircraft you are or have you been qualified to fly. (Disregard flight school aircraft unless you were a flight school instructor.)

_____
_____
_____
_____

11. About how many hours of flight time do you currently have? _____

12. About how many hours of night vision goggle (NVG) flight time do you currently have?
    _____

13. What is the date of your last NVG flight (month and year)?_____

14. When was your last low level helicopter navigation map preparation?
    Month _____ Year _____

15. When was your last low level helicopter navigation map flight?
Month _____ Year _____

16. During low level helicopter navigation do you normally use a hand held paper map (standard military 1:50,000)? Yes / No

17. Are you familiar with Fort Irwin area depicted on the map issued to you for this experiment? Yes / No

If yes:
Have you ever flown in the area? Yes / No

The following questions ask your opinion of acceptable criteria for low-level navigation as it pertains to the terrain of the Fort Irwin area during non-tactical flight. You may refer to your map at any time.

18. Being within _____ meters of the intended route of flight is the threshold for acceptable and substandard navigational performance.
❍100 ❍200 ❍300 ❍400 ❍500 ❍600 ❍700 ❍800 ❍900 ❍1000 ❍More

19. Being within _____ meters of the intended checkpoints is the threshold for acceptable and substandard navigational performance.
❍100 ❍200 ❍300 ❍400 ❍500 ❍600 ❍700 ❍800 ❍900 ❍1000 ❍More

20. During flight between checkpoints it is acceptable for the route of flight accuracy threshold to decrease.
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

21. Number the following in order of importance:

_____ Maintaining the route of flight
_____ Accurately knowing your present location (plotting to 8 digit grid accuracy)
_____ Accurately hitting your checkpoints
_____ Being off the intended route of flight and intending to intercept at the next check point
_____ Knowing your location by reference to a dominant terrain feature (plotting to 4 digit grid accuracy)
_____ Seeing your checkpoints, but not hitting them
_____ Being off the intended route of flight but working towards it.

22. Evaluation task:
You will be provided numerous map slides of the Fort Irwin area. The green path is the intended route of flight. Green circles are intended checkpoints. The black or red path is a recorded navigational performance; in other words, the black or red path defines where the pilot actually flew. The black or red circles indicate where the subject identified the checkpoint. (Note that subjects not on the intended route of

flight can still correctly identify a checkpoint, and that subjects on the intended route of flight can mis-identify a checkpoint.) It is your task to rank order these slides in terms of best navigation performance (the best performance would receive a rank of 1) to worst navigation performance (the worst performance would receive a rank of 15). Consider these plots to represent daytime, low level (200ft AGL) flights under excellent weather conditions.

BEST<----------->WORST

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Slide Letter															

23. Refer to your rank ordering from the last question. What do you consider the threshold between acceptable and substandard performance? On the evaluation table, circle the slide representing the minimum acceptable navigation performance. In other words, all slides ranked to the right of your circled slide represent performances that you find to be substandard.

24. Now consider that the same slides represent flights flown using NVGs, with identical weather conditions as the day flights, with 50-80% illumination, and 60 degree moon angle. Referring to your rank ordering from the last question, what do you consider the threshold between acceptable and substandard performance given that these were NVG flights? On the evaluation table from #22, put an X immediately under the slide representing the minimum acceptable navigation performance.

The Goal:
To become sufficiently familiar with the terrain in the Ft Irwin area so as to successfully navigate as much of the route of flight as possible in twenty minutes, under simulated NVG conditions, by providing voice navigational commands while using the Chromakeyed Augmented Virtual Environment (ChrAVE) system.

Your Resources:
-2 satellite images
- an image of the Fort Irwin area
- an image concentrated on and depicting the general route of flight

-A 1:50,000 map of the Ft Irwin area (you may write on the map)
-A kneeboard route card (you may write on the route cards)
-A set of map pens
-A collection of rulers, protractors, and stencils
-Two knee boards to use during the flying portion of the experiment
-A clock for timing (you may want to become familiar with its operation)

The Tasks:

Prepare the map: Utilizing the information on the kneeboard route cards and the other resources prepare the 1:50,000 map. You will be relying on this map during the virtual flight portion of the experiment. This will be a non-tactical flight; the emphasis is on terrain association and navigation. Prepare your map as though your flight will be conducted at night with NVGs. Take note of key terrain such as checking features, channeling features, and limiting features (boundaries). When you are comfortable with your preparation inform the proctor.

Maintain awareness of your location: You will be required to plot your direction and position on the map on demand (approximately every two minutes). **Place an arrow (↑) to represent your direction; the point of the arrow shall represent your position.** The proctor will call out a number for you to place by the arrow. You will be able to refer to the map, instrument panel, the timing clock, and the virtual world during the flight. Remember your view to the left will be limited to the edge of the blue screen. It will be important to associate terrain on the map with the terrain in the virtual world in order to maintain your position. Some (not all) roads are identifiable in the virtual environment. As a rule of thumb, roads and other manmade features clearly identifiable in the satellite imagery are identifiable in the virtual environment. If you are lost, you may instruct the pilot at the controls to orbit in order to regain your orientation. There will be a three minute familiarization flight. During this flight it will be important that you become familiar with giving voice commands, determine the time required to roll into and out of turns, and get used to the settings and imagery of the HMD. When you are comfortable with these factors, the proctor will reset the ChrAVE to the starting position and you will be asked to navigate as much of the route as possible in the time allotted (twenty minutes).

Monitor the radios: There will be radio chatter in the Fort Irwin area. Your aircraft's call-sign is "Ugly one-two". You are required to answer radio calls only to your aircraft by pressing the button on the cyclic and saying "Ugly one-two, roger." Disregard all other chatter. You may ask the proctor to adjust the volume for you.

Direct the pilot at the controls: During the flight portion of the experiment you will direct the flight of your aircraft by giving appropriate voice commands to the pilot at the controls (the proctor). Directional voice commands are restricted to:

"Left turn" / "Right turn" – These commands start a standard rate turn.

"Easy left turn" / "Easy right turn" – These commands start a half standard rate turn.

"Stop turn" – This command levels the wings.

O'clock position calls – These commands start a standard rate turn followed by and automatic rollout. Turns to 6 o'clock will be right hand turns unless "**Turn left to 6 o'clock**" is requested. A turn to one o'clock means a heading change of 30 degrees, two o'clock means a heading change of 60 degrees, etc.

"**Orbit left**" / "**Orbit right**" – These command should be used only when attempting to reestablish your orientation. These commands will initiate a standard rate turn that maintains altitude (climbs will be initiated only to avoid terrain). Remember a full turn of 360 degrees will take two minutes.

If there is any type of problem, the terms "**Game over**" or "**Pause game**" will pause the flight.

Maintain situational awareness: There may be other activity in the Fort Irwin area while you are navigating. Simply call the traffic or activity to the rest of your flight crew when you see it.

Cockpit management: Practice effective cockpit management skills. Remember this trainer will be unfamiliar to you. Plan your map folding adjustments during long straight stretches of flight. Organize necessary resources within your reach. Ensure you have adjusted the HMD settings optimally for visual presentation as well as physical comfort.

Flight parameters:

Your aircraft is a 'generic' helicopter.

You will be flying at 90 knots on a windless day. Airspeed equals groundspeed.
- -In one minute of flight at 90 knots your aircraft will travel 1.5 NM or 2.778 KM.
- -In two minutes of flight at 90 knots your aircraft will travel 3.0 NM or 5.556 KM.

The pilot at the controls will 'visually' maintain about 200 feet AGL. However if orbiting he will maintain 200 feet above the highest object in the orbit path.

Remember to lead your roll out calls; it takes longer to roll out from a standard rate turn than a half standard rate turn.

Do you have any questions?

Stop here.

Notify the proctor.

(proctor use only)

Un-Hooded Tests: Ensure the subject knows how to use the clock.

Check for history of epilepsy or proneness to simulator sickness

Eye Test:
Line:_____ Number correct:_____

Color Identification Test:

Blue:	Pass / Fail
Red:	Pass / Fail
Green:	Pass / Fail
Orange:	Pass / Fail
Purple:	Pass / Fail
Black:	Pass / Fail

Color Identification Test:
48 67 38 92 70
95 26 2 74 62

Subject was hooded at time _____.

Provide instructions on HMD adjustments and a warning on twisting the inertial tracker.

Flight Portion:
Set up:
Ensure ChrAVE is set up per NVG Experiment Instructions.

Radio Calls:

1st call:	❍Correctly heard & acknowledged
	❍Not acknowledged
	❍Acknowledged call for others
2nd call:	❍Correctly heard & acknowledged
	❍Not acknowledged
	❍Acknowledged call for others
3rd call:	❍Correctly heard & acknowledged
	❍Not acknowledged
	❍Acknowledged call for others
4th call:	❍Correctly heard & acknowledged
	❍Not acknowledged
	❍Acknowledged call for others
5th call:	❍Correctly heard & acknowledged
	❍Not acknowledged
	❍Acknowledged call for others

Other comments:
Head movements: Subtle / Moderate / Rapid
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

6th call:	❍Correctly heard & acknowledged	_____
	❍Not acknowledged	_____
	❍Acknowledged call for others	_____
7th call:	❍Correctly heard & acknowledged	_____
	❍Not acknowledged	_____
	❍Acknowledged call for others	_____
8th call:	❍Correctly heard & acknowledged	_____
	❍Not acknowledged	_____
	❍Acknowledged call for others	_____
9th call:	❍Correctly heard & acknowledged	_____
	❍Not acknowledged	_____
	❍Acknowledged call for others	_____
10th call:	❍Correctly heard & acknowledged	_____
	❍Not acknowledged	_____
	❍Acknowledged call for others	_____

Hooded Tests:

Eye Test:

Line:_____ Number correct:_____

Color Identification Test:

Blue:	Pass / Fail
Red:	Pass / Fail
Green:	Pass / Fail
Orange:	Pass / Fail
Purple:	Pass / Fail
Black:	Pass / Fail

Color Identification Test:

48 67 38 92 70

95 26 2 74 62

Subject was unhooded at time_____.

Total HMD exposure: _____.

Ask the subject if he/she had to adjust to the real world when the HMD came off?

Yes / No

Post-flight Questions:

ChrAVE Performance

(Select the appropriate response following each statement.)

25. NVG navigation in the ChrAVE resembled the actual task of NVG navigation.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

26. The ChrAVE performs as well as visual simulators I have used in the past with regard to the visual presentation of an NVG scene.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

27. The NVG scene presented during the first half of my flight was realistic, and closely modeled a real-world NVG scene.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

28. The NVG scene presented during the half portion of my flight was realistic, and closely modeled a real-world NVG scene.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

29. The ChrAVE required me to use cockpit management skills similar to cockpit management skills I use in actual aircraft.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

30. If the ChrAVE was available at the unit level, I would be likely to use it.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

31. The HMD I wore during the flight provided a feeling and visual presentation that was similar to that of wearing a flight helmet with NVGs.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

32. The ChrAVE performs as well as visual simulators I have used in the past with regard to NVG terrain flight navigation.
    a. ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree
    b. ❍Better ❍Same ❍Worse

33. Performing tasks in the ChrAVE would be beneficial to trainees undergoing initial NVG qualification training.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

34. Performing tasks in the ChrAVE would be beneficial for maintaining NVG flight skills for experienced aircrews that are not able to fly for extended periods of time.
    ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

35. Compared to TOPSCENE, the ChrAVE's visual presentation of NVG imagery is:
    ❍More Realistic ❍Less Realistic ❍About the same ❍Not familiar with TOPSCENE

36. The ChrAVE accurately modeled the visual 'noise' effects of NVGs:
❍True ❍False ❍Not sure

ChrAVE Aftereffects

37. The ChrAVE made me feel queasy / nauseous.
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

38. The ChrAVE is disorienting because it is a motionless platform.
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Experiment Tasks

39. The tasks were realistic.

Preparing the map
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Maintaining awareness of your location
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Terrain association
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Navigation
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Monitoring radio calls
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Using NVG scanning techniques
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Maintaining situational awareness / seeing other aircraft or activity
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

Cockpit management skills
❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree

40. The workload in the ChrAVE was the same as it is in real world low-level helicopter navigation.
a. ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree
b. ❍Less ❍Same ❍More

41. The stress level in the ChrAVE was the same as it is in real world low-level helicopter navigation.
a. ❍Strongly agree ❍Agree ❍Neither agree nor disagree ❍Disagree ❍Strongly disagree
b. ❍Less ❍Same ❍More

42. What suggestions for improvements of the ChrAVE do you have? Please add any other statements you may have concerning this experiment. (If you have a comment on a specific question please provide the question number.):

Thank you for your participation.

APPENDIX C. EVALUATION SLIDES

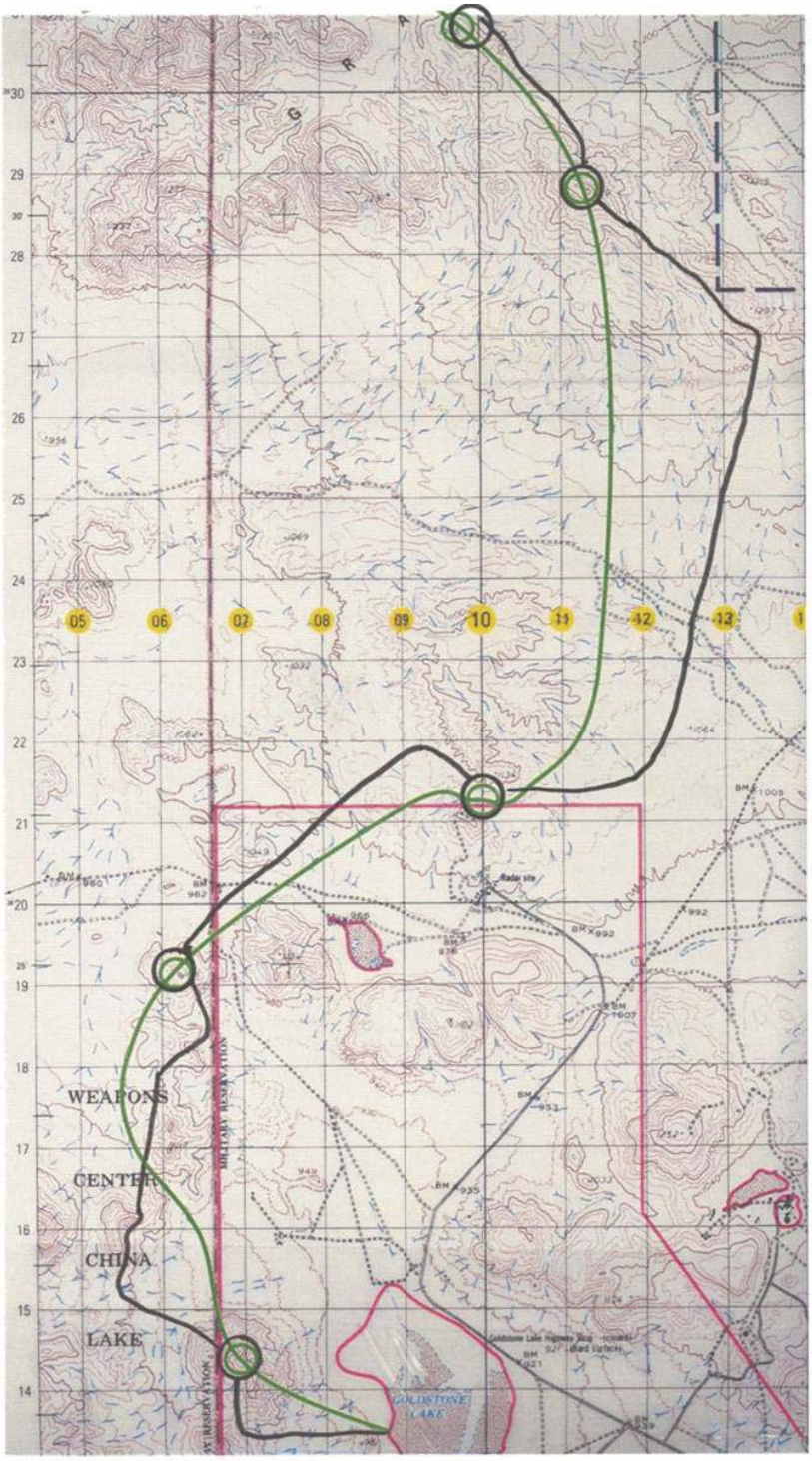

Figure 33. Evaluation Slide B

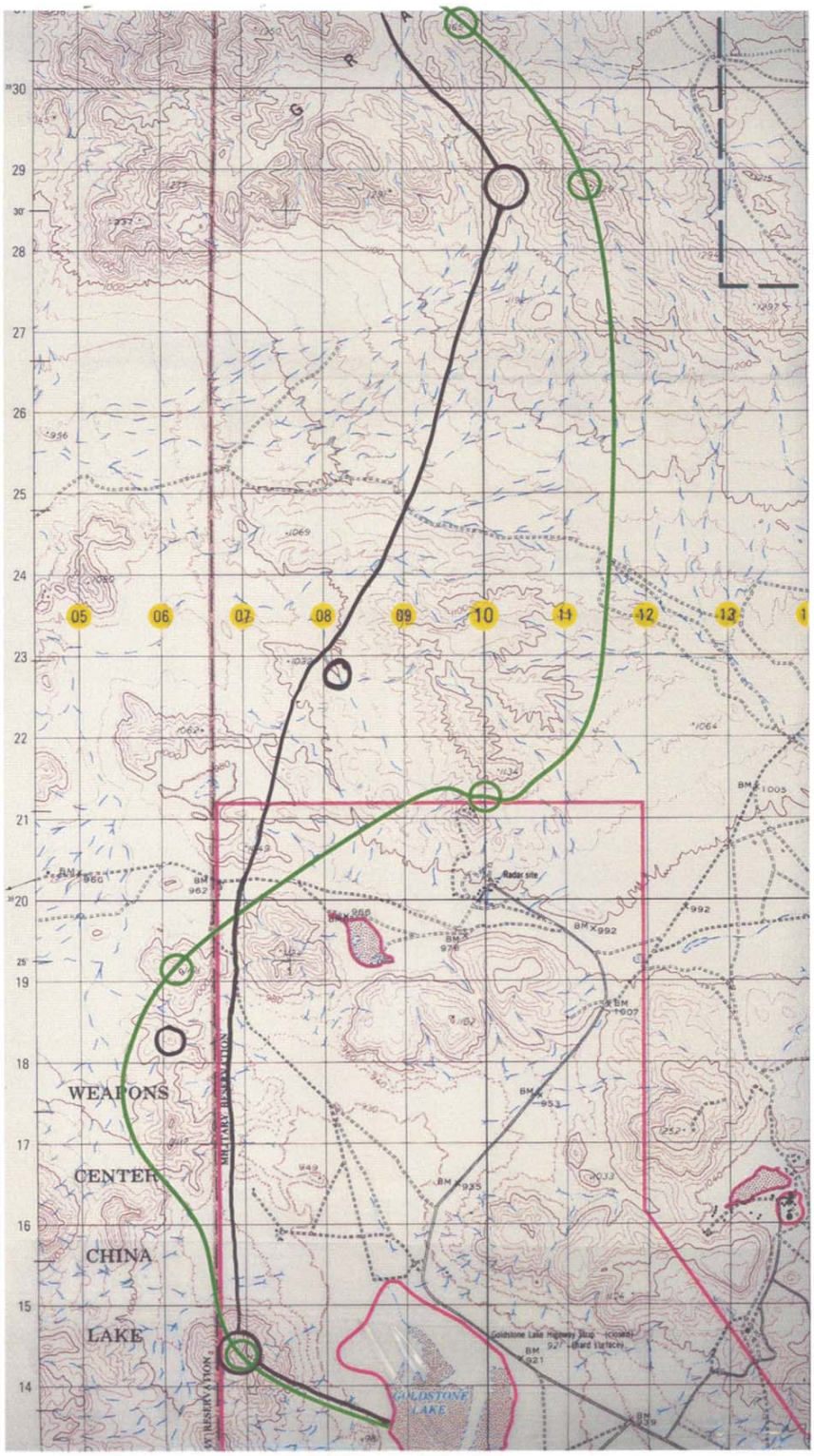

Figure 34. Evaluation Slide D

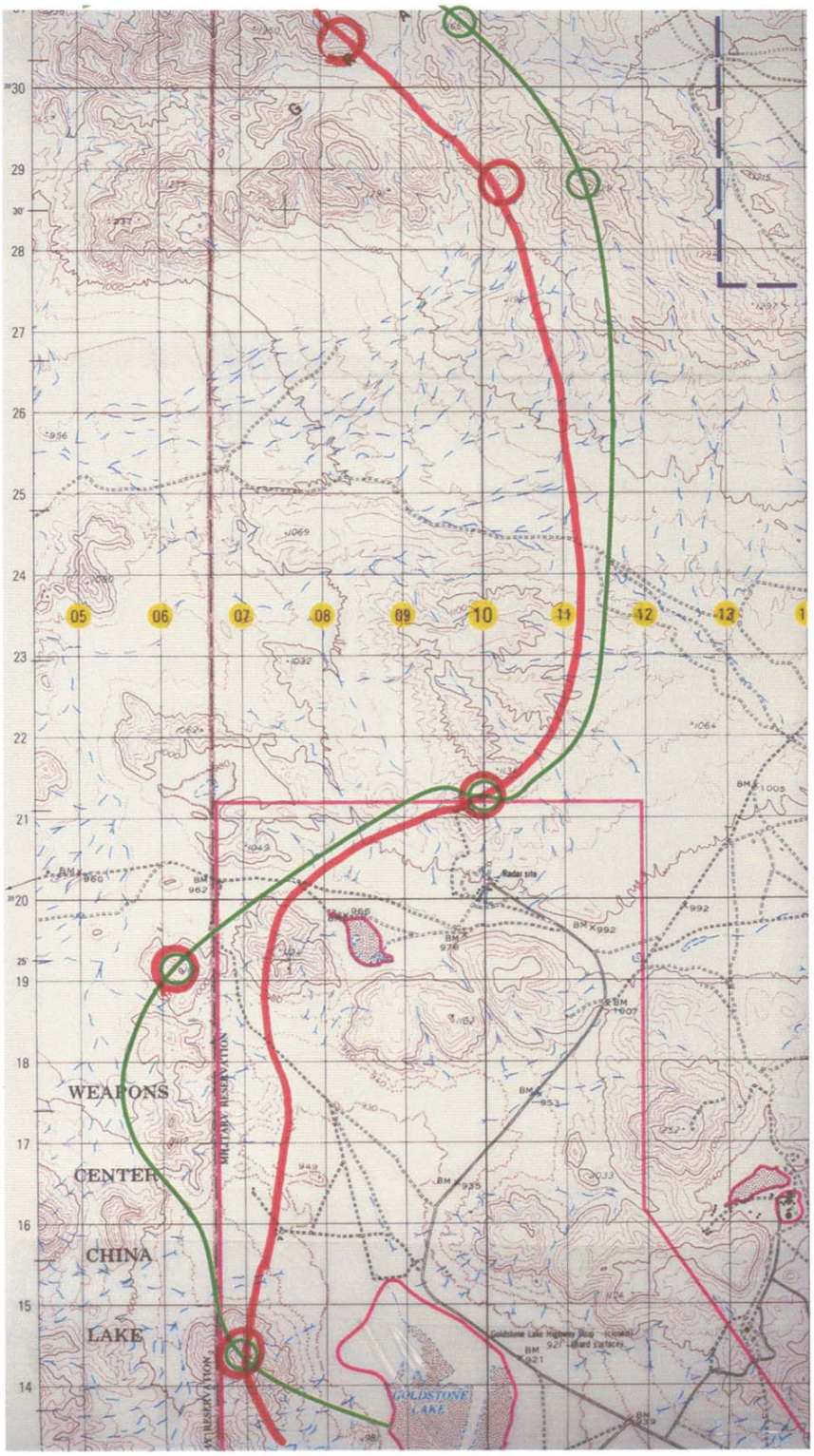

Figure 35. Evaluation Slide F

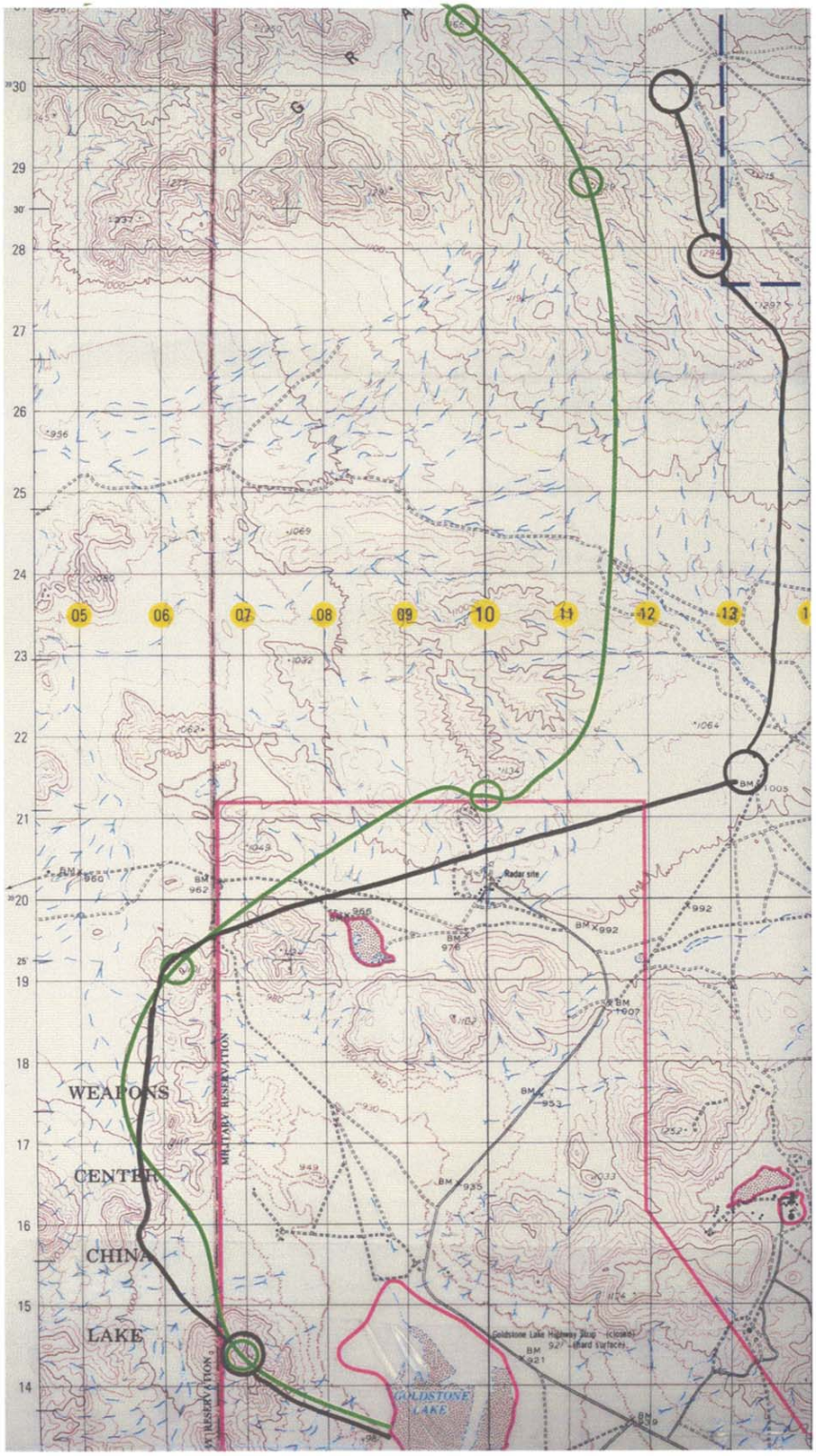

Figure 36. Evaluation Slide G

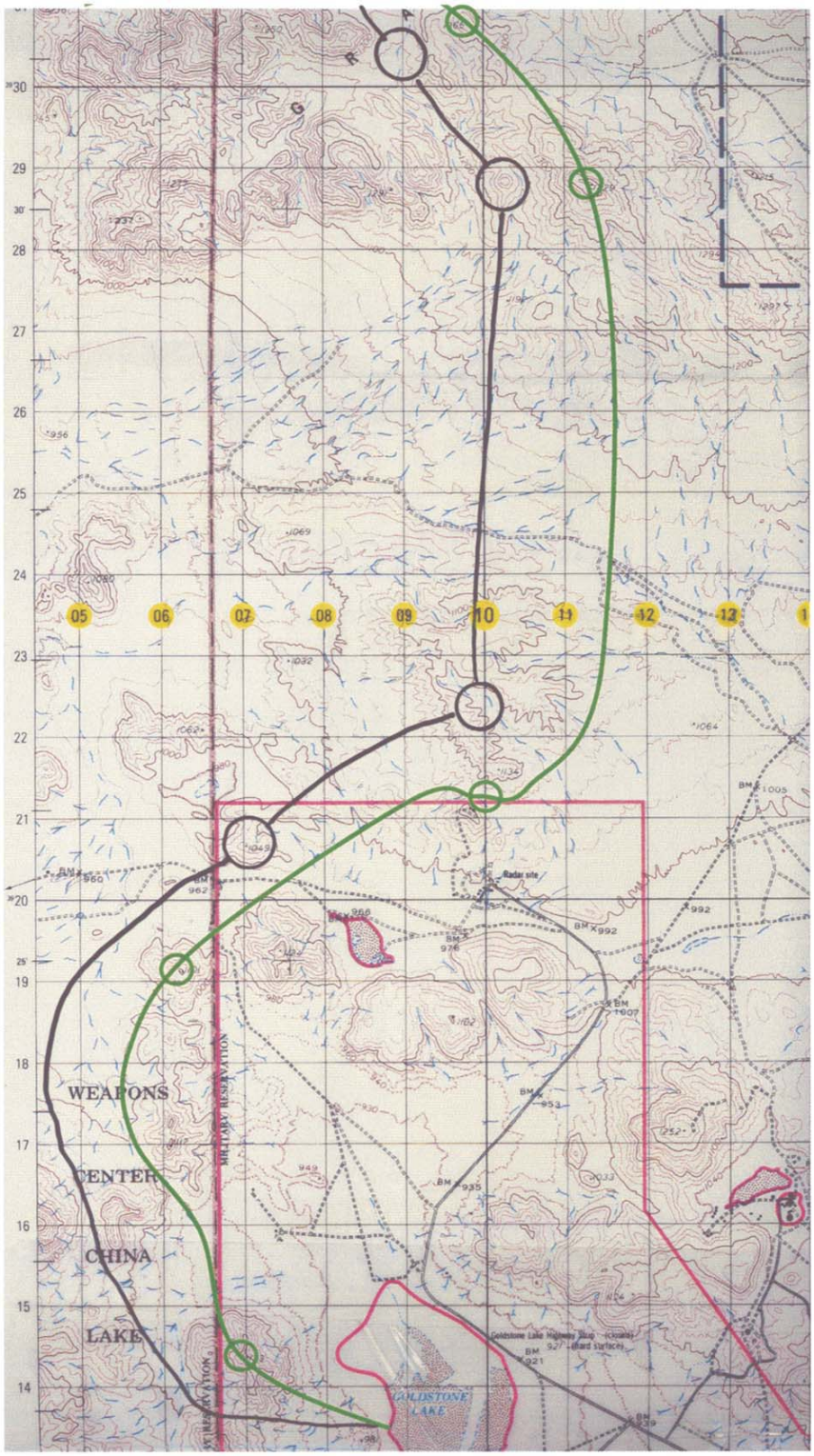

Figure 37. Evaluation Slide I

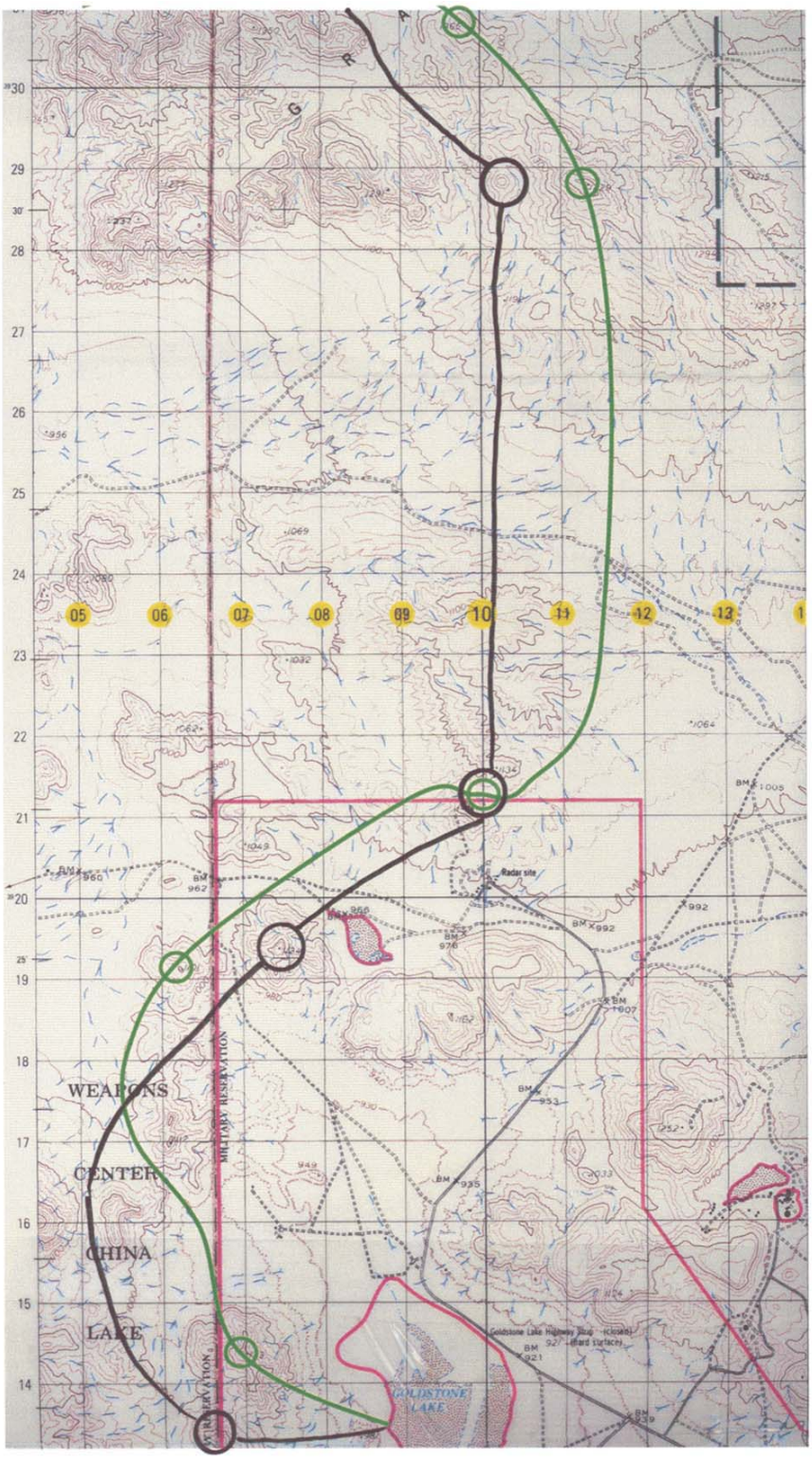

Figure 38. Evaluation Slide K

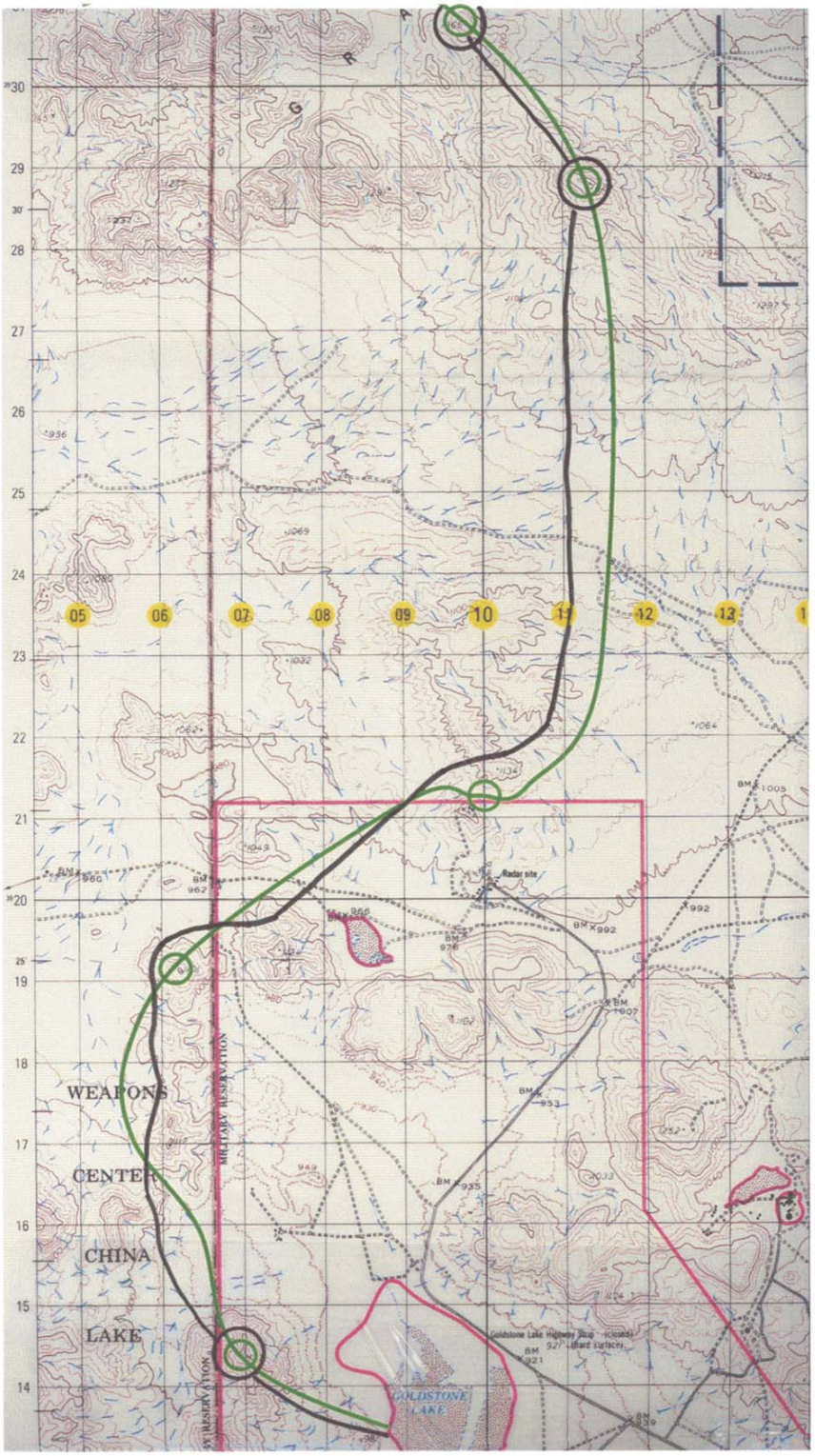

Figure 39. Evaluation Slide M

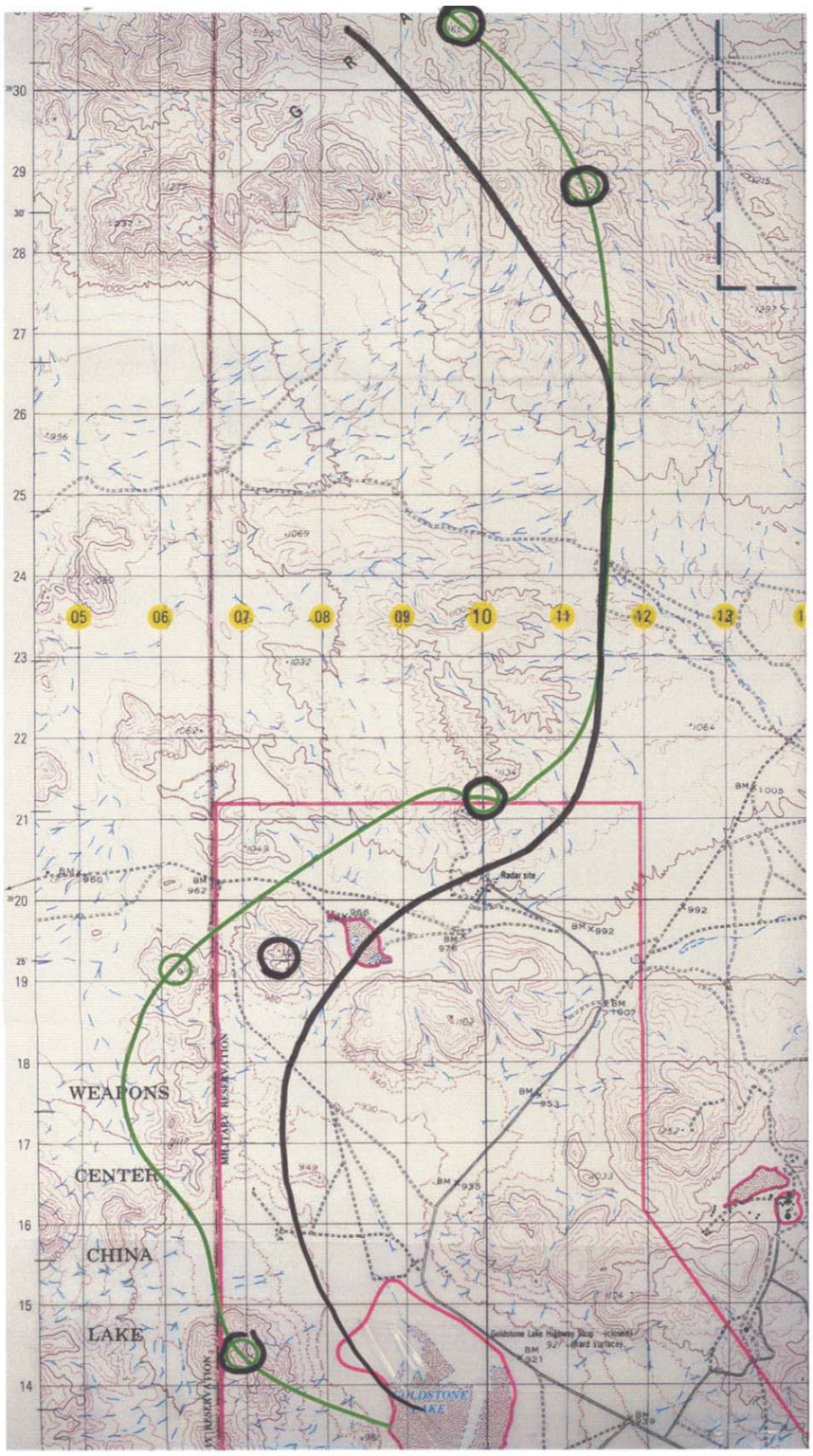

Figure 40. Evaluation Slide N

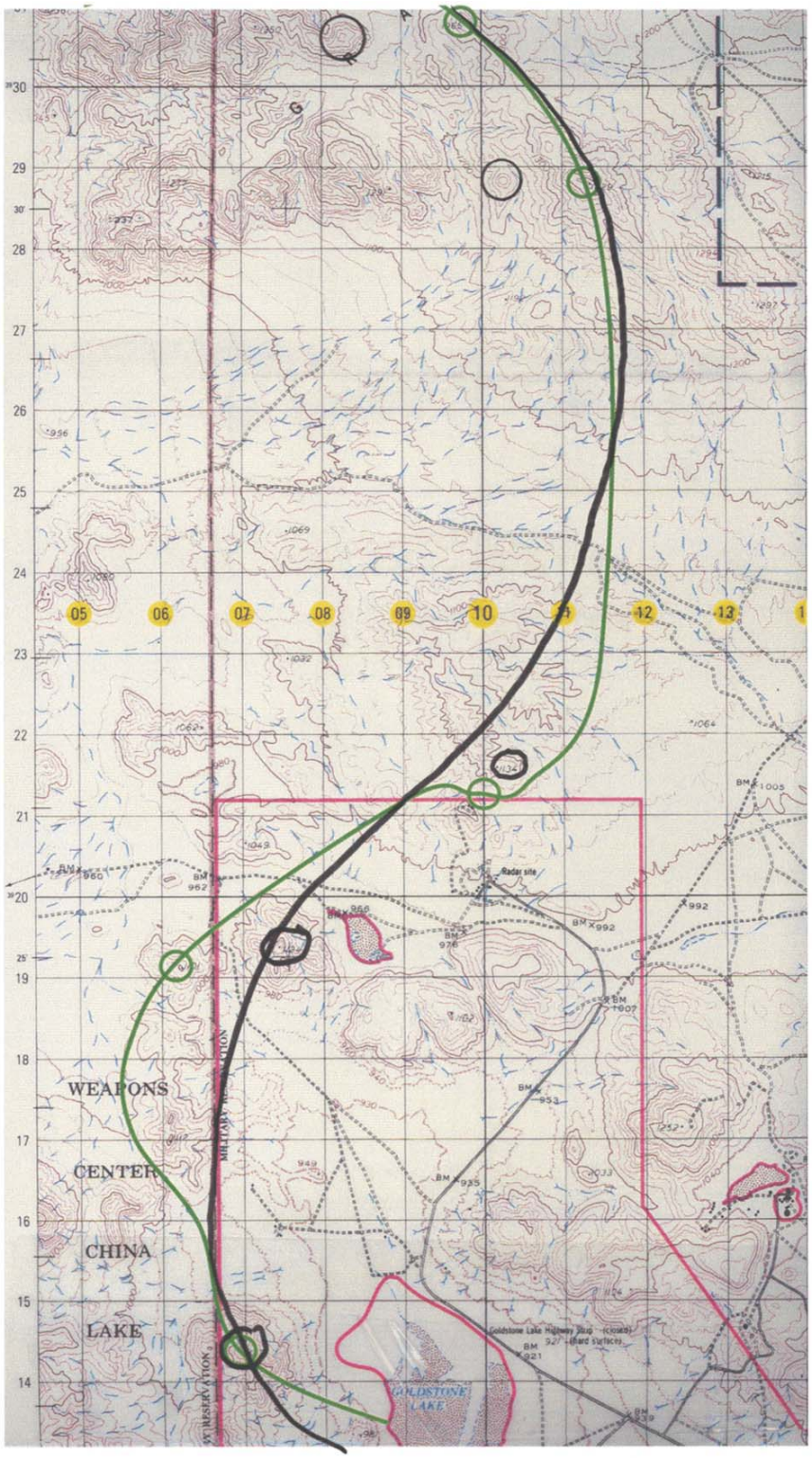

Figure 41. Evaluation Slide P

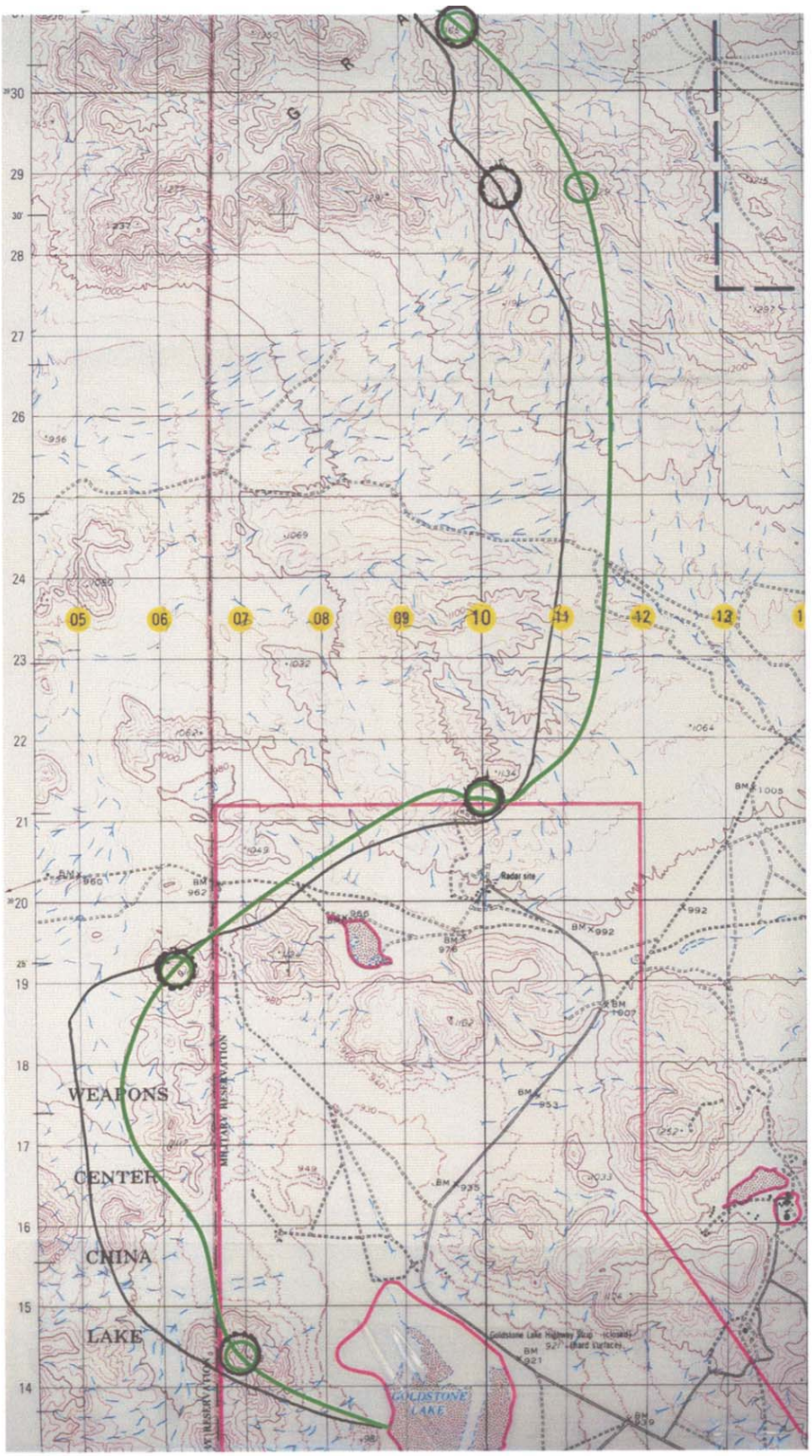

Figure 42. Evaluation Slide Q

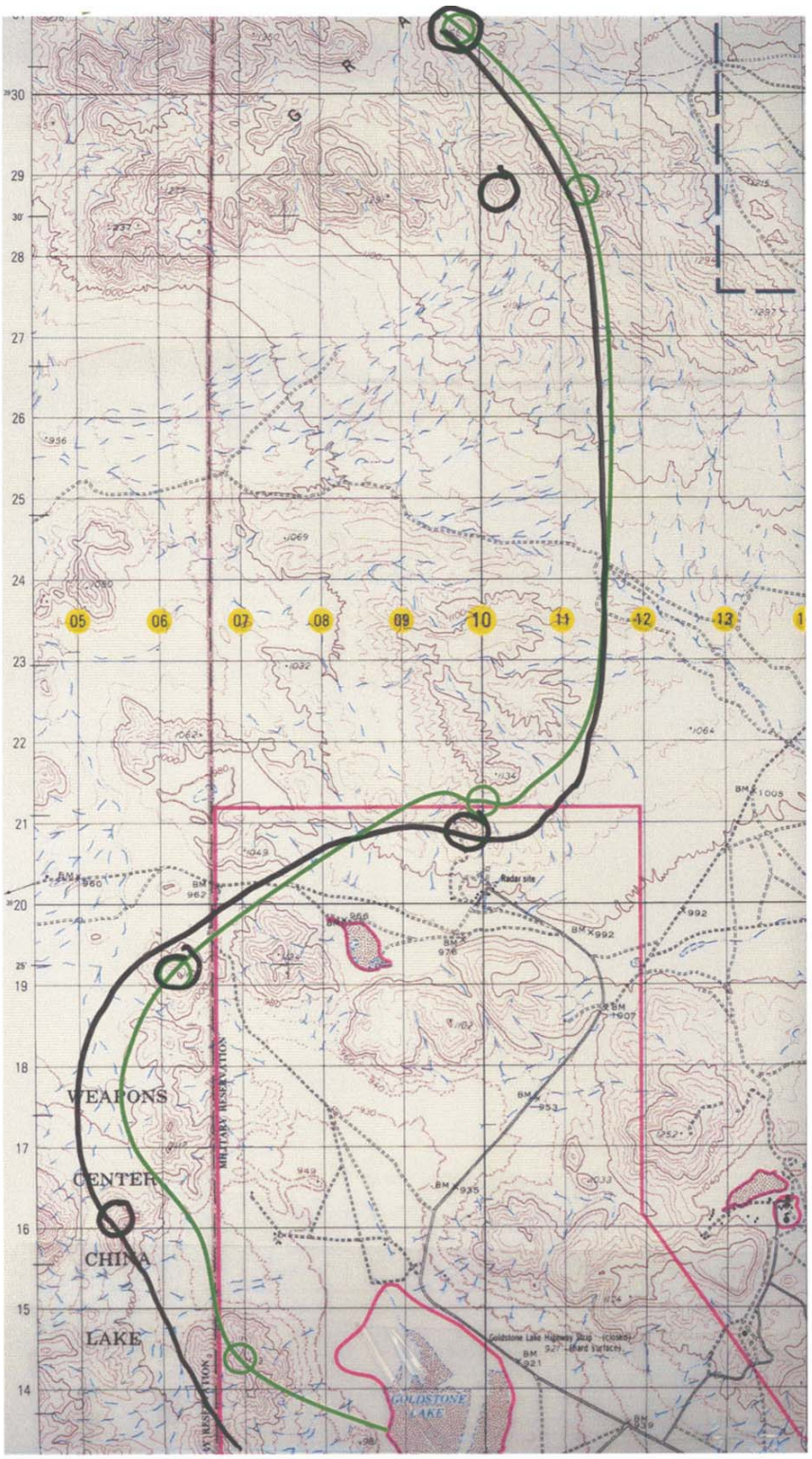

Figure 43. Evaluation Slide R

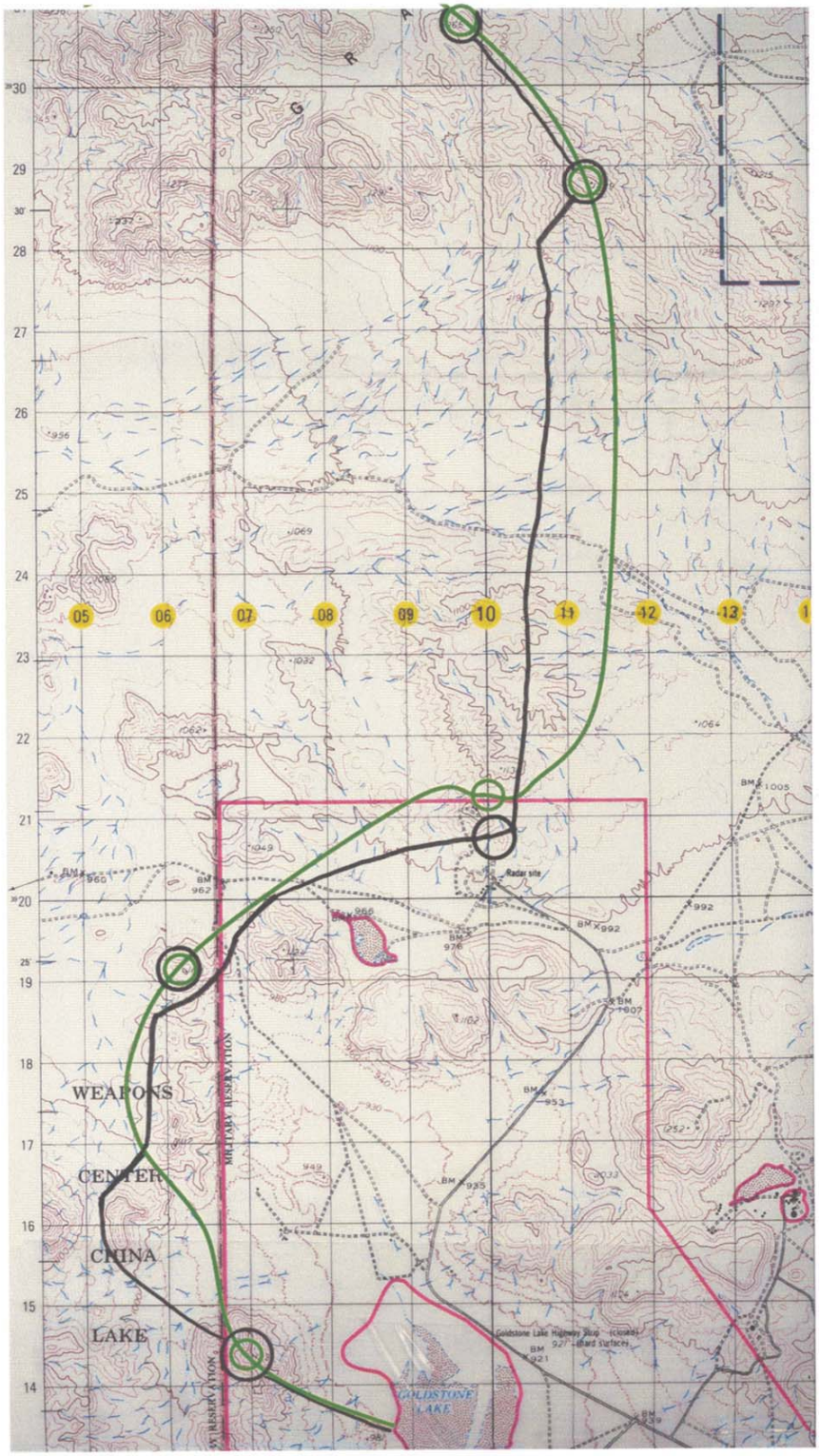

Figure 44. Evaluation Slide T

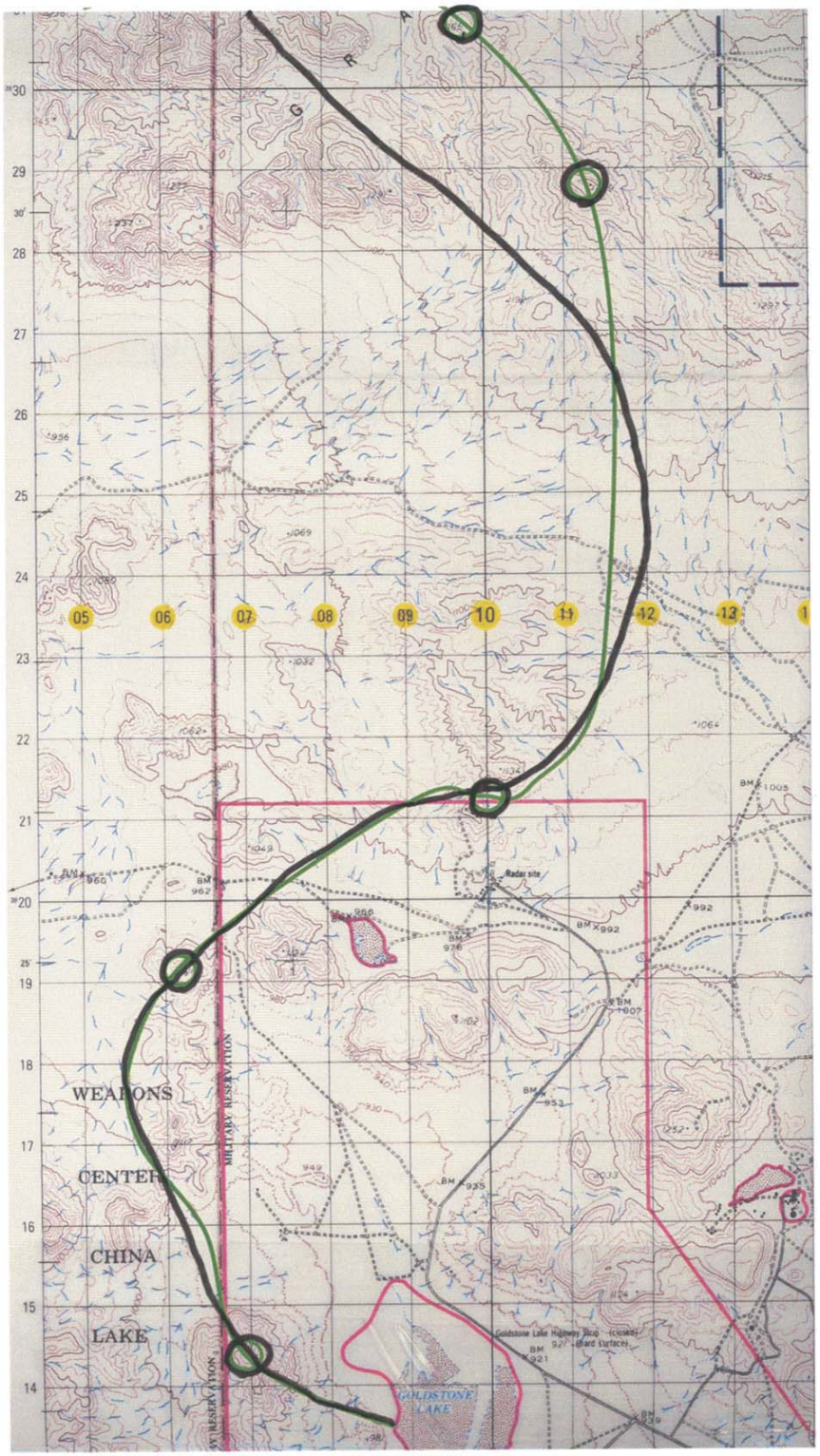

Figure 45. Evaluation Slide U

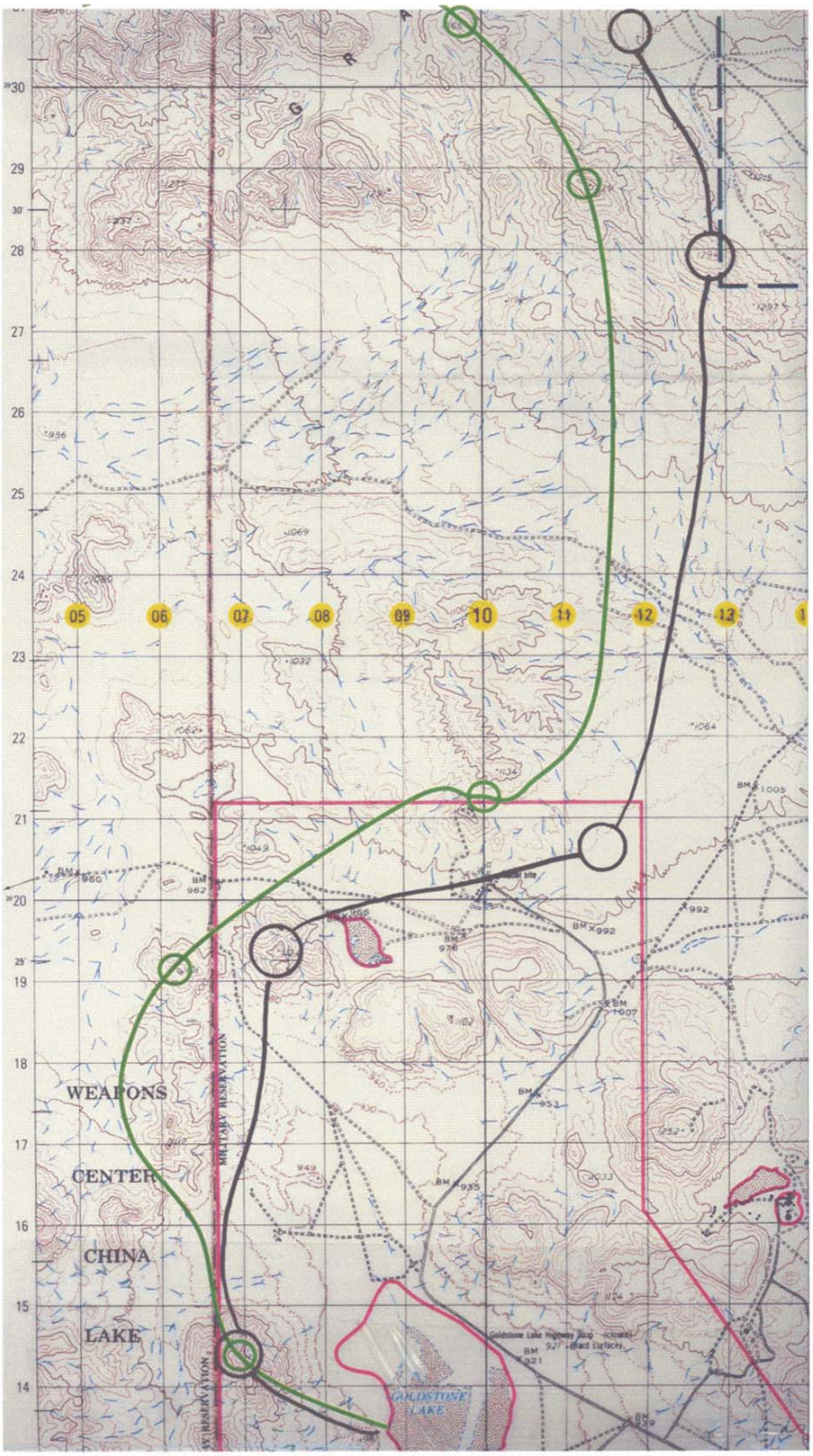

Figure 46. Evaluation Slide W

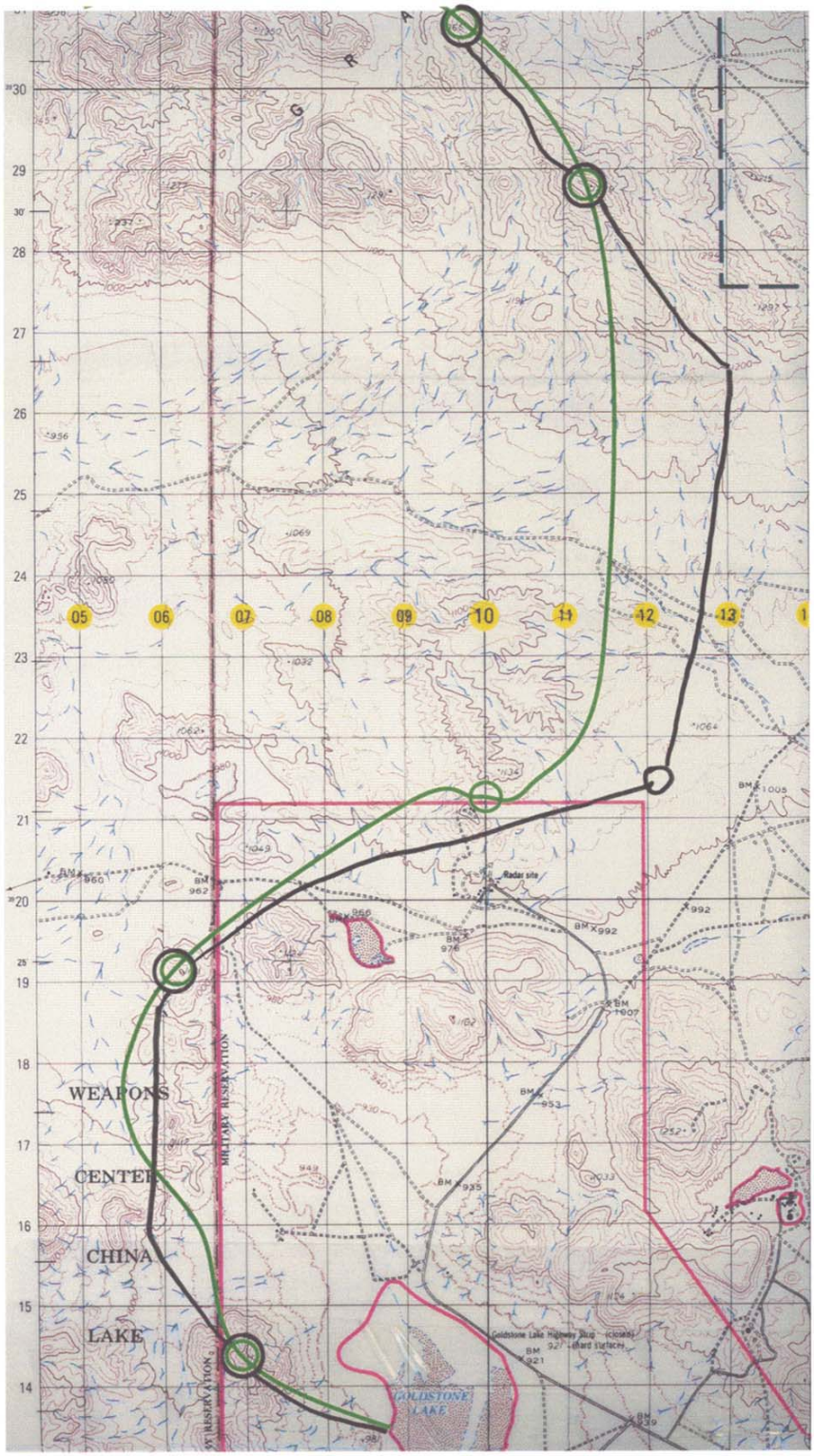

Figure 47. Evaluation Slide Y

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APPENDIX D. SUBJECT FLIGHT DATA

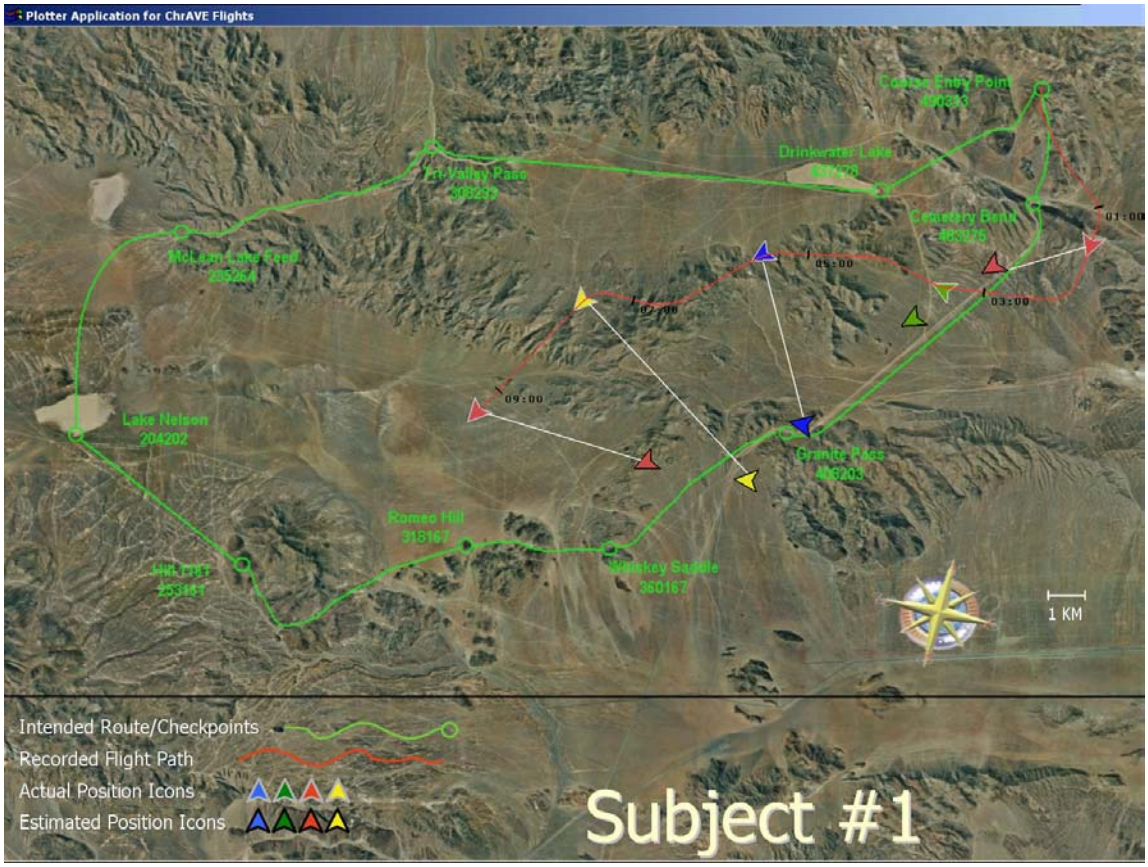

Figure 48. Navigation Performance of Subject 1

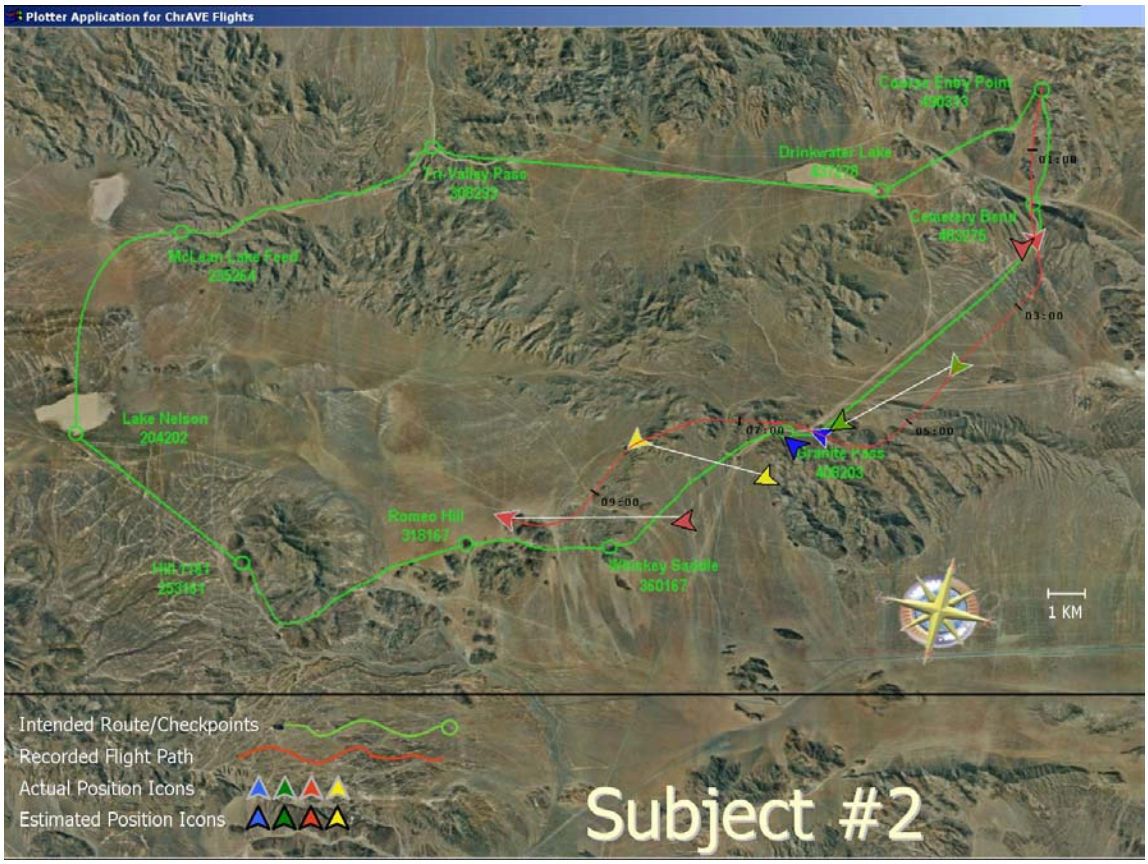

Figure 49. Navigation Performance of Subject 2

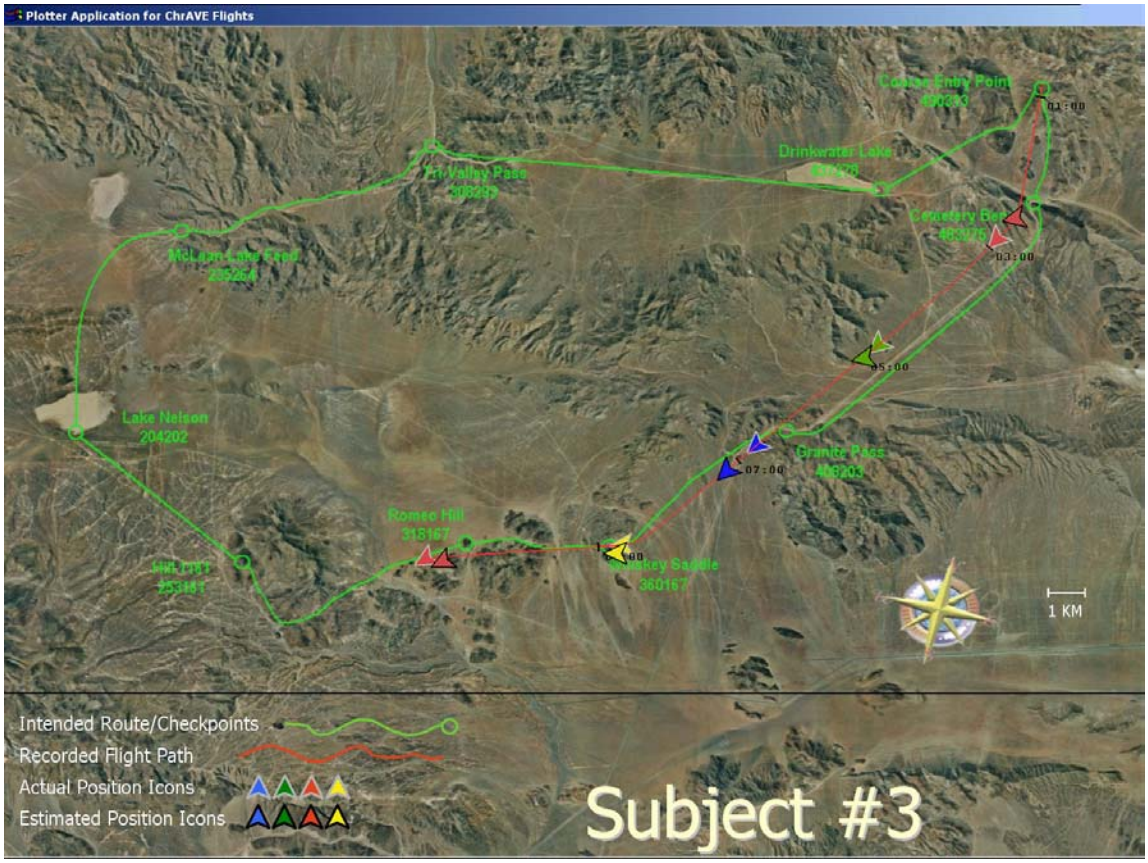

Figure 50. Navigation Performance of Subject 3

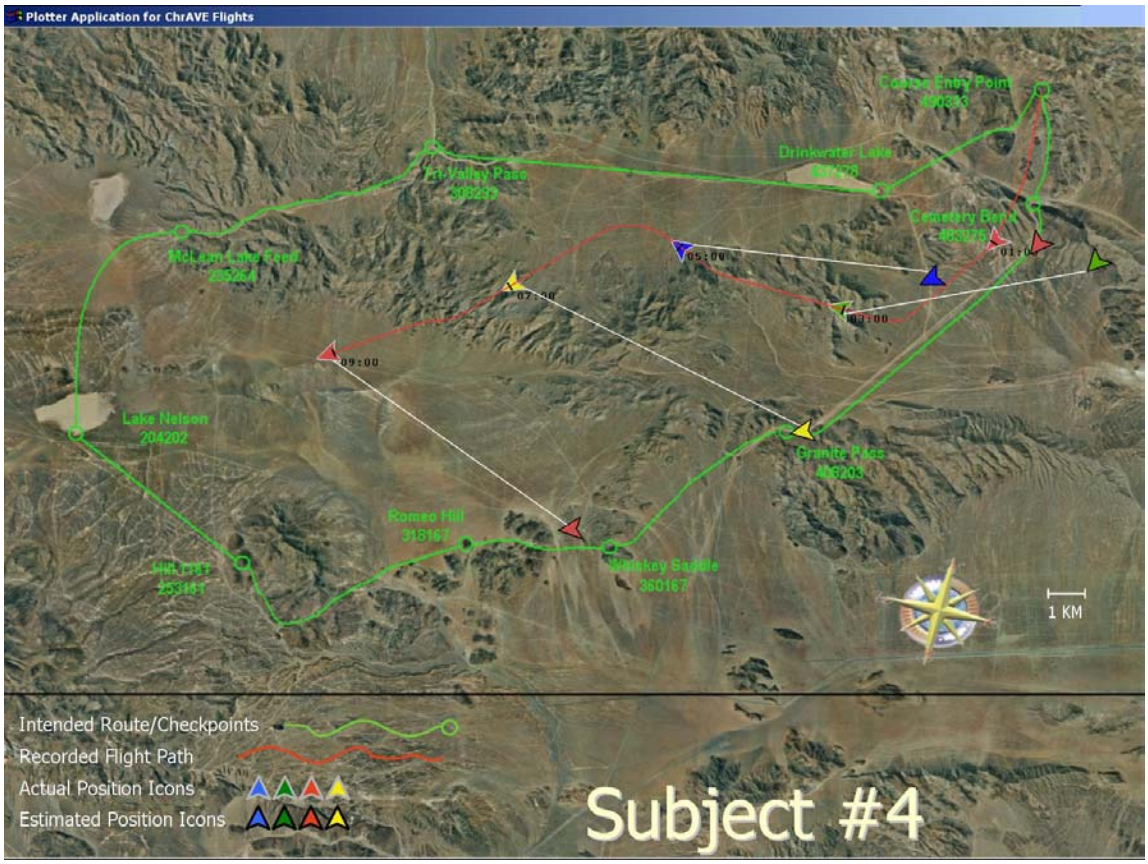

Figure 51. Navigation Performance of Subject 4

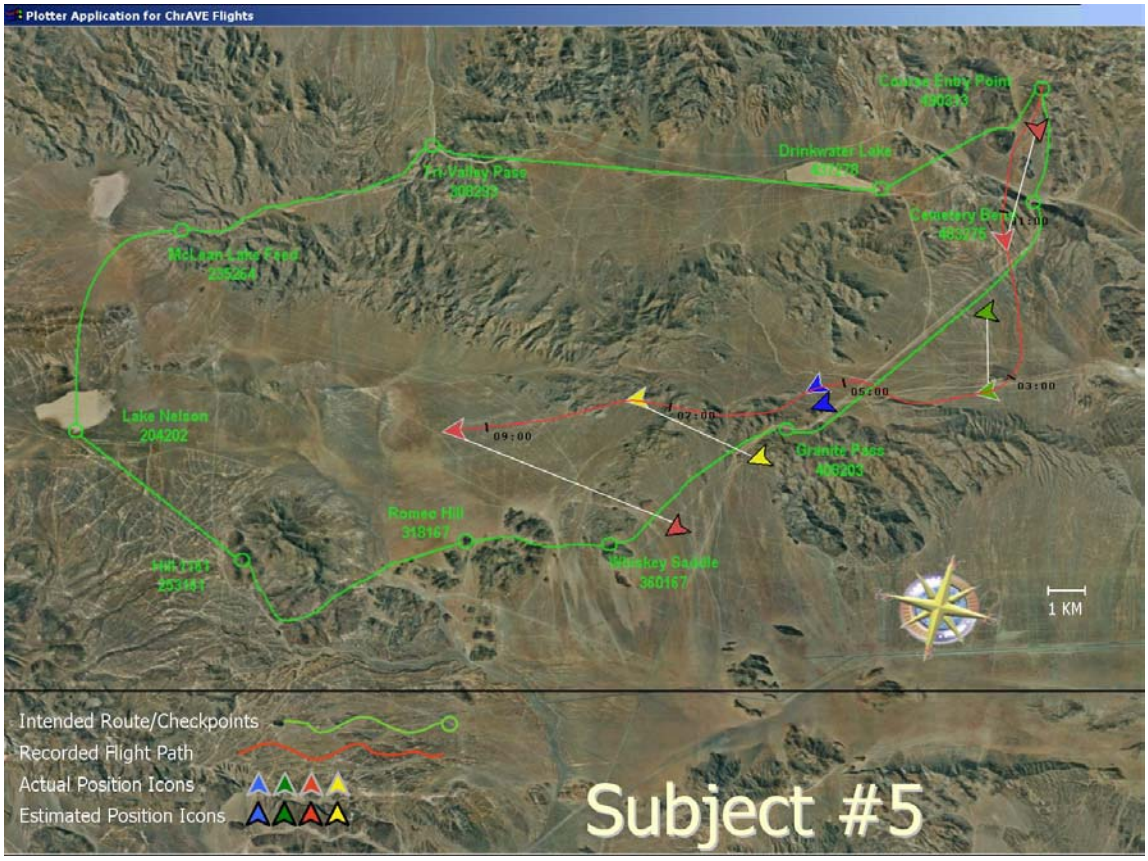

Figure 52. Navigation Performance of Subject 5

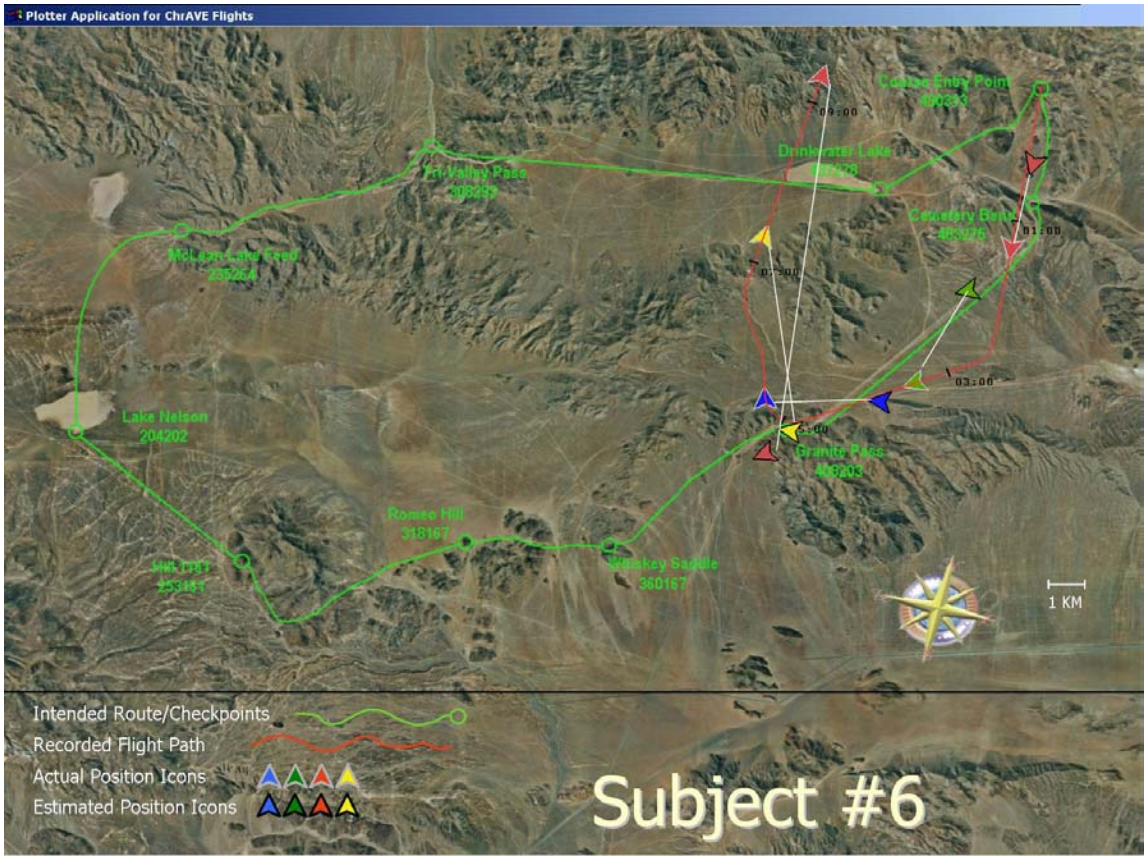

Figure 53. Navigation Performance of Subject 6

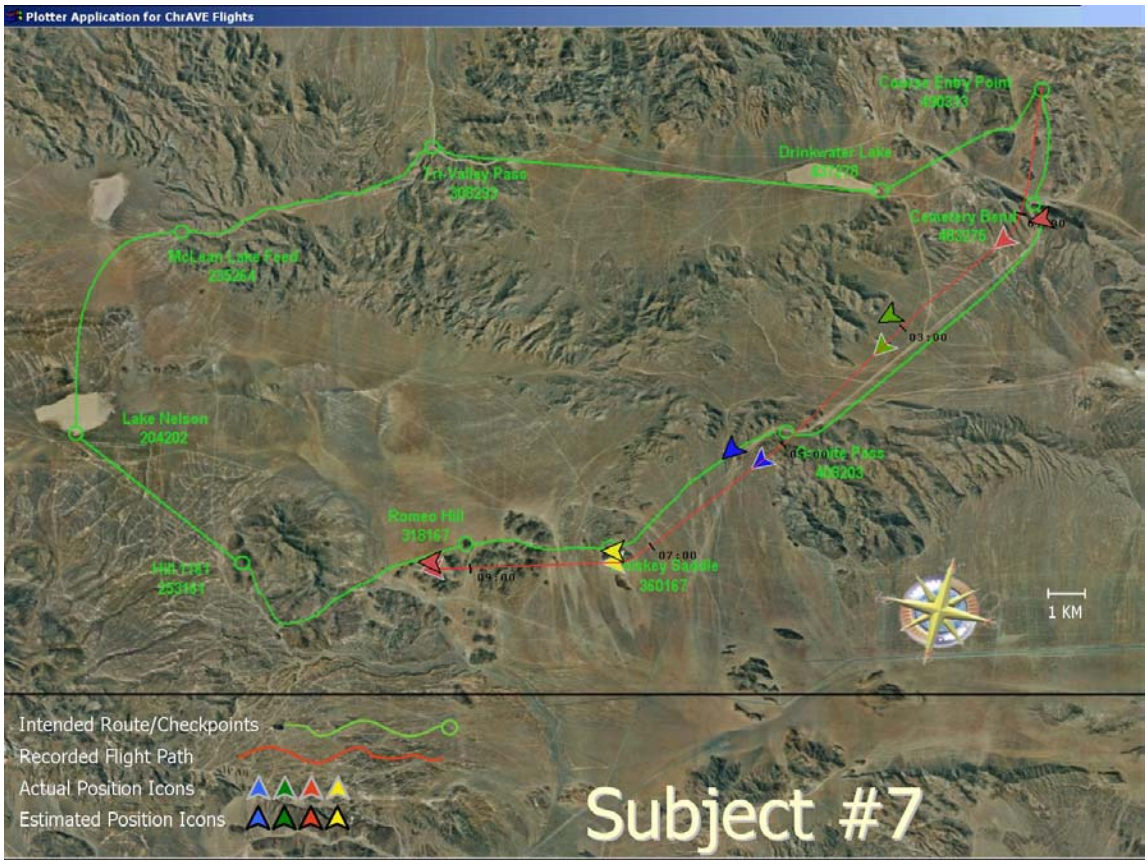

Figure 54. Navigation Performance of Subject 7

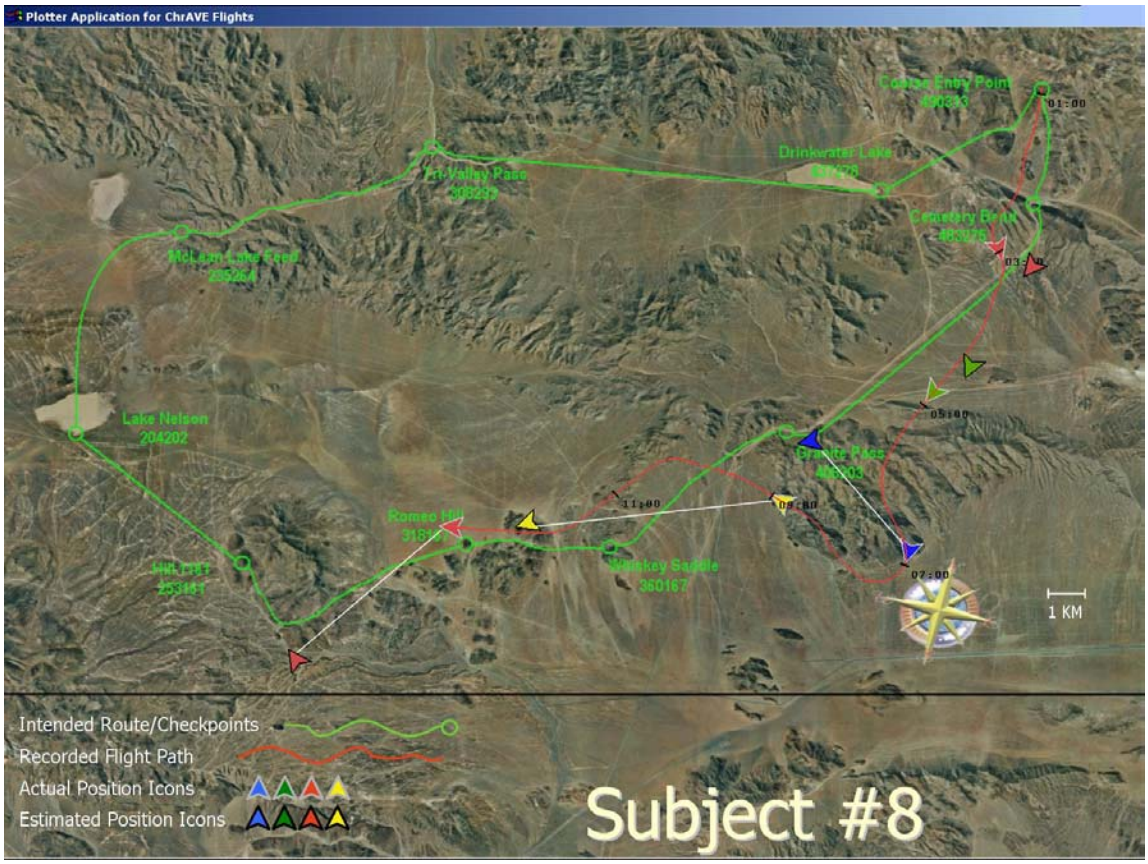

Figure 55. Navigation Performance of Subject 8

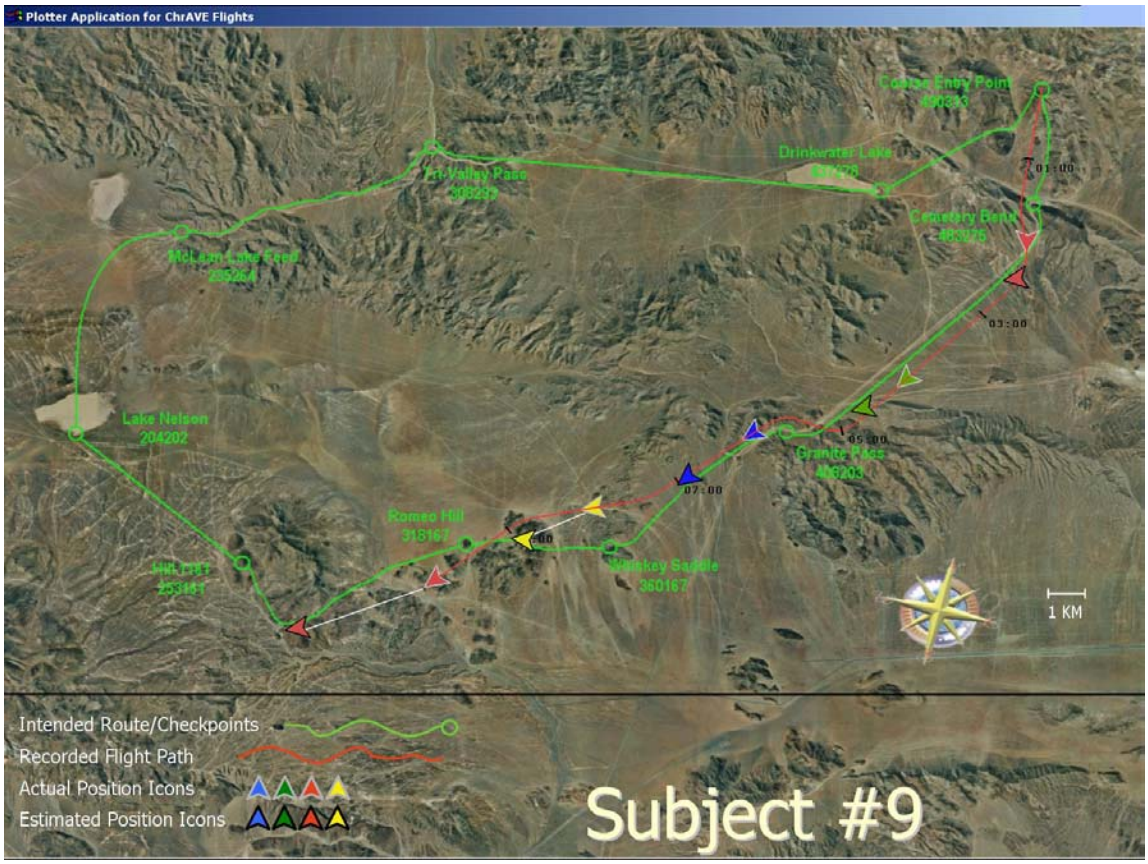

Figure 56. Navigation Performance of Subject 9

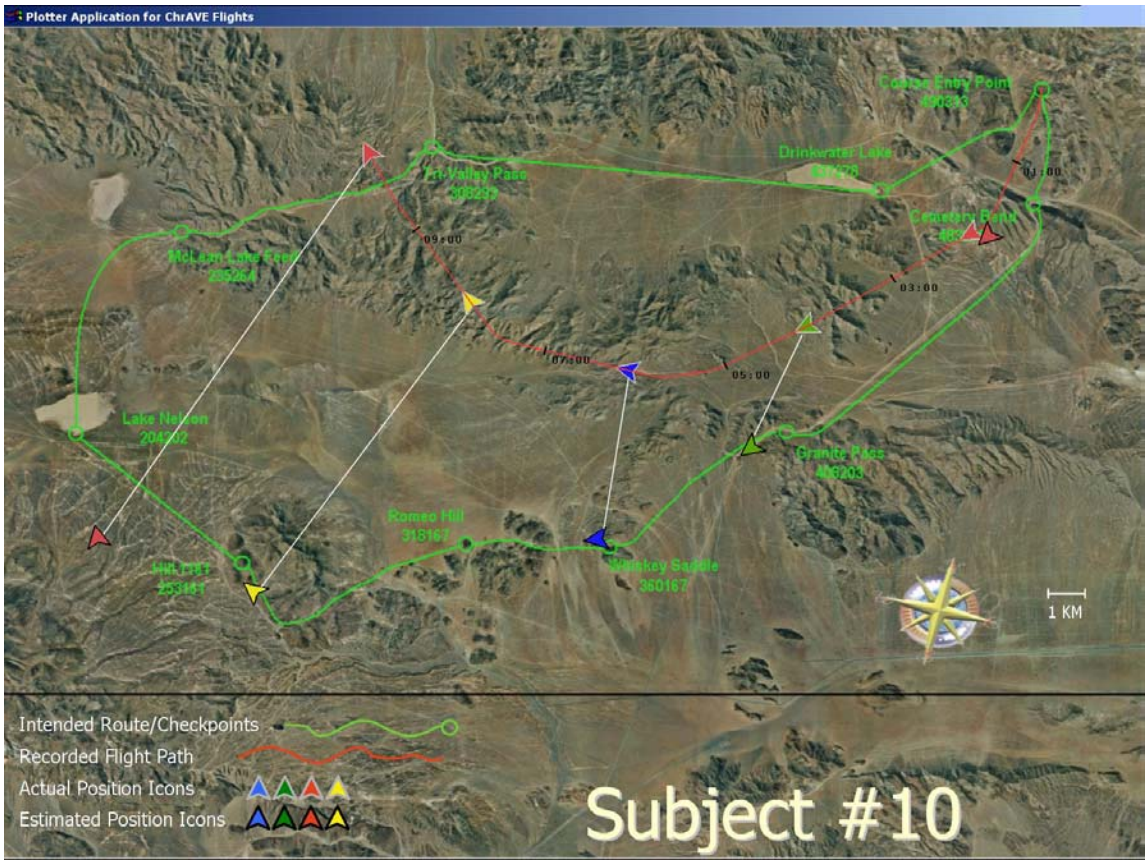

Figure 57. Navigation Performance of Subject 10

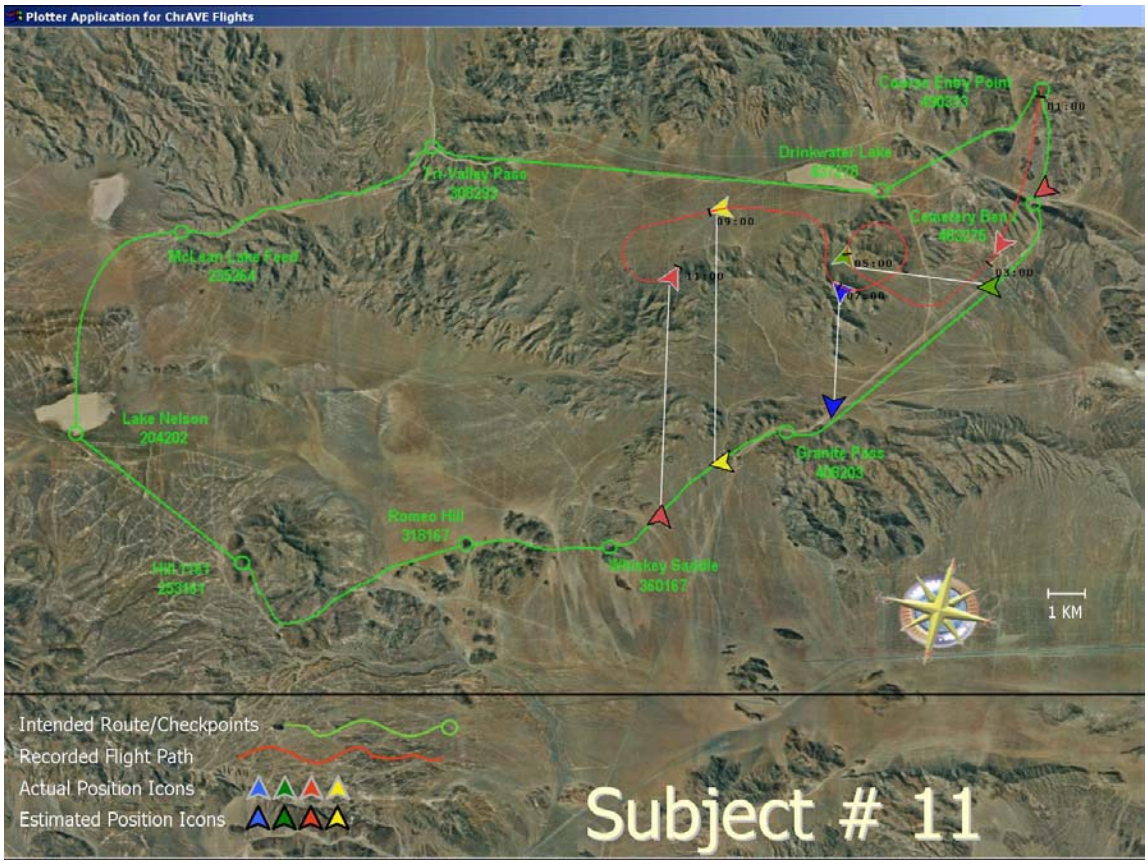

Figure 58. Navigation Performance of Subject 11

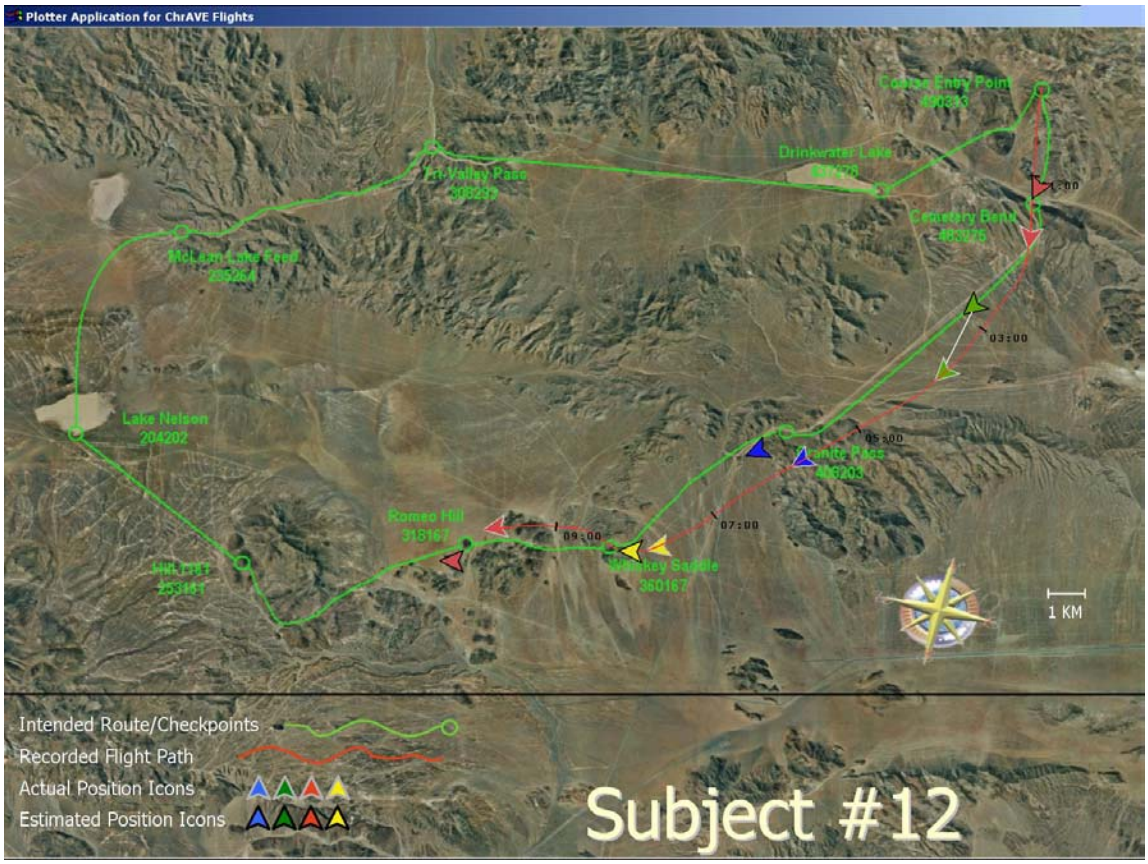

Figure 59. Navigation Performance of Subject 12

APPENDIX E. HARDWARE SPECIFICATIONS (ADAPTED FROM LENNERTON, 2002)

A. V8 Head Mounted Display from Virtual Research Systems

Display	• Dual 1.3” diagonal Active Matrix Liquid Crystal Displays • Resolution per eye: ((640x3)x480), (921,600 color elements) equivalent to 307,200 triads • Contrast ratio: 200:1
Optical	• Field of view: 60° diagonal • Multi-element glass, fully color corrected design • Interpupillary distance (IPD) range: 52mm to 74mm • Eye relief: Adjustable 10-30mm design accommodates glasses • Rubber eye cups prevent eyeglasses and lens contact • Overlap: Standard 100%
Audio	• Sennheiser HD25 high performance headphones • Headphones rotate above headband and snap off when not in use
Mechanical	• Single rear ratchet allows for quick, precise fit • IPD assembly moves fore/aft to accommodate glasses • IPD knobs accessible at sides of shell • HMD overall length/width/height: 17.5” x 8” x 6” (43 x 20 x 15 cm) • HMD Weight: 34 ounces (1.0 kg)
Cable	• Description: Custom molded cable • Length 13’ (3.9m) standard • Connector: 50 pin SCSI
Control Box	• VGA (640 x 480 60Hz) input format • Sync on green, separate H and V, or Composite (+ or - going) • Overall brightness and contrast • Stereo or mono input auto detected • Mono input drives right and left eye with one signal • Audio Input: 3.5mm mini stereo phone jack • Monitor Output: VGA (640 x 480 60Hz)
Electrical	• Power supply: Universal input (+5, +24, -12, VDC) output • Power consumption: 30W

B. GP-US542 3-CCD High Performance Micro Head Color Camera with DSP from Panasonic

TV System	NTSC (Available in PAL)
Pick-up System	Micro prism system
Pick-up Device	768 (H) x 494(V) Three 1/3" interline transfer (IT) supper high sensitivity CCDs
Scanning System	2:1 Interlace 525 lines, 60 fields, 30 frames

	Horizontal: 15.734kHz, Vertical: 59.94Hz
Synchronizing System	Internal or External (Gen-Lock)
• **Internal**	NTSC standard (Available in PAL as GP-US532E***)
• **External (Gen-Lock) Input**	VBS, VS, HD/VD SC Phase for Gen-Lock (VBS): Free adjustable over 360 H Phase for Gen-Lock (VS): Adjustable
Video Outputs	
• **Video 1,2**	1.0V [p-p] / 75 ohms NTSC composite video signal, BNC Connector
• **S-VIDEO (Y/C) Out**	(Y) 0.714V [p-p] / 75 ohms (C) 0.286V [p-p] / 75 ohms, S-VIDEO Connector x 1
• **RGB/SYNC**	(R/G/B) 0.7V [p-p] each / 750 (SYNC) 4V [p-p] / 75 ohms or 0.3V [p-p] 1750 selectable, D-SUB 9-pin Connector x 1
Required Illumination	2000 lx at F8.0 3200K
Minimum Illumination	9 lx (0.9 foot candle) at F2.2 with +18db gain, 30 IRE level
Signal-to-Noise Ratio	62dB (Typical, Luminance) without aperture and gamma
Horizontal Resolution	750 lines at center (Y signal)
White Balance	ATW (Automatic Tracing White Balance Control), AWO (Automatic White Balance Control) and Manual
Black Balance	ABC (Automatic Black Balance Control) and Manual
Color Bar	SMPTE color bar with 7.5% set-up
Electronic Shutter	ELC (Electrical Light Control) and Manual STEP: Selectable 1/60 (OFF), 11100, 1/250,1/500, 1/1000, 1/2000, 1/4000, and 1/10,000 sec SYNCHRO SCAN: Selectable from 1/525 to 254/525 line
Gain Selection	AGC, Manual Gain (0, +9, +18db Selectable)
Switches	Power On/Off (POWER), Camera/Color Bar Selection (CAM/BAR), Gain UP Selection (OFF/LOW/HIGH (0/+9/+18dB), White Balance Selection (ATW/AWC/MANU), ELC (Electronic Light Control) On/Off, PAGE, ITEM (AWC) <(ABC) and> Scene 1/2
Controls	R Gain, B Gain and ELC LEVEL
Computer Interface	RS-232C Control, D-SUB 9-pin Connector x 1
Lens Mount	C Mount
Power Source	12V DC
Power Consumption	8.4 W
Ambient Operating Temperature	32F - 113F (0C - 45C)

Ambient Operating Humidity	30%-90%
Dimensions	
• **Camera Head (Excluding Mounting Adapter)**	34 (W) x 44 (H) x 52 (D) mm [1-5/16" (W) x 1-11/16" (H) x 2" (D)]
• **CCU (Excluding Rubber Foot and connector)**	206.5 (W) x 44 (H) x 250 (D) mm [8-1/8" (W) x 1-11/16" (H) x 9-1/2" (D)]
Weights	
• **Camera Head:**	110g (0.24 lbs)
• **CCU:**	1.7kg (3.74 lbs)

C. Lenses

1. TV 1,5/4 C From Doctor®

Type	Manual Lockable
Format Sizes	Up to 1/3-inch
Mount Type	C
Focal Length	f = 4.2mm
Max. Rel. Aperture	K_{max} = 1.5
Image Diameter	2Y' = 6mm
Angle of View	$2\sigma = 72$
Number of Elements	7
Number of Groups	7
Back Focal Length	s'F' = 13.5mm
Front Focal Length	sF = 15.1mm
Cumulative Lens Thickness	Σ_d = 45.6mm
Pupil Distances	S_{EP} = 15.7mm S'_{AP} = -15.7mm
Pupil Diameters	$\varnothing_{EP}$ = 2.76mm $\varnothing_{AP}$ =

	19.47mm
Mount	C CS with adapter
Mounting Depth	4.2mm
Focus Range	e = 0.15m…∞
Unit Weight	.77 / 90g

2. 12VA6-13 ½-inch Format Varifocal Lens from Pelco

Type	Varifocal
Format Sizes	1/2-inch 1/3-inch
Mount Type	C
Focal Length	6-13mm
Zoom Ratio	2.2X
Relative Aperture (F)	1.8-Close
Operation	
• **Iris**	Manual
• **Focus**	Manual
• **Zoom**	Manual
Angle of View	
• **Diagonal**	35.5-75.5
• **Horizontal**	28.5-60.3
• **Vertical**	21.4-45.2
Minimum Object Distance	0.3m
Back Focal Length	8.7mm
Filter Size	N/A
Unit Weight	.20 lb (.09 kg)

D. IS-300 Motion Tracker from InterSense (TODO)

Maximum Angular Rate	1200°/sec
Angular Resolution	0.02° RMS
Angular Accuracy	0.25° RMS
Maximum Linear Velocity	15'/sec
Translation Resolution	0.01" RMS
Translation Accuracy	0.25" RMS
Prediction	0-50ms
Number of InertiaCube Sensors	Up to 4
Number of SoniDisc Beacons	Up to 8
Orientation Update Rate	Up to 500Hz
Position Update Rate	Up to 150Hz
Interface	RS-232C with selectable baud rates to 115,200
Protocol	Compatible with industry-standard protocol (FASTRAK™)
Max. System Configurations	GEOS: 4 orientation-only stations; PULSAR: 8 position-only stations; DUAL: 4 6-DOF stations; FUSION: 4 6-DOF stations Or any combination of Operating Modes that Make use of 4 InertiaCubes and 8 SoniDiscs
Power	100-240 VAC, 1.0A, 50-60W
Fusing	100-120 VAC: T250V, 1.0A 220-240 VAC: T250V, 0.5A
Operating Temperature	0 to 50C (32F to 122F)
Storage Temperature	-20 to 70C (-4F to 158F)

	Dimensions	Weight	Cable
InertialCube orientation sensor	1.06" x 1.34" x 1.2"	2.1 oz.	10' extendible to 30'
SoniDisc position sensor	1.0" x 1.0" x 0.65"	0.4 oz.	n/a
X-bar	41.4" x 3.0" x 1.7"	8.2 lb.	20' extendable to 34'*
ReceiverPod (each)	4.75" x 3.0" x 1.7"	0.8 lb.	24" extendable to 34'*
Base Unit Signal Processor	16.75" x 12" x 4"	8.4 lb.	n/a

*Total X-bar plus ReceiverPod cable length not recommended to exceed 40'

Compatibility	The InterSensevIS-600 Mark 2 is compatible with all the industry leading software and hardware
Virtual Research	Superscape Sense8 Meta VR Division
Thomson T&S	Softimage Multigen nVision Xtensory
Kaiser Electro-Optics	

E. VSC 200D Video Scan Converter from Extron Electronics (VGA to D1)

Video Input	
• **Number / Signal Type**	1 VGA, 1 Mac RGBHV, RGBS, and RGsB
• **Connectors**	VGA 1 15-pin HD female + adapter cable Mac 1 15-pin D female
• **Nominal Level(s)**	Analog 0.7V p-p
• **Minimum / Maximum Level(s)**	Analog 0V to 2.0V p-p with no offset
• **Impedance**	75 ohms or High Z (switchable)
• **Horizontal Frequency**	Autoscan 24 kHz to 811 kHz
• **Vertical Frequency**	Autoscan 50 Hz to 120 Hz
• **Resolution Range**	Autoscan 560 x 384 to 1280 x 1024
• **External Sync (Genlock)**	0.3V to 1.0V p-p
Video Processing	
• **Encoder**	10 bit digital
• **Digital Sampling**	24 bit, 8 bits per color; 80 MHz
• **Colors**	16.8 million
• **Horizontal Filtering**	4 levels
• **Vertical Filtering**	5 levels
• **Encoder Filtering**	3 levels
Video Output	
• **Number / Type / Format**	1 RGBHV / RGBS / RGsB or component video or 1 digital component video (CCIR 6011 / ITU-R BT.601)(VSC 200D only), or 1 S-video, or 1 NTSC / PAL composite video
• **Connectors**	5 BNC female — 1 RGBHV / RGBS / RGsB or component video 1 BNC female — 1 digital component video -- VSC 200D only 1 4-pin mini-DIN female — S-video

	1 BNC female	composite video
• **Nominal Level**	RGBHV / RGBS / RGsB S-video and composite	0.7V p-p 1.0V p-p
Impedance	75 ohms	
Sync		
• **Input Type**	Auto detect RGBHV, RGBS, and RGsB	
• **Output Type**	RGBHV, RGBS, and RGsB (all RGB formats are swith selectable)	
• **Genlock connectors**	1 BNC female 1 BNC female	genlock input genlock output (terminate w / 75 ohms if unsed)
• **Standards**	NTSC 3.58 and PAL	
• **Input Level**	1.5V to 5.0V p-p	
• **Output Level**	5V p-p	
• **Input Impedance**	75 ohms	
• **Output Impedance**	75 ohms	
• **Polarity**	Negative	

F. ADC-6801 signal Converter From LeiTch (RGB to D1)

Input		
• **Sampling Rate**	27MHz Y 13.5MHz Cr/Cb	
• **Quantization**	10 bits	
• **Input Standards**	SMPTE / EBU, MII, Betacam component or RGB at 525 or 625 lines rates	
• **5 BNCs**	Ext. Sync, Loop Through G/Y, B/B-Y, R/R-Y	
Component Analog Input		
• **Connector**	BNC per IEC 169-8	
• **Impedance**	75 ohms unbalanced	
• **Signal Level**	1 V	
• **Adjustable Gain**	±10%	
• **Time Adjustment Range**	±1.8μs	
• **Return Loss**	>40dB to 5.5 MHz	
Filtering As Per CCIR 601 Specifications		
• **Frequency Response**	Y channel	±0.1 dB to 5.5 MHz
	Cr, Cb Channels	±0.2 dB to 2.75 MHz
• **Signal to Noise Ratio on all Channels**	>64 dB RMS, relative to 0.714 V, 10 kHz to 5.5 MHz	
• **Interchannel Crosstalk**	<-50dB	
• **2T K factor**	<0.5%	

• **Luminance Non-linearity**	<1%
• **Gain Alignment**	<1%, typically better than 0.5%
• **DC Clamping**	Typically within 1 quantization level on field average.
Output	
• **Output Standard**	4:2:2, two BNCs as per SMPTE 259
• **Input to Output Delay**	3.6µs

G. Ultimatte 400-Delux Composite Video Mixer From the Ultimatte Corporation

Specifications	• Conforms to CCIR 601 • 10-bit or 8-bit SDI inputs and outputs • Internal Foreground and Matte processing 4:4:4:4 • 525 / 625 Auto-selectable
Video	
• **I/O Resolution**	4:2:2
• **FG Input**	4:2:2
• **BG Input**	4:2:2
• **Matte In**	4:0:0
• **Digital Reference**	4:2:2
• **FG and BG Out**	4:2:2
• **Internal FG Processing and Matte Generation**	4:4:4:4
• **Inputs**	Serial CCIR 601, BNC 75
• **Outputs**	Serial CCIR 601, BNC 75

H. SDC-100 Serial Digital to VGA Monitoring Converter From Leitch (D1 to VGA)

Serial Digital Input	BNC 75 ohm; 270Mb/s; 259M-C Up to 100m automatic cable equalization
Input Return Loss	13.9 dB at 270 MHz
VGA Monitor Output	Sub-D 15-pin female connector
RGB	±3 dB 0.7V, H+V TTL
Frequency Response	
• **Luminance**	±0.5 dB from DC to 5.25 MHz ±3 dB up to 10 MHz
• **Chrominance**	±3 dB up to 4 MHz
• **Gamma Correction**	Automatic
• **Standards**	525-line and 625-line auto switching

• **Signal-to-Noise**	-64 dB
625 line / 50 Hz mode with line doubling	
• **Horizontal Frequency**	31.25 kHz
• **Vertical Frequency**	50 Hz
525 line / 60 Hz mode with line doubling	
• **Horizontal Frequency**	31.469 kHz
• **Vertical Frequency**	59.94 Hz

I. VE CPU

Manufacturer / Model	Dell / Dimension 8100
CPU	Intel® Pentium® 4 1300 MHz
Memory	128 MB RAM
Operating System	Microsoft Windows 2000 5.00.2195 Service Pack 2
Monitor	Set to 640 x 480 for HMD compatibility 60 Hz
Power	Industry Standard for U.S. desktop computers

J. Instrument Panel

Manufacturer / Model	SGI / Silicon Graphics 320/540
CPU	X86 Family 6 Model 7 Stepping 2 SGI-320_ARCx86_mp
Memory	200 MB RAM
Operating System	Microsoft Windows 2000 5.00.2195 Service Pack 2
Monitor	SGI 1600 SW 60 Hz
Display Adapter Information	
• **Graphics Processor**	GeForce2 MX/MX 400
• **Bus Type**	AGP
• **Bios Version**	3.11.01.17.20
• **On-Board Memory**	32 MB
• **TV Encoder Type**	Conexant Bt869
Power	Industry Standard for U.S. desktop

	computers

K. Top Down View CPU

Manufacturer / Model	Dell / Dimension 8200
CPU	Intel® Pentium® 4 2.0 GHz
Memory	256 MB RAM
Operating System	Microsoft Windows 2000 5.00.2195 Service Pack 2
Monitor	Set to 640 x 480 for HMD compatibility 60 Hz
Power	Industry Standard for U.S. desktop computers

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