NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

HELICOPTER URBAN NAVIGATION TRAINING USING VIRTUAL ENVIRONMENTS

by

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June 2000

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2000	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

TITLE AND SUBTITLE : Helicopter Urban Navigation Training Using Virtual Environments	**5. FUNDING NUMBERS**
5. AUTHOR(S) Wright, George T. Jr.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE**

ABSTRACT ***(maximum 200 words)***

Helicopter missions are never defined as "…successful navigation to and return from a location." Navigation, in and of itself, is not the mission – it is, however, a skill that all helicopter pilots are expected to master in order to function as pilots. *Navigation is a means to an end.*

Helicopter operations, being inherently expensive and unforgiving of mistakes, are prime candidates for such innovative training techniques as virtual (3-D) fly-throughs. This thesis, as a logical extension of previous research, seeks out ways to enhance current training methods for urban helicopter navigation using state-of-the-art-technology. Using empirical data from pilot surveys and controlled experiments, principles can be formulated to determine the level of computer graphics fidelity necessary for helicopter crews to conduct a virtual flight in an urban setting that is a credible, effective tool in preparation of an actual flight.

This research does not seek a replacement method of training helicopter terrain navigation – pilots must still be taught the fundamental skills of map interpretation and terrain association using conventional training techniques. However, it is the intent of this research to explore methods of enhancing and supplementing site-specific helicopter navigation training through the transfer of spatial knowledge from the virtual world to real-world applications.

14. SUBJECT TERMS Helicopter, Urban Terrain, Virtual Environments, Navigation, Training, Mission Rehearsal, Spatial Orientation, Situational Awareness	**15. NUMBER OF PAGES** 130
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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HELICOPTER URBAN NAVIGATION TRAINING USING VIRTUAL ENVIRONMENTS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
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LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

2-D	Two Dimensional
3-D	Three Dimensional
AGL	Above Ground Level
API	Application Programmers Interface
ASH Manual	Assault Support Helicopter Manual
ASO	Aviation Safety Officer School
ATA	Airport Traffic Area
CBT	Computer Based Trainer
CDARG	Compressed Arc Digitized Raster Graphics
CIB	Controlled Image Base
CNO	Chief of Naval Operations
COTS	Commercial Off-the-Shelf
CPU	Central Processing unit
CSAR	Combat Search and Rescue
DED	Digital Elevation Data
DTED	Digital Terrain Elevation Data
FOV	Field of View
GB	Gigabytes
GeoTiff	Geo-Referenced Tagged Image File Format
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human Computer Interface
HMX-1	Marine Helicopter Squadron One
HS-10	Navy Helicopter Antisubmarine Squadron Ten
HUD	Heads-Up Display
Hz	Hertz
INS	Inertial Navigation System
IP	Initial Point
IT-21	Information Technology for the 21st Century Initiative
Knots	Nautical Miles per Hour
LADM	Large-Area Database Management System
LOD	Level of Detail
LZ	landing Zone
MB	MegaByte
MBT	Motion Based Trainer
MHz	MegaHertz
MITAC	Map Interpretation and Terrain Association Course
MITAVES	Map Interpretation and Terrain Association Virtual Environment System
Mm	Millimeter
MOOTW	Military Operations Other Than War
MOUT	Military Operations on Urban Terrain
MPEG	Motion Picture Expert Group

MSL	Mean Sea Level
NAVAIRSYSCOM	Naval Air Systems Command
NEO	Non-combatant Evacuation Operation
NIC	Network Interface Card
NIMA	National Imaging and Mapping Agency
NITF	National Imagery Transmission Format
NM	Nautical Miles
NOE	Nap-of-the-Earth
N-PFPS	Navy Portable Flight Planning System
NPS	Naval Postgraduate School
NVG	Night Vision Goggles
OPNAV	Office of the Chief of Naval Operations
OS	Operating System
PC	Personal Computer
RAG	Replacement Air Group
RAM	Random Access Memory
RPF	Raster Product Format
SGI	Silicon Graphics, Incorporated
TAMPS	Tactical Aviation Mission Planning System
TOPSCENE	Tactical Operation Preview Scene
USGS	U.S. Geological Survey
VE	Virtual Environment
VFR	Visual Flight Rules
V-HUNT	Virtual Helicopter Urban Navigation Trainer
VRML	Virtual Reality Modeling Language
WINTEL	Windows/Intel
WYSIWYG	What You See is What You Get
YAH Map	You Are Here Map

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank several individuals and organizations who, through their help, advice and support have made the completion of this thesis possible. First, I would like to thank Dr. Rudy Darken for providing me with the proper guidance, tools and environment with which to accomplish this meaningful task. John Locke's experienced and unique insight to the three-dimensional world, tireless devotion to the model creation, and infinite patience as a teacher and mentor proved to be invaluable throughout this research. I thank Barry Peterson for his help and insight into spatial cognition and the human-computer interaction aspect of my research. I want to thank Kristin Darken for graciously and professionally representing MultiGen-Paradigm, Inc., who provided the necessary tools and support for the model creation and run-time environment. The dedication of three fine military organizations – HMX-1, HS-10, and the School of Aviation Safety (ASO) – who supported this research project by providing valuable user input and feedback, is greatly appreciated. I owe a debt of gratitude to ONR and the MOVES research department for funding my research-related travel, and for providing me with the high-quality computer equipment with which to conduct my study.

Finally, I would like to say a special thank you to my devoted wife Lisa, daughter Amanda and sons Brad and Brian for their understanding and unwavering support during my two years of hard work and long hours at the Naval Postgraduate School. The completion of this thesis and earning a Masters Degree could not have been possible without their love and sacrifice.

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I. INTRODUCTION

A. PROBLEM STATEMENT

Helicopter overland navigation is a unique task, and a skill that does not come naturally to humans. It is an acquired skill that all pilots are introduced to during the ground-school portion of flight training, long before they are allowed to take the controls of an aircraft for the first time. But that's only the beginning. In order to become highly proficient at navigation, this perishable skill must be continuously honed over the course of an aviator's career, gaining experience navigating in all-weather conditions, and in many varied environments.

Although some pilots are better navigators than others, all are trained using identical training methods and techniques. The task of navigating in any environment is best learned through study, memorization, and repetitious training. For years, the teaching methodology for both civilian and military aviation training has been to use two-dimensional maps, aviation charts, photos, diagrams, images, etc. for helicopter route navigation planning. In preparation of a training flight, a pilot is typically expected to study the route, noting any significant cultural features, landmarks, man-made structures, etc., and perform a mental transformation to envision how the terrain would appear three-dimensionally through the aircraft's windscreen. Aside from training flights, however, preparing for real-world helicopter missions usually involves the use of the same 2-dimensional products, requiring the pilots to form a "mental picture" of the intended route.

Once in the air, the pilot attempts to "match" the actual terrain and/or man-made features on the ground with depictions on the maps or photos. Of course, on-board navigation systems and old-fashioned "dead-reckoning" techniques – applying heading, airspeed, timing and wind correction – are used to aid the pilot in staying on course and ultimately arriving at the desired destination. Ultimately, however, successful navigation depends on the pilots' ability to visually recognize the landmarks and checkpoints along the route to the final destination. This is a challenging task in good weather, during daylight hours in a familiar setting. If the scenario is set in darkness, with reduced visibility, and unfamiliar terrain, the challenge for the aircrew increases many-fold.

Helicopter missions are never defined as "...successful navigation to and return from location ABC." Navigation, in and of itself, is not the mission – it is merely a skill that all helicopter pilots are expected to master in order to perform their duties as pilots. While the mission might be to conduct a troop insertion at location ABC, or to evacuate U.S. citizens from Embassy XYZ, mission success may hinge on the pilot's ability to navigate to the prescribed location. Still, negotiating the prescribed route to the final objective is not the desired end result. *Navigation is a means to an end.*

Helicopter operations, being inherently expensive and unforgiving of mistakes, are prime candidates for such innovative training techniques as virtual 3-dimensional (3-D) fly-throughs. This thesis, as a logical extension of previous research, seeks ways to assist pilots in planning routes for and navigating in an urban environment using state-of- the-art-technology – namely, 3-D graphical displays and virtual fly-through computer models. The goal is to develop principles for the determination of the level of computer graphics fidelity necessary for helicopter crews to conduct a virtual flight in an urban setting that is a credible, effective tool in preparation of an actual flight.

Current high-end simulators and mission rehearsal trainers, such as the U.S. Navy's Tactical Operation Preview Scene (TOPSCENE™), while adaptable to helicopter operations, are primarily designed to aid fixed-wing pilots in mission rehearsal. Tactical Aviation Mission Planning System (TAMPS) is dated technology, and requires extensive training for proper use. Preliminary research also indicates that these systems are too costly for wide distribution, too large for space-conscious units such as shipboard-based squadrons, or too difficult to use and maintain. Furthermore, a recurring complaint heard through personal interviews with fleet helicopter pilots who have used such systems is that the database has limited coverage, and doesn't present the proper information in a usable form.

Commercial off the shelf (COTS) products, such as Microsoft's Flight Simulator ®, although inexpensive and easily obtained, are marketed as procedural trainers, designed primarily for fixed-wing pilots in the direct vicinity of well-known airport traffic areas. These low-end products use low-end graphics, too crude to be effective as a tool for helicopter pilots navigating in urban terrain. These systems will be covered in more detail in later chapters.

B. MOTIVATION

Current methods used by pilots for map interpretation, terrain association, route planning, and navigation are antiquated and hardly adequate. Using 2-dimensional maps, charts, and photos, pilots, both in the training commands and in operational squadrons, establish a route, conduct a pre-flight route study, then fly the route in the aircraft.

In the Naval Aviation Training Commands, using current training methodology, the majority of the practical navigation training takes place in the air. This is a very expensive, time-consuming, and inefficient means for teaching pilots to navigate – not to mention the inherent safety issues associated with complex aviation tasks.

In operational units, when a lack of time or presence of a threat precludes a mission rehearsal flight, the only opportunity for studying and practicing the route of flight is on the ground (or ship) prior to take-off. Hereto, pilots are relegated to conducting route navigation planning using 2-dimensional maps, charts, and photos.

Commands that are involved in real-world contingencies may have the good fortune to access up-to-date, high-resolution satellite imagery of the mission area. If the location is one in which previous operations have occurred, there may be video footage of the exact intended route of flight. These products, when available, can be invaluable tools for realistic, up-to-date route planning and mission rehearsal flights. In most squadrons, these luxuries rarely exist.

The aforementioned scenarios, and many others not mentioned here, all involve navigation, and lend themselves well to computer-based training (CBT) in preparation for helicopter missions. Using technological advances in computer graphics and virtual environment technology, a computer-based trainer offers pilots an interactive method of helicopter route navigation training. When used as a supplement to, not a replacement for conventional 2-D maps, CBT's can provide immediate feedback and unlimited repetition to reinforce learned skills, offering a low-cost, non-threatening environment for navigation practice. They enhance the pilots' navigation skill and performance in the aircraft by reinforcing what is learned through conventional methods, while eliminating the inherent safety concerns associated with actual helicopter training flights.

Previous research has shown that CBT's are an effective and efficient means for teaching pilots to navigate (Sullivan, 1998, McLean, 1999). LCDR Joseph Sullivan, USN, created a system at the Naval Postgraduate School in Monterey with the intent to improve the method used to train navigational skills for flight students in HS-10, the Navy's Antisubmarine Replacement Air Group (RAG) Helicopter Squadron. His system, called Map Interpretation Terrain Association Virtual Environment System (MITAVES), takes its name from the current system used at the Navy's Flight School, Map Interpretation Terrain Association Course (MITAC). Captain Timothy McLean, USMC, developed a follow-on system compliant with the Information for the 21st Century (IT-21) concept, dubbed MITAVES II. MITAVES II, a Microsoft Windows NT®-based implementation of the original MITAVES system, has improved graphics fidelity, high-resolution data and a better user interface.

MITAVES and MITAVES II utilized graphics models of undeveloped, open desert terrain. Although there are hills, small mountains, and dirt roads, these models did not include 3-dimensional man-made structures such as buildings, major highways, or bridges typically found in the urban environments.

The goal of this thesis is to continue to improve upon the previous system designs. In this, the third generation system for virtual helicopter navigation, the intent is to construct a model that incorporates urban terrain, including most of the natural and man-made features one would expect to find in a typical metropolitan area. This latest implementation, called Virtual Helicopter Urban Navigation Trainer (V-HUNT), running on the same Windows NT platform as MITAVES II, will be tested to evaluate its effectiveness as a credible training aid to helicopter pilots operating in and navigating through urban environments.

C. RESEARCH QUESTIONS

This research sets out to answer several key questions. First, what level of graphics fidelity is required for effectiveness in virtual models? High-fidelity graphics with detailed textures impose a tremendous burden on processing power and memory.

This research intends to introduce a method of reducing this strain on computer systems by performing selective modeling – modeling/texturing only those items and features necessary to accomplish the task.

This leads to the second research question: What needs to be modeled in order to produce an effective, credible training aid for helicopter urban navigation? Initially, it appears as if the degree of detail and fidelity in models is user perspective-specific. That is, certain tasks, such as strolling down city sidewalks, performing virtual window-shopping, demands great detail. Other applications, those that cover large geographical areas and are viewed from high altitudes for example, tend to have varying levels of detail. Some applications tend to model everything; others tend to omit too much detail. This research seeks to determine what needs to be modeled for applications in the helicopter flight regime – 0 to 10,000 feet altitude, and 0 to 180 knots airspeed.

Lastly, can this system be an effective training tool for pilots navigating in urban environments? Although it seems logical and intuitive that CBTs, using advanced technology, must aid in the training of navigation skills, research has shown that, in certain scenarios, using virtual worlds for training has a negative effect (Goerger, 1998). A goal of this research is to evaluate, through a controlled experimental setup, the V-HUNT system for its intended use – as a tool to help helicopter pilots plan routes for and navigate in urban areas.

It is not the intent of this research to seek alternative methods of training helicopter pilots in urban terrain navigation – pilots must still be taught the fundamental skills of map interpretation and terrain association – but rather to seek out ways to supplement, compliment, and enhance current methods of helicopter navigation training through the use of advanced technology; namely, computer-based trainers using virtual urban environments.

D. ORGANIZATION OF THESIS

This thesis is organized into the following chapters:

1. Chapter I: Introduction. This chapter includes an introduction to the problem, motivation, and an outline for this thesis.
2. Chapter II: Background. This chapter contains pertinent

Background information including a summary of Sullivan's and McLean's work, a description of helicopter navigation, Military operations on urban terrain (MOUT), urban helicopter navigation, and current methods used for navigation training.

3. Chapter III: Specifications. This chapter provides specifications for a computer based navigational training system, including the system, interface, Heads-Up Display (HUD), and terrain model requirements.
4. Chapter IV: Implementation and Verification of the Specifications. This chapter describes the implementation and verification of the MITAVES II and V-HUNT system according to the specifications outlined in chapter III.
5. Chapter V: Evaluation. This chapter describes the experiments used For evaluating the V-HUNT system.
6. Chapter VI: Conclusions. This chapter contains the conclusions reached from the testing process.
7. Chapter VII: Future Work. This chapter describes potential future work in this subject area of research.

II. BACKGROUND

A. HELICOPTER NAVIGATION

Helicopter navigation is a very difficult and challenging task. Due to the unique capabilities and missions of helicopters, they routinely operate in unusual environments where the difficulty of navigating is compounded. This section provides background information on the task of helicopter navigation, and describes what makes it such a unique, difficult, and challenging undertaking.

1. Basic Helicopter Terrain Navigation Task Description

What makes navigating from a helicopter more challenging than navigating on the ground? The Assault Support Helicopter (ASH) Manual describes the fundamental skills involved and lends some insight (CNO, 1992, p. 13-3):

> *The copilot/observer ... must be able to visualize from the map how the terrain around him should appear. He must also be able to look at the terrain, identify his location, and locate his position on the map.*

From a helicopter pilot's perspective, looking through the windscreen at the terrain as one flies over it and correctly identifying one's position on a map is not a trivial task. Helicopter flight crews generally use National Imaging and Mapping Agency (NIMA) 1:50,000 meter scale contour maps for flying over rural, unpopulated terrain, and Visual Flight Rules (VFR) sectionals, Terminal Area Charts, Helicopter Route charts, or City (tourist) maps in urban settings and populated areas. From the pilots' perspective, the task is to analyze the 2-dimensional maps in order to become familiar with the terrain, and then perform a mental transformation to imagine how the terrain will appear 3-dimensionally. Once airborne, the task is to form a comparison between the mental models and the egocentric map view to determine if there is a correlation. This process of associating viewed 3-D terrain features and the 2-D map, a process that is very familiar to infantrymen, continues until a match is found, and the navigator is convinced that he knows where he is "on the map". Although helicopter terrain navigation involves the same basic skills as traditional land-based terrain navigation, it becomes considerably more difficult as speed over and proximity to the ground increases.

a. Flight Planning

Once the geographical area is chosen for the flight, the appropriate map products are assembled and a thorough pre-flight map study begins. The purpose of the map study is to gain familiarity with the general lay of the terrain, vegetation, and the hydrographic and cultural (man-made) features of the area. The map study will also include identifying any hazards to flight. Although there are numerous natural terrain features that pose a danger to low-flying aircraft, the primary focus of the hazard review is the identification of man-made features including power lines, microwave towers, radio antennas, etc. There are modern electronic systems available that aid pilots in the process of route selection and planning, such as the Navy's Portable Flight Planning Software (N-PFPS), which will be addressed in chapter four.

Once the aircrew is familiar with the key features of the area, they will evaluate potential routes of flight to the intended objective area. Routes are defined by a sequence of prominent, identifiable landmarks known as *checkpoints.* Generally, the path between the checkpoints is only roughly planned. Routes are planned with specific criteria based on the mission; however, several factors are common to all missions. Route planning should make the best possible use of the terrain. Since the primary means of navigating relies on visual terrain recognition, one of the fundamental considerations is choosing routes that will sequentially connect easily recognizable terrain features. Terrain features used as aids to navigation fall into three categories: channeling features, checking features and limiting features. A *channeling feature* is used to maintain orientation during transit between checkpoints. Following along a river or mountain ridgeline is an effective use of a channeling feature. A *checking feature* is an easily identifiable terrain feature that will be visible along the intended route of flight. Any unique natural or man-made feature that can be seen from the planned altitude can be used as a checking feature. Examples include distinct river bends, highway intersections, water towers, lakes, and mountain peaks. Checking features can also be used as route checkpoints. Care must be taken when choosing man-made features as checking features and checkpoints. In tactical scenarios, or when using out-dated mapping products, man-made terrain features can appear and disappear rather quickly and unexpectedly. *Limiting features* are easily recognizable landmarks that indicate a checkpoint has been missed or passed. A prominent river, highway, or ridgeline perpendicular to the route of flight can be used as a limiting feature. Generally, 1:250,000-scale maps are used for the majority of the transit from base to the objective area. These maps offer a balanced mix of terrain contour lines for relief and high-level map symbology. They are also manageable and easily handled in the small confines of a cockpit. 1:50,000-scale maps are used once the aircraft approaches five miles of the objective area. These maps offer greater detail, and are therefore good for planning the terminal phase of the flight and the landing zones. Because two or more different scale maps may be used in the course of a single flight mission, a map *changeover point* is chosen and briefed to all crewmembers, so that everyone involved in navigation is reading from the same map with the same scale at the same time.

Flying with two or more different scale maps presents yet another challenge to the aircrew. When using the high scale map, the aircraft moves much slower over the paper than when a low scale map is used. For example, one inch on a 1:250,000-scale map is approximately 6,500 meters, while one inch on a 1:50,000-scale map is approximately 1,300 meters. When changing between maps with different scales, the aircrew must be aware of this fact and adjust accordingly. Although this is a basic concept introduced early in initial flight training, it often becomes a major learning point for novice pilots, and must be emphasized throughout the training evolution.

b. Navigation and Aircrew Coordination

During a flight, there are many demands on the aircrew, only one of which is accurate navigation. In multi-piloted aircraft, precise aircrew teamwork and cockpit coordination is required. Because the crew is required to perform multiple tasks simultaneously, the tasks of flying (actual manipulation of the controls) and cockpit management (including navigation) are divided among the aircrew. The pilot at the controls is in charge of flying and avoiding obstacles. His focus is primarily outside the aircraft. He must not be distracted from his flying responsibilities, particularly with cockpit related matters. He reports terrain and landmark/checkpoint information to the pilot not at the controls. The co-pilot, or pilot not at the controls, is responsible for accurately navigating from checkpoint to checkpoint along an intended route of flight. He must remain oriented at all times and inform the pilot at the controls of the direction and route to be flown and of appropriate airspeed adjustments for timing purposes. He is also in charge of general cockpit management –monitoring cockpit instruments, navigational equipment, radios and the lights and gauges associated with the mechanical functioning of the helicopter.

2. Military Operations on Urban Terrain (MOUT)

Based on historical precedence, military planners generally agree that most future conflicts will involve Military Operations on Urban Terrain (MOUT). Past Military Operations Other Than War (MOOTW) such as Non-Combatant Evacuation Operations (NEO) in Hanoi, Grenada, Liberia, Zaire, and humanitarian/ peacekeeping operations in Somalia and Bosnia, are clearly indicative of the necessity for increased MOUT training if we are to be successful in future military operations in urban environments. As long as the U.S. and its allies seek to further regional stability throughout the world using military intervention, our military commanders must train to be proficient at integrating all combat arms in MOUT.

The future of warfare is destined to take place in city streets, amongst high-rise buildings, third-world ghettos, alleys, and industrial parks. Recent history shows us that the next likely mission environment is in populated urban settings. Due in large part to the intense urbanization that has occurred since the 1940's, MOUT operations have continued to play a key role up to the present: In Grenada and Panama, U.S. Marines and soldiers found themselves committed to the MOUT battle, as did coalition forces in the liberation of Kuwait City during Desert Shield/Desert Storm. In 1993, U.S forces found themselves decisively engaged with a stubborn enemy on its own territory – the streets of Mogadishu, Somalia. As of March 1999, 237 of the last 250 USMC overseas deployments involved urban operations (Usry, 1999). As world population increases, the potential for heightened instability in some of the world's larger cities is inevitable.

Intervening military forces must be prepared to manage the many diverse complexities associated with operations in these environments.

For the aviation units, providing air assets in support of ground forces operating in urban terrain is a most challenging task Communications, logistics, supporting arms coordination and navigation are but several areas of concern to aviation units operating in an urban setting – a setting far more complex, diverse and uninviting than wide open terrain. Future urban warfare will likely utilize aviation assets more often due to advancements in fixed and rotary wing aircraft. Helicopter gunships will be required to provide close air support in the confines of city streets, the transport helicopters will be tasked with the timely delivery of ground forces to the urban area of operations, or conduct a NEO from a downtown location, or perform a medical evacuation of wounded from the city to a remote hospital facility or ship, or execute a tactical recovery of downed aircraft and personnel (TRAP) mission. Since we plan to fight like we have trained, we must endeavor to train as we intend to fight.

a. Urban Helicopter Navigation

Navigation in urban environments can be more difficult than over natural terrain due to an *over-abundance* of visual cues. The high density of structures, wide variety of geographical features, and increased lighting levels can create a "visual saturation" for the aircrew. Familiarity with the characteristics of urban terrain allows the aircrew to discern and identify key features from the cluttered urban environment. Typically, when we look at a city, we see clutter, confusion and chaos. Thorough pre-mission planning, to include a detailed study of all available flight planning appropriate for the mission, is essential to preparing for urban flight operations.

Accurate and efficient navigation performance in urban areas, like wayfinding tasks in general, improves with increased spatial knowledge of the environment (Darken & Sibert, 1996). This knowledge is described in terms of three hierarchical levels of information (Thorndyke & Goldin, 1983):

- *Landmark knowledge: information about the visual details of specific locations in the environment. It is memory for notable perceptual features such as uniquely shaped buildings.*
- *Procedural knowledge (route knowledge):- information about the sequence of actions required to follow a particular route. Procedural knowledge is built by connecting isolated bits of landmark knowledge into larger, more complex structures.*

- *Survey knowledge: configural or topological information. Object locations and inter-object distances are encoded in terms of geocentric, fixed, frame of reference. A geocentric frame of reference is a global, map-like view, while and egocentric frame of reference is a first-person, ground-view relative to the observer. Survey knowledge has been found to be essential for skillful wayfinding (Lynch, 1960).*

Unlike natural terrain flight, urban areas offer numerous vertical and linear visual references. Selection of key features within an urban area facilitates general orientation and back-up navigation. The most prominent vertical structures – radio antennas, microwave towers, distinctive skyscrapers – are visible from nearly any direction in a major metropolitan city. Use of these features as heading references is an effective method of remaining spatially oriented. Linear features such as major highways, rivers and coastlines, form key lateral boundaries that assist the aircrew in maintaining orientation over unfamiliar terrain.

One of the key factors to successful pre-flight preparation in urban areas is the amount of intelligence data and flight planning products available. Aircrews need every possible intelligence item available to assist in developing a mental picture of the ingress route, landing areas, and egress route. Specifically, intelligence should provide to the aircrew appropriate maps, charts, and photos of Initial Point (IP), checkpoints, and Landing Zones (LZs) from as many different angles as possible to help the crews identify these areas. The aircrew must memorize the route of flight from the IP to the LZ. Ground and aerial photos, combined with urban city maps, and augmented with satellite imagery will assist the aircrew in this task.

Military tactical land maps, particularly contour maps, are not well suited for operations in the urban environment. The scale and level of detail are not sufficient for terrain orientation required in cities and built-up areas. Furthermore, the procedures for map interpretation and terrain association using contour maps in open, natural terrain are quite different from the procedures using city maps in urban areas.

Accurate urban navigation requires the use of NIMA 1:12,500, 1:25,000 or larger scale civilian city maps. These maps are very useful for pre-mission planning, and should be augmented with recent aerial photos/imagery products to reflect key natural and man-made terrain features and obstacles to flight. Often, tourist maps show greater detail and are more current than military maps. Although these types of maps may be ideal for planning the route, they are sometimes too large to manage in the cockpit. For this reason, the map may need to be divided into logical, manageable sections. An effective technique for combining the vital flight information and reducing the number of maps used in the aircraft is to transpose key flight information from a VFR sectional chart onto the city map.

b. Selection of Route Checkpoints

Route selection is a critical aspect of helicopter urban operations. Preparing for and conducting a flight along a navigation route requires the use of all three types of spatial knowledge. Because visual identification and landmark recognition is critical for each individual checkpoint, pilots must rely on landmark and survey knowledge. Procedural knowledge is applied for sequential navigation along the route linking the checkpoints.

The mission and/or the threat will determine the altitude, airspeed, and flight formations. Route selection should take into consideration the tactical element of surprise, flight safety, ease of navigation, and threat avoidance. For tactical missions, pilots should attempt to use terrain masking and cover from possible threat locations, avoiding exposure to heavily populated areas as much as possible, and minimize the risks of encountering urban hazards to flight.

Route planning in urban areas differs from other environments due to the fact that no two urban areas are identical. What works well in San Francisco, California may not be appropriate for Beirut, Lebanon. Timing and clock references are critical to accurate navigation for helicopters, even when aided by on-board state-of-the-art equipment such as Inertial Navigation Systems (INS) and Global Positioning System (GPS). Urban navigation is less difficult if prominent road intersections, vertical development, or even radio towers are used as checkpoints along the intended route of flight. Two features that make good checkpoints for night missions are cemeteries and city parks, because they typically have little or no lighting in an area otherwise saturated with lights.

Other urban features that make excellent checkpoints to helicopter route navigation include:

- Tall, distinctively marked or oddly shaped buildings
- Churches with high steeples
- Major highways, road networks, and intersections
- Rivers, lakes, reservoirs
- Major power lines
- Radio antennas and microwave towers
- Sports stadiums
- Ball fields (Football, soccer, baseball, etc.)

Generally, manmade structures provide excellent geographical checkpoints. The density of wires, towers, signs and poles is greater in an urban area than in a rural environment and will require avoidance procedures. If aircrews operate in the same urban area for several days, a master hazard map should be created, updated and consulted prior to each flight by every flight crewmember. Many built-up areas with low elevations and high water tables must place all cables, pipes, etc., above the ground. Urban coastal cities have many above ground obstacles to flight. Bridges may be of sufficient height for helicopters to fly beneath them vice over them. In order to accomplish this, a thorough bridge survey must be conducted to include water line clearance and associated hazards.

Urban man-made structures can be treated the same as any other topographical feature. Large high-rise buildings can be considered similar to mountains, and a six or seven block area of high-rise buildings can be treated in a similar fashion as a canyon area with appropriate draws and saddles. Considering man-made structures as normal topographical features, along with the additional hazards inherent to urban areas, can make the flight planning process more straightforward. Selection of route checkpoints, IPs and LZs should rely on readily recognizable urban structures such as tall buildings, power plants, sports stadiums, ball fields and city parks. Photos of IPs and LZs are recommended to aid in positive identification.

c. Landing Zone Selection

Landing Zone (LZ) selection considerations vary only slightly from rural LZ considerations. Planning begins with physical inspection of the LZ if time and tactical scenario permits. If not, intelligence information gathering, studying all available and appropriate flight planning products, and answering the questions in a typical LZ brief will suffice. In urban areas, the following considerations need to be addressed:

- What identifiable features around the LZ offer visual references for helicopter ingress and egress?
- Are there unmistakable landmarks around the LZ that will give the aircrew critical reference information as the helicopter approaches from the IP?
- Are nearby buildings, parking lots and streets lighted?
- Will a steep approach or unusual maneuver be required for landing?
- How will the wind affect approach, landing and departure?

As flight crews become more familiar with the operating area, more use is made of local landmarks during flight. It is natural, even expected, that aircrews will become more comfortable with the urban geography and major landmarks as familiarity is built in the operating area.

B. CURRENT NAVIGATION TRAINING METHODS

The task of navigating, although encompassing many varied skills, can be reduced to the act of *map interpretation* and *terrain association.* Map interpretation is the ability to read a map, to understand the meaning of the mapping symbology, the cultural and man-made features, and to interpret the relative scaling, size of objects and geographical distances depicted. Terrain association is the act of correlating the mental model of the terrain to its corresponding "real-world" appearance.

The procedures for map interpretation and terrain association are completely familiar to infantrymen, and many flight students begin this portion of training having had some previous exposure to map-reading from the ground perspective. Nonetheless, adapting these procedures to the air, from a helicopter traveling at speeds up to 180 knots at altitudes of 50 to 1,000 feet are quite difficult. Additionally, these skills must be adaptable to changes in flight profiles – altitude and airspeed for example – for each flight regime requires a slight variation of map interpretation and terrain association skills and procedures. For example, the navigation skills involved in flying over terrain at 1,000 feet above ground level (AGL) and 70 knots are quite different from those skills requires to navigate at 50 feet AGL and 100 knots. Furthermore, navigation skills must adapt to various types of terrain. The skill required to navigate over a desert differs from those required to navigate through mountainous terrain, which differs from navigating in an urban environment. These concepts are summarized in (CNO, 1992, p. 13-6).

> *Navigation during terrain flight would be no appreciable problem for the experienced pilot if the navigation skills used at higher altitudes could be employed at terrain flight altitudes. However, these skills cannot be transferred, and experience navigating at altitude does not prepare a pilot for navigating in terrain flight, particularly when using Nap of the Earth (NOE) flight techniques.*

1. Navigation Training in Naval Training Commands

The technique of reading a map and associating it to terrain features is introduced to student naval aviators in the Map Interpretation and Terrain Association Course (MITAC) during initial flight training. This course is designed for students who have completed primary helicopter training in the TH-57 Bell Jet Ranger, and are entering the intermediate phase of training. By this phase, the students are comfortable and very familiar with how to fly the helicopter, and are now beginning to investigate helicopter tactics. The first stage of MITAC training is designed to familiarize the student with how to read a 1:50,000 scale contour map. This course is primarily VHS video based. Students watch a videotape, followed by a question and answer period in which an instructor answers students' questions about the subject material. The tape is divided into two parts – the first part explains how contour lines on the map represent terrain features on the earth. Various examples of contour lines representative of major terrain features, such as mountains and valleys, are shown and correlated to actual pictures of the terrain. Next, students are instructed on standard terminology used to describe terrain. Lastly, contour map symbology is discussed.

This portion of the MITAC training is an excellent introduction to map interpretation. It presents material that must be memorized through repetitive exposure. Wickens (1992) describes this as *declarative knowledge*, and suggests that this type of knowledge is best learned through study and rehearsal. Accordingly, the first portion of the MITAC video lesson results in a solid introduction to the terminology, mapping symbols, and the specifics of map interpretation.

The second part of the course instructs the students on how different environments, such as desert or mountainous terrain, are represented by the contour lines on a map. More specifically, and more importantly, this section of the course teaches the student how to associate the terrain in front of them to the contour lines on their maps. This technique is called *terrain association.* The first step in this series of instruction is a thorough map study. Students become familiar with how the terrain from a specific area is represented on a map. Then the flight period begins by showing a helicopter moving approximately twice its normal speed over open terrain. While watching the video, the student is tasked with tracking the helicopter's flight path on a laminated contour map using a grease pencil. The video runs continuously, from the beginning of the route to the end. The student must interpret the terrain they see from the helicopter cockpit perspective, and quickly and accurately associate it to the contour lines on the map. The last period is a flight debrief that re-flies the route, stopping at key points along the way to show the students the visual cues they should have been looking for as the flight progressed.

This portion of the MITAC course is an exercise in frustration, and is completely ineffective in training new pilots the task of navigational skills. While the students' heads are down looking at the map, they miss a lot of critical information on the video screen, and because the aircraft is traveling at such a high airspeed, there is never a chance to recover from disorientation. Projecting the video onto a single screen presents a severe limitation in the students' field of view, with no opportunity to scan the peripheral for other key visual cues for navigation and orientation. Lastly, the MITAC video is completely non-interactive. For the duration of the flight, the students are in the "information receive" mode, with no feedback, and no chance to offer input or ask for assistance. There is no ability to track students' progress, so they never know if they are on course or if a mistake has been made. The MITAC training system is not designed to allow a student who becomes disoriented to go back, correct a mistake and get back on course.

Due to these shortcomings of MITAC training, students often make mistakes very early in the videotaped flight, and since the video never stops or slows down, a five-minute training evolution quickly becomes a useless, frustrating, counterproductive period. While making mistakes during these early stages of training is expected, the training environment should attempt to minimize their likelihood. These types of mistakes, caused more by a training environment that doesn't allow for interactivity than by the students' inabilities, may cause students to become so frustrated that they actually lose confidence in their ability to learn this critical skill. Because students may feel uncomfortable performing these tasks during the training flight, their apprehension could lead to a severe barrier to learning.

This portion of the MITAC training attempts to teach students how to perform the task of map interpretation and terrain association. These tasks are best described by Wickens (1992) as *procedural knowledge* tasks used in the performance of an action, best learned through performance, practice, and rehearsal. The second half of the MITAC training actually violates several key points that Wickens (1992) makes regarding training. He suggests that it is crucial that students not be allowed to make mistakes early in their training. Preventing errors early on will build self-confidence, and reinforce proper habit patterns related to the task. Allowing the student to make a significant amount of mistakes while learning a new task or skill can have reverse effects. MITAC videos allow students to make errors early and often, without any opportunity for correction, thereby limiting its value as an effective training tool.

Wickens (1992) also suggests that knowledge of results can be very beneficial to students. Feedback – positive or negative in nature – tends to encourage students to perform the task correctly, and assists the students in identifying and correcting mistakes as they are made. Unfortunately MITAC videos provide no feedback to students in the performance of the route-tracing task, so students are void of any constructive feedback information until the task is completely over.

2. Navigation Training in Operational Squadrons

As mentioned before, navigation is an integral part of virtually every helicopter flight. Current training in operational helicopter commands continues to build upon previous navigation skills taught during initial flight training. The basic procedures employed for most any navigation tasks are very similar to those introduced during initial flight training. For the remainder of an aviator's career, he or she will continuously hone and improve their navigational skills.

When preparing for a flight, the aircrew devotes some amount of time during pre-flight planning to select, study, and mentally rehearse the intended route of flight. Using standard NIMA 2-dimensional maps and charts, supplemented with photos if available, aircrews conduct a thorough map study of the geographical area expected to be covered during the flight. If the terrain is familiar to the aircrew, the map study may be merely a brief review. If this is a flight over unfamiliar terrain, the map study may be very in-depth, and could take two to four times the amount of effort and time to become familiar enough for successful navigation. The mental rehearsal of the intended route of flight should be repetitive in nature.

Prior to departure, a cockpit crew-coordination brief will delineate responsibilities and aircrew duties to be performed throughout the flight. It is the navigator's responsibility to remain oriented at all times, and to constantly feed vital navigational information using standard terminology to the pilot at the controls. The route of flight will most likely be a series of pre-selected checkpoints, connected from the start of the flight to the end. Depending on the mission, the threat, and the aircrews' familiarity with the terrain, there may or may not be an opportunity to return to missed checkpoints for positive identification. If there is an opportunity to return to missed checkpoints, the aircrew may decide this is necessary in order to remain exactly on course and completely oriented throughout the course of the flight. Otherwise, the navigator must know at all times where he/she is on the map and over the terrain. If a checkpoint is missed or flown past, it is the navigator's responsibility to know which direction and at what distance the checkpoint was missed or over flown.

It is evident then, that regardless of the mission or familiarity with the terrain, a thorough pre-flight route study using all available products and tools is essential to a successful navigation evolution. The better the pre-flight preparation is, the less difficult the actual navigation task becomes once in the air.

Using current navigation training techniques and procedures, the majority of the practical training occurs in the aircraft. Unless the route of flight is familiar to the aircrew, it is very difficult for them to know precisely what to expect the terrain to really look like until they actually see it from the aircraft. This brings up several key issues. The cost per flight-hour to operate a helicopter for training flights is substantial – obviously less for smaller helicopters and more for larger ones – and considerable maintenance time and costs are incurred for each training evolution. Furthermore, while nothing can replace the experience received from actual aircraft flights, the more preparation that can be conducted on the ground, the better prepared the aircrew will be in the air. This preparation will enhance the training experience received during the actual flight, resulting in a reduction in the number of mistakes made and time-to-train, and, correspondingly, a significant reduction in overall aircraft flight time. Lastly, and most importantly, quality time spent in pre-flight preparation by the aircrew adds significant value to the precious time spent in the air, and reduces the amount of time exposed to an environment inherently unforgiving of mistakes.

C. SUMMARY OF PREVIOUS RESEARCH

The Naval Postgraduate School (NPS) has been experimenting with virtual environments and how humans interact with them for several years. Spatial knowledge, or spatial cognition, is a mental representation of a real or virtual environment. Spatial knowledge of the environment is essential for the development of an accurate mental map, and fundamental to effective and efficient navigation skills. The Interact Research Group at NPS has been conducting research to determine if virtual worlds can help individuals gain spatial knowledge of urban and natural environments.

Experiments measuring the usefulness and effects of navigation training using virtual worlds have been conducted using open terrain models and multi-storied buildings as virtual environments. Previous work at NPS in the field of virtual environments as it relates to land navigation includes: Major William Banker's Virtual Environments and Wayfinding in the Natural Environment (Darken and Banker, 1997), Captain Simon Goerger's Spatial Knowledge Acquisition and Transfer from Virtual to Natural Environments for Dismounted Land Navigation (Goerger, 1998), and LtJG Helsin Cevik's Map Usage in Virtual Environments (Cevik, 1998). Previous work at NPS in the field of virtual worlds as it applies to helicopter route navigation includes: LCDR Joseph Sullivan's Helicopter Terrain Navigation Training Using a Wide Field of View Desktop Virtual Environment, (Sullivan, 1998), and Captain Timothy McLean's An Interactive Virtual Environment for Training Map-Reading Skills in Helicopter Pilots, (McLean, 1999).

Sullivan's work identified helicopter pilots as the principle subjects in an open terrain experiment. In his work, a desktop computer system was developed to teach helicopter pilots how to navigate using 1:50,000 contour maps. The computer used was an Indigo2 graphics workstation from Silicon Graphics, Inc. (SGI). The system was composed of a single R4400 200 MHz CPU, 128 megabytes of RAM, a High Impact graphics board with one megabyte of texture memory, and an IMPACT Channel Option Board. The IMPACT board allowed for the use of up to four monitors. Four 19-inch monitors, with 640 x 680 resolution each, were set up in a semi-circular configuration, which provided 95 degrees field of view (Figure 1).

A Flybox from BG Systems, Inc. (Figure 2) was used as the control device and consisted of a control stick similar to that in an aircraft. The stick had a trigger button on the front, and the stick was able to rotate about its axis to provide for control in the yaw axis. There are 10 buttons and two additional levers on the base of the Flybox. One of the levers was used as a throttle, and the other lever and all ten buttons were not used.

Figure 1. Original MITAVES four-monitor configuration.

The software for the simulation was developed using the Performer application programming interface (API) from SGI. A simple form of terrain following was created that eliminated the possibility of crashing into the ground. Altitude, airspeed and bearing were fixed, and the helicopter basically flew itself. This was done to reduce the cockpit workload on the student who was concentrating strictly on navigation.

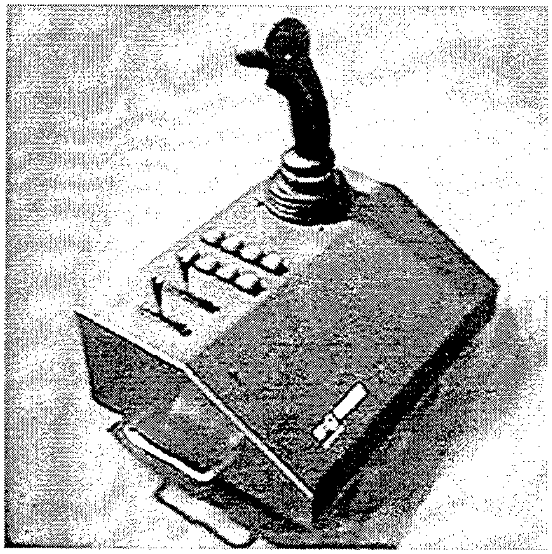

Figure 2. Original MITAVES Flybox Interface.

Sullivan's goal was this:

> *To design a functional computer-based simulation tool with a simple user interface to a virtual fly-thru application and with a wide field-of-view display to help train helicopter pilots the skill of terrain navigation.*

Mechanisms for increasing a student's spatial awareness in the simulation were incorporated. These mechanisms were developed with the intention of making it easier to teach a student the art of map interpretation. One such mechanism was the ability to display an exocentric, or external, viewpoint within the virtual environment (Figure 3). The exocentric viewpoint can be thought of as a momentary departure from the helicopter to gain a "birds-eye" view from outside, giving the user the freedom to view his spatial position and orientation from different perspectives and viewpoints. Previous studies suggest that an exocentric view is useful for information about a large-scale space (Koh, 1997; Elvins, 1998) "This view can be useful for navigation because it shows the local context around the viewpoint without losing perspective" (Sullivan, Darken & McLean, 1998). Sullivan decided to integrate the egocentric and exocentric viewpoints. To accomplish this, the student can detach the egocentric viewpoint and move up and away into the exocentric viewpoint. This facilitates a smooth transition from the egocentric to the exocentric viewpoint and keeps the user oriented. Also, this method minimizes the potentially disorienting effects of sudden teleportation to a different location. Once outside and away from the helicopter, the viewpoint is moveable in a circular fashion, pivoting about the helicopter's position. This feature allows the student to look around, yet stay oriented towards the helicopter located at the center of the circle. When the trigger on the joystick is released, the viewpoint slowly and smoothly retraces the path and returns to the helicopter's perspective view. The slow rotation and smooth transition from exocentric to egocentric views helps keep the student oriented while maintaining situational awareness.

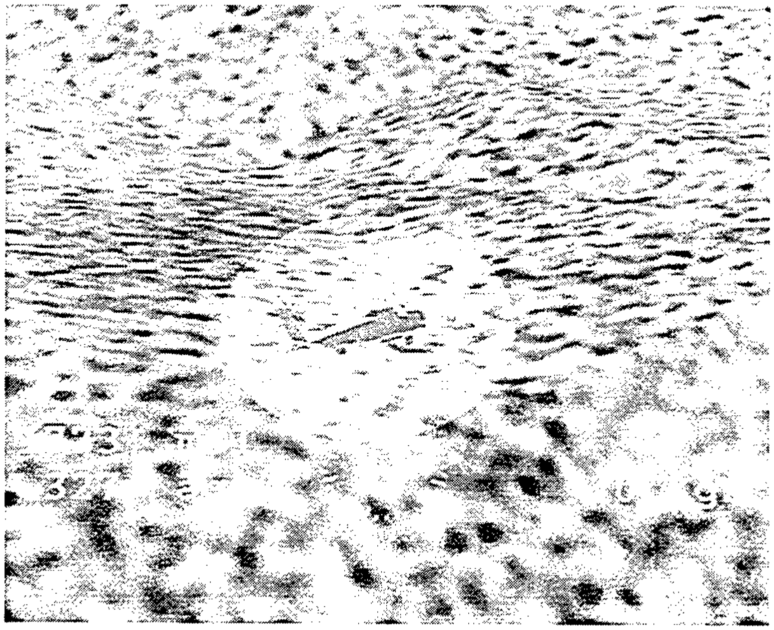

Figure 3. Original MITAVES Exocentric view.

A heads-up display (Figure 4) was used to give the student important information relevant to the flight. Hereto, this information is presented less to simulate the interior design of an actual aircraft, but to assist in keeping the student spatially oriented. This information included readings for:

- barometric altitude -- height above mean sea level
- radar altitude – height above the ground
- heading
- airspeed

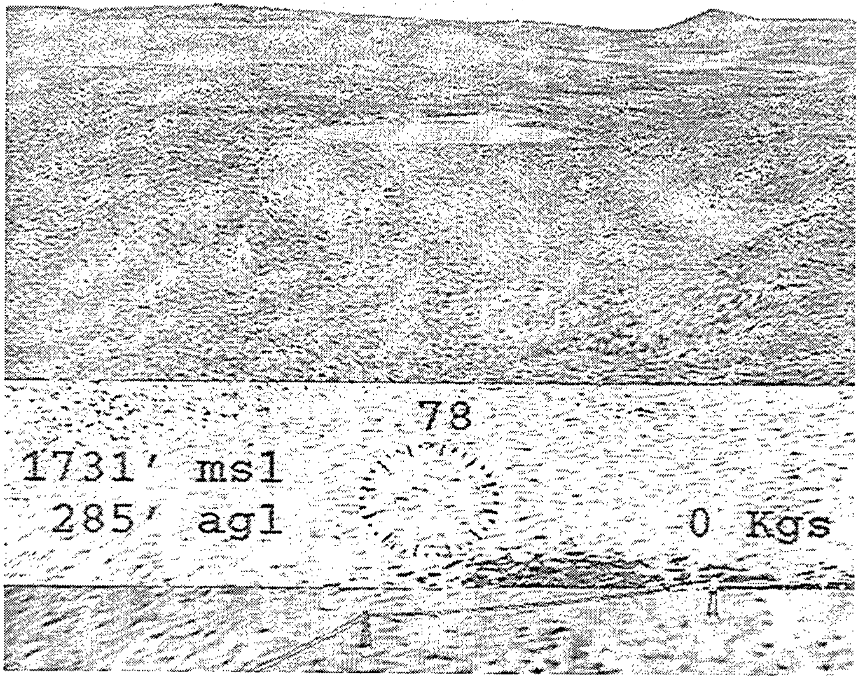

Figure 4. Original MITAVES Heads-Up Display (HUD).

Another mechanism for helping to maintain spatial orientation, as well as for teaching map interpretation is the "You Are Here" (YAH) feature (Figure 5). This map was intended to be referenced by student pilots when they needed assistance in regaining positional orientation, or used as confirmation of exact geographical location. The presumption here is that the more oriented a pilot is while operating in the virtual world, the less time is spent lost, confused or disoriented, the more valuable the time is learning map interpretation using the virtual trainer. By pressing the keyboard spacebar, the pilot could instantly display a digital representation of the paper map being used for navigation. On the YAH map was a black line indicating the intended route, a red line indicating the actual path flown, and a marker showing the current position of the helicopter. The top of the YAH map was always relative to the direction the student was flying instead of a "north-up" view. This was because previous studies suggest that track-up maps are best for egocentric tasks such as navigation (Aretz, 1992; Levine, 1982; Cevik, 1998). When the YAH map was displayed, the motion of the helicopter was frozen so the student could study the map, yet not continue to fly with the map displayed. Pilot studies conducted during the initial MITAVES implementation (Sullivan, 1998) have shown that if the motion continues while the YAH map is displayed, students will simply attempt to fly the helicopter in such a manner as to ensure the red line matches the black line, gaining no appreciable training from the tool.

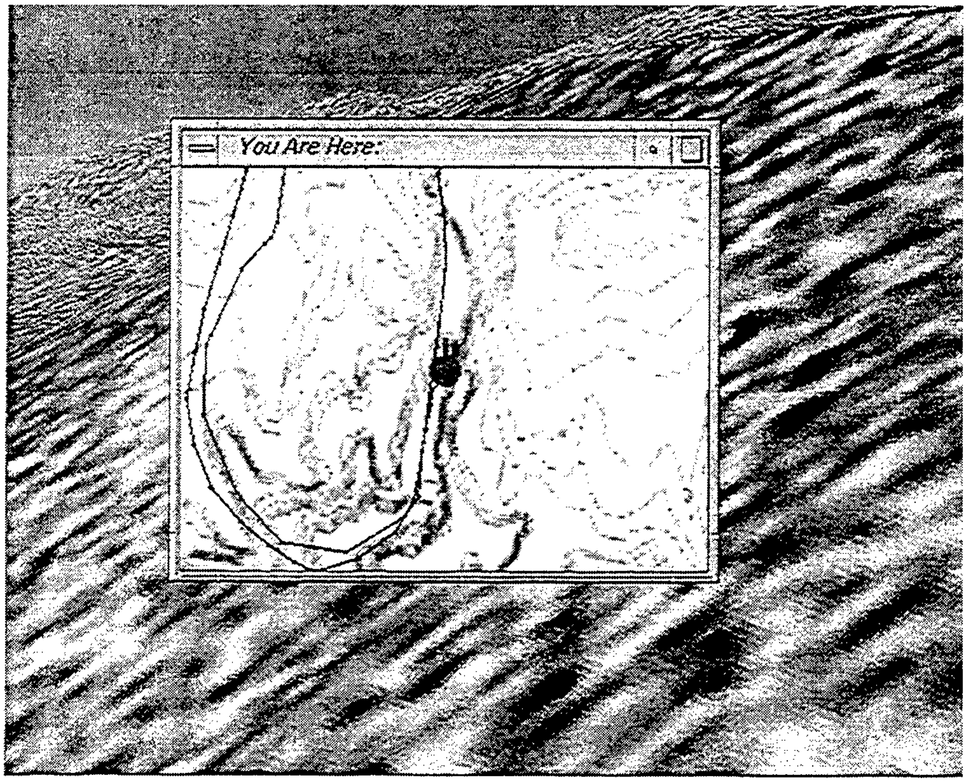

Figure 5. Original MITAVES "You Are Here" (YAH) Map and HUD.

The original terrain database was virtual Camp Pendleton, California. This area was chosen for several reasons:

- Proximity to Naval Postgraduate School was convenient for conducting this research.
- Military Installation, therefore NIMA unclassified data was available.
- Co-located with a pool of users for proof of concept system evaluation.

The data used to generate the terrain model included Digital Elevation Terrain Data (DTED) level 1, and geo-rectified multi-spectral satellite imagery. DTED level 1 is 100-meter resolution, and the satellite imagery used was 30-meter resolution rendered in color. Due to the low resolution of the texture, the terrain appeared as large colored blotches when flying over it at low altitudes. This lack of resolution provides little contrast between the terrain features, and makes it difficult to determine one's relative speed across the terrain. These limitations forced the use of a detail texture to be added to the imagery in order for the virtual terrain to be interpretable.

Sullivan's experiment was conducted using test participants from HS-10, the Navy's Antisubmarine Helicopter Squadron at NAS North Island, Coronado, California. Through experiments with this group of student pilots and instructors, Sullivan concluded that students were able to correlate the contour map to the terrain in the virtual environment. Furthermore, the feedback and the interface in the system's design were determined to be effective, thus increasing the student's ability to resolve the egocentric view with a contour map representation. This was the first in a series of studies to be conducted by NPS master's candidates in this field of research.

Captain Timothy McLean, USMC, (McLean, 1999) continued the research in the field of virtual environments relating to helicopter terrain navigation training. By identifying some critical shortcomings of the original MITAVES design, McLean set out to make improvements to the system. His first goal was to move the terrain database model from the SGI proprietary hardware to a platform conforming to the Information for the 21st century (IT-21) standards. This was accomplished using an Intergraph® GT1 2000 PC, with a three-screen monitor configuration, and Windows NT operating system. The Intergraph box consisted of dual Pentium® II 450 processors, 512 megabytes RAM, three Wildcat 4000 graphics cards, and a geometry accelerator (Figure 6). The software used for terrain generation was the commercially available MultiGen-Paradigm, Inc.'s Creator®. The runtime environment was MultiGen-Paradigm, Inc.'s Vega® version 3.2.

For MITAVES II, the terrain database used was virtual Ft. Irwin, California. The elevation data used for the terrain model was DTED level 2, and the satellite imagery for the texture was Controlled Image Base (CIB) 5. All the data formats were unclassified, and obtained free of charge through NIMA.

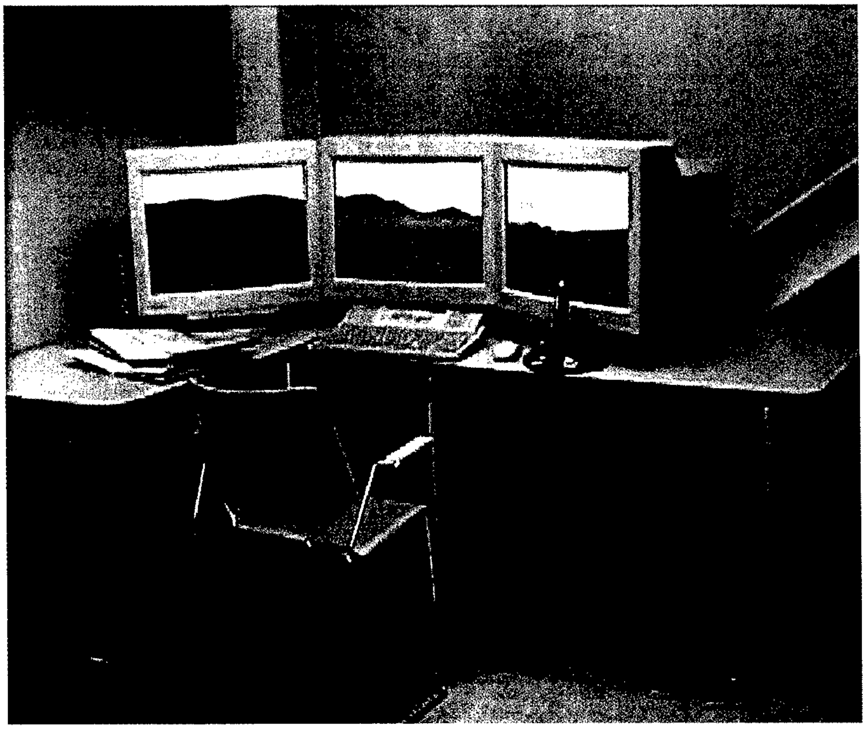

Figure 6. MITAVES II Three-Monitor Configuration.

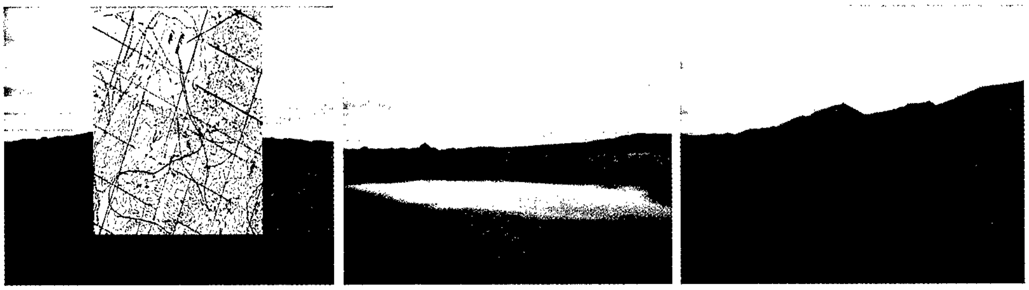

Figure 7. MITAVES II "You Are Here" (YAH) map and HUD.

Other important improvements incorporated into the 2d generation model, called MITAVES II, included a better Heads-Up Display (HUD), an improved YAH map display, and a simpler user interface. The flight information provided to the user via the

HUD included heading, barometric altitude, radar altitude, airspeed, and an artificial horizon showing indications of pitch, roll and angle-of-bank (Figure 7). The user interface was a Microsoft Sidewinder 3D Pro® joystick.

Improvements to the MITAVES hardware, combined with utilizing CIB 5 and DTED level 2 data, significantly enhanced the resolution and fidelity of the terrain model. Also, improvements to the HUD and using a modern "helicopter-like" joystick as the user interface made the system easier to operate and more user-friendly. Although the differences in the systems' hardware from the first generation MITAVES to MITAVES II are substantial, the changes in the training aids of the two systems are relatively minor. Most of these changes result from the ability of the more capable hardware to handle the increased resolution of the terrain data. For the most part, the basic functionality of the original MITAVES was preserved in the more advanced, IT-21 compatible second-generation system.

McLean's research goals were these:

- Migrate to an IT-21 compliant, PC-based platform.
- Improve upon the original MITAVES design with better graphics, improved HUD, and higher resolution data.
- Conduct a more focused study with pilots to determine if the 2d generation system could be used to train the tasks of map interpretation and terrain association.

MITAVES II was deployed to HS-10 for an evaluation period by student and instructor pilots. The data collected during this study showed that MITAVES II was an effective training tool for its intended use – helping to train helicopter pilots in the task of terrain navigation. Student pilots who used the system generally earned higher navigation grades compared to students who did not use the trainer. In the opinion of the instructor pilots at HS-10, MITAVES II was an invaluable tool for training the necessary navigation tasks. However, all research to this point has been specific to contour map interpretation and terrain association in undeveloped, natural desert environments.

The intent of this thesis is to employ the same hardware and software applications employed by previous designs, with specific focus and emphasis on the task of helicopter navigation in urban terrain.

III. SYSTEM SPECIFICATIONS

A. SYSTEM REQUIREMENTS

System requirements define the general characteristics and specifications of the system's hardware. Some requirements are dictated by military standards, while others are self-imposed based on this author's goals and expectations for the system's intended applications. The system requirements and specifications contained herein for the V-HUNT design, with few exceptions, are identical to, and have been adapted from the system requirements and specifications as outlined for the MITAVES II design (McLean, 1999).

1. The System Must be Unclassified

At its lowest security level, the system must be unclassified. This requirement stems from the fact that this system is intended to satisfy the needs of a broad audience from various communities with varying levels of security clearances. There are numerous unclassified uses and applications for this system, and lack of a clearance should not be a barrier to the invaluable training available through the use of this device. Conversely, if there is an application suitable for this system that requires a higher level of security, the steps and procedures to elevate the level of classification should be easily managed.

Another reason for an unclassified system is data access and storage. For the purposes of designing, maintaining and securing the system, doing so in an unclassified environment allows for greater access to data, widening the scope of available information needed in the design phase, and significantly reducing the security burdens inherent to classified systems.

2. The System Must be IT-21 Standards Compliant

The system must comply with Information for the 21st Century (IT-21) standards. IT-21 was promulgated by standard Navy message in March 1997 (IT-21, 1997). IT-21 (1997) describes the direction and implementation of the IT-21 concept. IT-21 (1997) directs that all Department of the Navy (DoN) activities will use PC solutions based on the Windows/Intel (WINTEL) platform. Microsoft Windows NT®

4.x is to be the standard operating system, and software such as Microsoft Office® and Microsoft Exchange® are to be the IT-21 standard for office automation. IT-21 also directs a minimum standard for future purchases of PC hardware. The minimum processor speed is to be that of an Intel Pentium 200 MHz processor, minimum memory (RAM) is to be 64 megabytes, and a 100 Mbps network interface card (NIC) or faster are requirements for all PC desktop systems.

Although simulators and training systems are not specifically required to conform to IT-21 standards, it would be highly beneficial if they did. If all systems operate on common platforms with common hardware, centralized supply and standardized maintenance procedures will reduce costs and repair time. IT-21 compliant systems would be designed using modular parts that are interchangeable. Also, common hardware and software ensures broad system compatibility, and a reduction in system administrator training and overhead.

3. The System Must be Deployable

Systems used by U.S. Navy and Marine Corps units must be deployable to remote areas and aboard ships. Due to severe space limitations aboard ships, deployable equipment must be space-conscious. Additionally, deployable systems must be rugged and durable, able to withstand the bumps & jolts of being moved from shore-to-ship, and ship-to-ship. Most standard medium to full-sized PC towers and desktops, along with 17-inch monitors, carry a reasonable footprint, and meet the aforementioned space-conscious and durability prerequisites imposed on deployable systems.

4. The System Must be Affordable and Highly Accessible

A training system is only effective if it is used. For this system to be effective as a training tool, it must be highly accessible to its users. With greater numbers of deployable systems, the greater the availability and access, the more valuable the training will be. A recurring theme heard through personal communications with experienced Naval Aviators exposed to high-end trainers, simulators and mission rehearsal systems is that there aren't enough of them. Affordability breeds strength in numbers, and increased numbers leads to increased usage and a better trained force.

5. The System Should Require Minimal Maintenance and Support

A dedicated system administrator should not be required to operate the system for the user. The system should be totally self-contained – a virtual "walk-up-and use" application – requiring minimal instruction and familiarization training. This requirement goes hand-in-hand with accessibility and usability. If the system is simple to use, operate and maintain, it will likely be used more often, resulting in an increase in its effectiveness as a training tool. Conversely, if it is difficult to operate, or requires special skills to use and maintain, it will likely become a giant dust collector, occupying valuable space in a space-limited environment, and ineffective as a training device.

Anyone familiar with PC technology should be capable of performing routine system maintenance and hardware/software upgrades. Although no computer system is completely maintenance-free, the system should not require a dedicated administrator with specialized computer skills to perform routine maintenance and care.

6. The System Must Employ Open-Systems Architecture

The system must be expandable and up-gradable, with the ability to evolve into a mission planning and rehearsal tool. Shrinking budgets, combined with demands for multifunctional systems and applications, require new systems to be efficient, affordable, adaptable, expandable and up-gradable. If the system is developed using open-systems architecture, with well-known standards and data formats, a logical extension can be formed, transforming this seemingly narrowly scoped navigation trainer into a universally applicable mission rehearsal tool.

B. INTERFACE REQUIREMENTS

Interface requirements define how the user will interact with the system. Today, the user interface is the first thing people ask about when discussing new applications. In many applications, from the user perspective, *the interface is the system.* For example, for most users, Automatic Teller Machines (ATM) are "walk-up-and-use" applications, requiring no special skills or training for their use. The simple numeric keyboard and digital display screen is the interface, and from the user's perspective, it is the only part of the system they interact with. The functionality of the remainder of the system is transparent to the user. Regardless of how well-designed the total system is, the interface must be easy to use. Interfaces that lead to system non-use can have a direct impact on productivity.

Successful interface designs stem from a thorough understanding of the system's intended use, and an intimate knowledge of the user pool. A recurring phrase often heard when discussing interfaces is "user friendliness". To most, the real issue is not so much having a friend inside the computer, but rather hassle-free productivity. This is referred to as *usability*. Hix and Hartson (1993) give insight to this commonly used phrase with this explanation:

> *Usability – from a technical viewpoint – is a combination of the following user-oriented characteristics:*
>
> - *Ease of learning*
> - *High speed of user task performance*
> - *Low user error rate*
> - *Subjective user satisfaction*
> - *User retention over time*

Systems with poorly designed interfaces are generally perceived by the user to be flawed or difficult to use. This creates a barrier to learning in systems designed for training, and for all practical purposes, renders the system worthless.

1. The Trainer Must be Easy to Use

As discussed, trainers cannot be effective if they are not used. For the system to be used, there must be a requirement for minimum system indoctrination to use the system. The system is designed to be an aid to its users, to augment existing tools and products. It should not be seen as yet another piece of equipment that requires extensive training and time in order to use. Pilots at all levels of experience have enough demands on their precious time. There is no room in the training or operational pipeline for another system with a steep learning curve, requiring countless hours of training and familiarization to learn.

2. The Trainer Must Employ a Basic Control Device

This trainer is not meant to teach pilots how to fly. The trainer assumes its users are skilled aviators. It must be designed using simple, familiar control device inputs that minimize distractions and allow pilots to focus on the task it is meant to teach – navigation. The underlying motion model must be very straightforward to allow a single user to fly the virtual aircraft while concentrating on the navigation task at the same time.

The virtual aircraft must be very stable, and not be allowed to slip out of control while the pilot's attention is on map interpretation. The motion model must be designed such that it assists in gaining and maintaining the user's spatial orientation, with gentle rates of turns and reasonable climb/descent rates.

The interface control device must be familiar to the users. A joystick common to most helicopters is preferred. Users shouldn't be forced to learn how to use a new control device. The trainer should adapt to the user, not vice-versa.

3. The Trainer Must Have a Wide Field of View

Helicopter pilots naturally rely on peripheral vision to navigate. As stated in (CNO, 1992, p. 13-4):

> *For terrain navigation, use is made of both the central and peripheral visual fields, but the peripheral is the decisive field.*

While flying in close proximity to the earth, helicopter pilots scan from side-to-side, using peripheral vision to gain as much information as possible about the surrounding environment. Accordingly, helicopter navigation training devices must incorporate a wide field of view (FOV). If a narrow field of view is used for training, pilots form poor scanning habit patterns by only focusing on objects straight in front of them. This lack of peripheral scanning creates a type of "tunnel vision" effect, and can cause pilots to miss critical elements of information and visual cues off to the sides that could otherwise be seen and used for navigation and orientation.

The field of view of a computer-based trainer should be representative of that experienced in actual aircraft. The most economically feasible way to accomplish this is through the use of a multiple monitor configuration. By using a single monitor setup, training devices force pilots to form bad scanning habits that will transfer to habits used in the aircraft. Advancements in technology allow for the configuration of computer graphics subsystems to output to multiple monitors. These monitors should be linked and configured such that a "cockpit-like" field of view is realized. As an example, the field of view in a Sikorsky H-60 Blackhawk approaches 160 degrees. Therefore, helicopter trainers should attempt to replicate this wide field of view through an appropriate multi-monitor wrap-around design.

Sullivan (1998, p. 16) demonstrated the need for a wide FOV in a hypothetical example using two aircraft; one with a FOV of 30 degrees, and the other with a FOV of 90 degrees. If both aircraft are traveling at 90 knots and see a terrain feature 0.5 nm from their intended track, then the aircraft with the wider FOV will have the terrain feature in view 54 seconds sooner than the other aircraft. In this example, there is a significant difference in the time to acquire a terrain feature from the periphery – valuable time that can be used by the pilot for better orientation and increased situational awareness.

4. Relative Flight Information Must be Displayed

As stated earlier in section III.B.2, the system is not designed to teach flying skills. Having said that, its user pool is assumed to be skilled aviators. Although the users may not expect the trainer to behave exactly like an actual helicopter, the users should expect a certain amount of relative flight information to be displayed in the cockpit that contributes to general spatial orientation and navigational reference. At a minimum, the following relative flight information that is always available to pilots for general orientation should be displayed:

- Heading
- Altitude
- Airspeed
- Angle of bank (Turn) Indicator

Aircraft heading, displayed in degrees, helps orient the pilot to magnetic north. Two types of altitude are important for vertical orientation – barometric altitude, determined by barometric pressure, is an indication of the aircraft's height above mean sea level (MSL), and radar altitude, determined by an on-board radar, gives an accurate reading of the aircraft's height above ground level (AGL). The aircraft's airspeed, given in knots, or nautical miles-per-hour, is required to determine groundspeed, which is used for navigational timing. These essential elements of flight information are the necessary for pilots to maintain situational awareness and prevent them from becoming spatially disoriented.

C. TERRAIN MODEL REQUIREMENTS

1. A High-Resolution Database Must be Used in the VE

High fidelity models result from high-resolution data and state-of-the-art hardware and software applications. The virtual environment used in the trainer must be of sufficient fidelity and level of detail for users to perform the task of terrain association. Fidelity is the visual clarity of the virtual terrain. Level of detail (LOD) is determined by the degree of texturing performed and the number of polygons used in constructing the model. As more polygons are added, the greater the LOD. There must be sufficient polygons present in the model to accurately depict the natural and man-made terrain features such that the user easily recognizes them. The virtual environment must accurately depict the real world. There exists the possibility of negative training transfer if the virtual terrain is not representational of the actual terrain. For example, if the model fails to accurately depict a terrain feature that exists in reality, confusion and disorientation can result. The same is true for models that depict features that do not actually exist.

The fidelity of the virtual environment is directly proportional to the resolution of the data used. When a model is rendered at low altitude perspective, the texture's pixels become very large, causing the image to become distorted, giving it a washed-out appearance. When the image becomes distorted, it can negatively impact the effects on training. For example, if the model's virtual terrain is so distorted that it does not provide adequate contrast for delineating key terrain features, it could become completely unusable as a navigational aid to terrain navigation training. Changes in elevation and airspeed may not be apparent until the viewpoint is too close to the terrain feature for the user to react. This can make terrain association very difficult, and can actually result in negative training transfer. Therefore, the virtual terrain must be of sufficient graphical fidelity – visual clarity – and level of detail to provide for terrain feature proportionality, adequate terrain contrast, and proper height and velocity perception.

D. VERIFICATION AND VALIDATION

1. The System Must be Proven to Work

The purpose of verification and validation is to establish the credibility and effectiveness of a model and/or system. *Verification* is the process of determining that the system works as the developer expected. By formal definition, it is:

> *The process of determining that a model [or system] implementation accurately represents the developer's conceptual description and specifications* (Piplani, 1994).

Once the system has been designed and developed according to the specifications outlined herein, evidence must be gathered that shows this system can actually be used to train pilots in the task of helicopter navigation in urban environments. We can ill-afford to spend valuable time, money and resources developing or purchasing new technologies simply because they are different.

Validation determines how well the model represents what it claims to represent. The formal definition of validation is:

> *The process of determining (a) the manner and degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model, and (b) the confidence that should be placed on this assessment (Paplani, 1994).*

Validation encompasses the entire system – the model, data, and the operators who will use the model.

Experiments must produce empirical data that verify the development of the right system for the right reason, and validate the system's design. Without positive proof, there exists the very real possibility of wasted effort, time and money, and could potentially result in a system that has no positive impact, or worse yet, produces negative training transfer.

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IV. IMPLEMENTATION OF THE SPECIFICATIONS

A. SYSTEM REQUIREMENTS

1. The System Must Be Unclassified

a. Hardware

The system hardware used to implement the V-HUNT system is identical to that used in the MITAVES II design. It includes a commercially acquired PC by Intergraph® Corporation – TDZ 2000 GTI with dual Pentium 450 processors, 512 megabytes RAM, three Intergraph® Wildcat 4000 graphics cards with on-board geometry accelerators and 64 megabytes of texture memory, and three Intergraph® Interview 24 inch monitors, each with a 16:9 aspect ratio yielding a 1360 x 786 resolution. With all three screens active, the desktop resolution is 4080 x 786 (Figure 8).

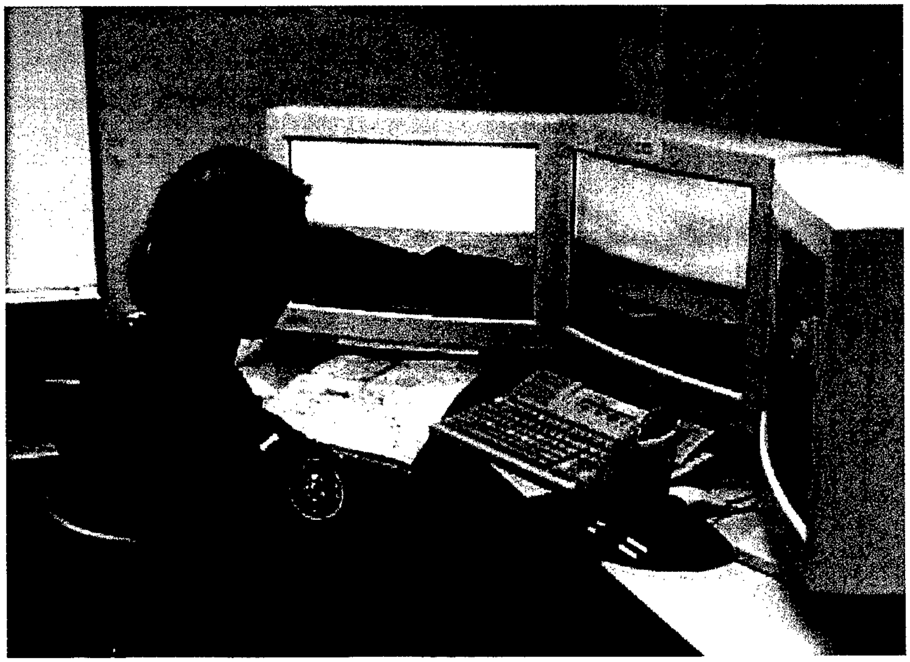


Figure 8. MITAVES II / V-HUNT System Configuration.

The system hardware used in the terrain database generation is a high-end, mini-main-frame computer by Silicon Graphics, Inc., a multi-processor, multi-pipe graphics work station with specialized graphics acceleration hardware purchased in 1996 at a cost of $203K. This computer runs a proprietary operating system called IRIX – SGI's version of UNIX – with installed utilities optimized to run graphics intensive applications such as MultiGen Paradigm's Creator®. The system specifications include:

- 4 x 194 MHZ IP25 processors
- CPU: MIPS R10000 Processor Chip Rev. 2.5
- FPU: MIPS R10010 Floating Point Chip Rev. 0.0
- 128 Mbytes Main Memory, 2-way interleaved

b. Software and Data Formats

The software used for the terrain model generation is the commercially available application from MultiGen-Paradigm, Inc called Creator®. The system run-time environment is Vega Lynx® version 3.2, also a product available from MultiGen-Paradigm, Inc.

The data formats used in the terrain model were all unclassified, and obtained free of charge from NIMA in the form of compact discs (CDs). Digital Terrain Elevation Data (DTED) level 2 (30-meter postings) was used to show the relief in the terrain, and Controlled Image Base (CIB) 5, a 5-meter resolution, black & white satellite image was used for texture and draped over the DTED.

The tool used to access these two products from the medium is Fusion, a NIMAMUSE 2.1.3 utility available by download from NIMA's web site. The tool used to drape the satellite image over the DTED was MultiGen-Paradigm's Creator® application, version 2.2.1. Creator is the tool used in the model construction process, starting with polygons to give shape to the man-made features, and enhanced using Adobe Photoshop® for detailed texturing and coloring of items such as windows in buildings.

2. The System Must be IT-21 Standards Compliant

Since the requirements for IT-21 compliance were drafted over three years ago, IT-21 standards compliance is quite easily achieved, as this system has been fully implemented with components that far exceed the minimum required levels mandated by the IT-21 standard (see sect. 1.a.). The second and third generation designs both run on Microsoft Windows NT® 4.0 operating system (OS). In keeping with the spirit of IT-21, the hardware and the OS are commercial-off-the-shelf (COTS) products, and the data used in terrain model generation is freely available, unclassified, and in standard NIMA data formats.

3. The System Must be Deployable

In its current configuration, the system's deployability is questionable. The complete system is comprised of a tower PC, three monitors, keyboard, mouse and joystick. While the Intergraph® TDZ 2000 tower PC is comparable in size to any standard full-size computer tower, each monitor is a 24-inch, wide aspect ratio, measures 22 inches wide and weighs approximately 75 pounds. The footprint – physical space requirement – of the monitors covers a five-foot desktop area. A more space-conscious configuration would implement lightweight, thinner, flat-panel monitors. These smaller, lighter monitors, while readily available through commercial sources, are still very expensive. As the technology and consumer demand drive hardware prices downward, these hardware components will become more affordable, and deployable total-system configurations will soon become economically feasible solutions.

4. The System Must be Affordable and Highly Accessible

In order for this system to be effective as a tool for training the task of helicopter navigation through repetitive rehearsal, it must be accessible. The best way to achieve high accessibility is to design an affordable system that can be purchased in sufficient numbers for aviation units and commands at every level to make them available to all aircrew. There are numerous examples of very good, high-end simulators designed for mission rehearsal. The drawback to most of these trainers, however, is they are too expensive to buy in sufficient quantities, or so complex that they require dedicated specialists to maintain them. This results in military units acquiring trainers in very low numbers, forcing aviation commands to share them. A recurring comment often heard when asked about the usefulness of high-end mission rehearsal and planning systems is that they are great – there just aren't enough of them. Infrequent system usage directly affects system learnability and memorability. Therefore, effectiveness as a training tool is impacted as a result of limited system access.

For the purposes of examining system functionalities versus cost, two systems were chosen for analysis: TOPSCENE™ and Microsoft Flight Simulator®. While these two products are on opposite ends of the quality and price spectrum, it is interesting to note the advertised intended use of these products, and their similarities and differences.

a. TOPSCENE™

Tactical Operation Preview Scene (TOPSCENE™), a Lockheed Martin Vought proprietary operational training system consisting of 3D imagery products and infrastructure, is a battlefield visualization system that lets aircrew and commanders conduct high frame-rate rehearsals of their missions before actual flight using virtual images of the mission area. It is a U.S. Navy program managed by PMA-205, Naval Air Systems Command (NAVAIRSYSCOM) located at NAS Patuxent River, Md.

The procedures used to develop the terrain databases for TOPSCENE™ systems are very similar to those used in the terrain models for MITAVES II and V-HUNT. Off-site teams at NAS Fallon, Nevada, and Dallas, Texas use satellite imagery, digital terrain data and photographs to create a 3-D model of the terrain. Using the database generation system (Figure 9), a 2-D mosaic-orthogonal map is computer-constructed, draped over polygonized elevation data, and enhanced with 3-D cultural features, yielding a 3-D, high-resolution model with imagery sufficient enough to see major and minor roads, buildings, vehicles, doors and windows. These databases are stored on 18 gigabyte (GB) "hot-swap" hard drives, 8mm tapes or digital video disks, which are then distributed to deployable units.

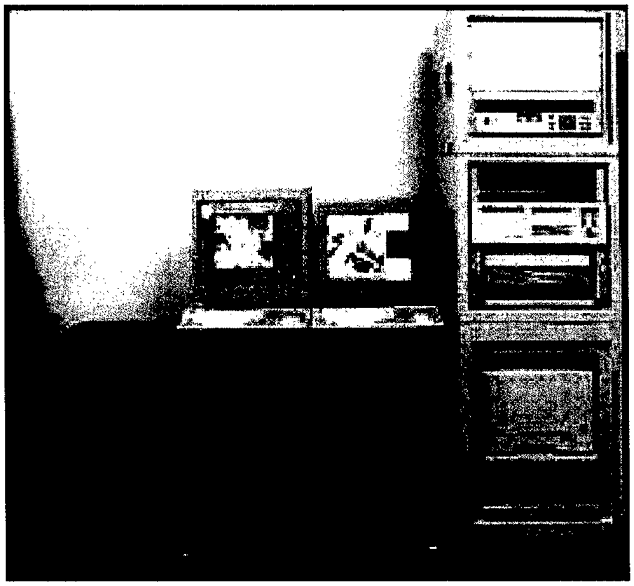


Figure 9. TOPSCENE™ Database Generation System (PMA-205, 2000).

The TOPSCENE™ system is available in a variety of models:

The model 3500 (Figure 10) is a top-of-the-line system. It provides interactive flight through imagery-derived terrain and cultural features at 30 Hz frame rates.

Figure 10. TOPSCENE™ Model 3500 (PMA-205, 2000).

Model 3500 system elements include:

- SGI Onyx VTX with dual R440 processors
- IRIX version 5.3
- 6 x proprietary accelerator boards
- SGI Indy computer
- 76 MB texture memory – expandable to 152 MB
- Disk storage chassis with 5 x 4.3-GB hot swap drives

Terrain imagery is stored on video disks. It's the proprietary boards, not the Onyx hardware that performs the texturing. Cultural data is stored on the Onyx. The SGI Indy provides Windowing and menuing functionality.

The model 4000 (Figure 11) is another high-end version. The system is stored in a single-rack, self-contained console, transportable in three sections, with a footprint approximately the size of a desk, with a 24-inch monitor, keyboard, joystick and throttle.

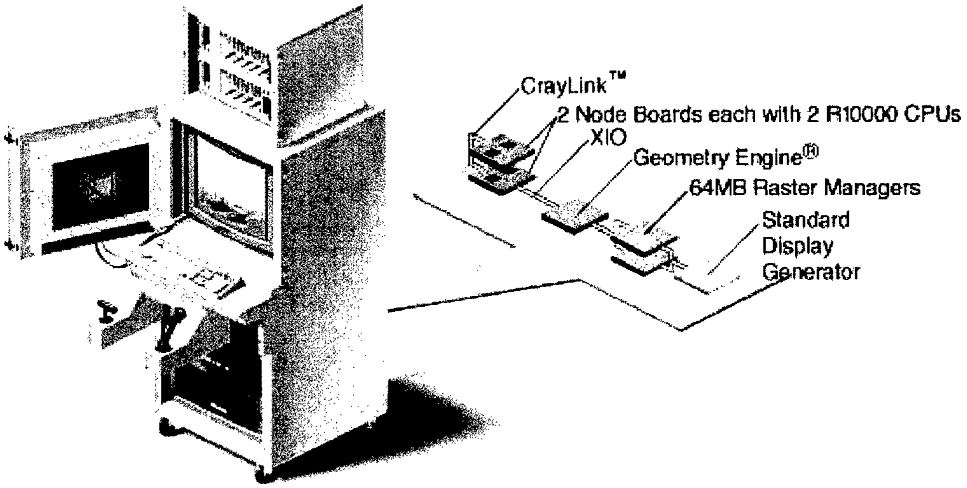


Figure 11. TOPSCENE™ Model 4000 (SGI, 1999).

Model 4000 system elements include:

- SGI Onyx2 Infinite Reality® deskside computer
- 4 x MIPS R10000 processors
- 64 MB texture memory
- 200 GB of removable digital storage
- 8mm tape drive
- Generates views at 30 Hz frame rates

The system has all the features of the 3500, and is capable of various visual environment display enhancements, such as visibility, time of day, instrument indications, threat warnings, and battlefield effects such as fire, smoke, tracers and debris.

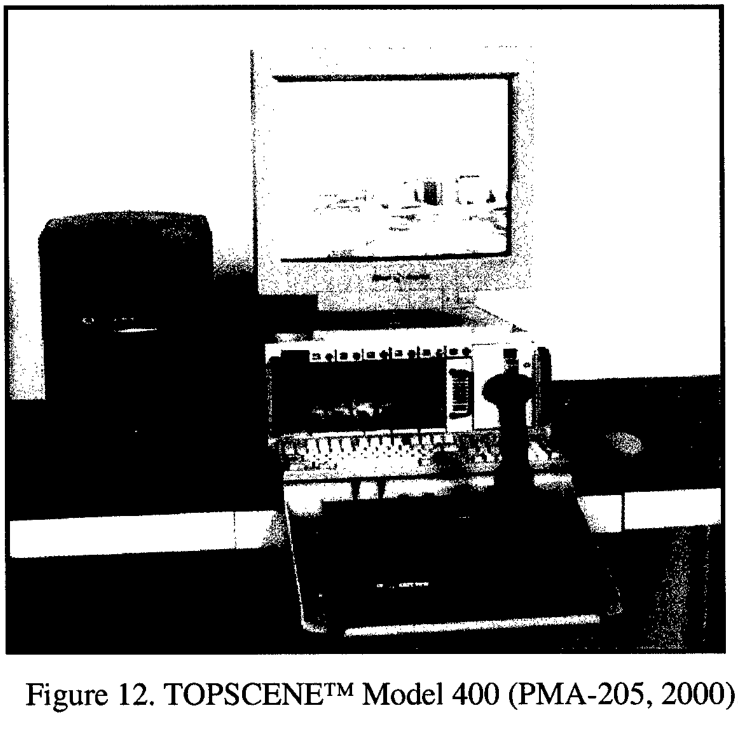


Figure 12. TOPSCENE™ Model 400 (PMA-205, 2000).

The model 400 is a more compact version with reduced performance at a reduced cost. This model uses a Silicon Graphics Octane® computer and a smaller monitor to form a desktop workstation with the footprint of a typical PC. Its system elements include:

- SGI OCTANE®
- User interface – mouse, keyboard, control box
- Up to 100 GB of removable digital storage
- Generates views at 5-10 Hz frame rates

All of these systems have tremendous capabilities. The TOPSCENE™ concept addresses the issues raised herein regarding training, practice and rehearsal. The U.S. Navy realizes the importance of practice and rehearsal for operational preparedness, and as such, has a substantial investment in the TOPSCENE™ program. Although TOPSCENE™ claims to use all COTS products, some models contain proprietary hardware components (ARMYTEC web page, 1999).

There are very few TOPSCENE™ systems in use today. As of early 2000, only forty-three systems were in use on base or aboard ships for mission preview work (SGI web page, 1999). This is likely due to the exorbitant costs of these trainers. Models 3500 and 4000 come with price tags of $522K and $560K respectively. The model 400 costs approximately $100K (ARMYTEC web page 1999). These systems are too costly for volume purchasing, limiting distribution to front-line units, deployed ships and units in pre-deployment work-up training. With one or two systems onboard an aircraft carrier of eight squadrons and over 120 pilots, availability and accessibility is severely degraded for most, and non-existent for many. When commanding officers are required to share expensive, limited distribution systems, they are forced to establish a set of priorities as to who gets to utilize them. Limited access to technologically advanced training tools equates to a force whose readiness depends upon antiquated methods for mission planning, preparation and practice.

b. Microsoft Flight Simulator®

A widely distributed product that is commercially available is Microsoft's Flight Simulator® (FS). FS is a low-end ($25), low performance graphics game suitable for novice pilots and adolescents. The slogan Microsoft uses in its FS advertisements and on the product's packaging boasts "As real as it gets". While the 3-D cultural features near the airport maybe somewhat representational of the actual scenery, the graphics quality declines severely as distance from the airport increases. The details in FS's models focus only in the immediate vicinity of airport traffic areas (ATA). As the user flies further from the airport, the graphics degrade to a degree that it's impossible to determine one's geographical location, rendering FS useless as a navigational trainer. Its only contribution as an effective training device to professional, military or student pilots is as a procedural trainer for ATA's – establishing good piloting habits while in the airport traffic pattern – and practicing the necessary communication calls with the controlling agency.

In contrast to these two systems, the V-HUNT system is designed from the ground up with helicopter navigation in mind. It is not a fixed-wing system retrofitted to adapt to the needs of the helicopter community. It is an affordable, COTS alternative to Motion-Based Trainers (MBTs), or high-end mission rehearsal systems like TOPSCENE™, with comparable graphics fidelity, allowing for wider distribution and placing it in the hands of more users. Its software design and graphical fidelity far exceed that of low-end applications like Microsoft's Flight Simulator®, making it more effective as a training device.

5. The System Should Require Minimal Maintenance and Support

Although no computer system is entirely maintenance-free, the V-HUNT system does not require a dedicated system administrator or someone with specialized training for operation, routine maintenance and hardware/software up-grades. Anyone familiar with standard PC technology and Microsoft Windows® Operating Systems (OSs) and applications should be capable of using, maintaining and performing routine system upgrades on this device.

Data files are stored in the same directory the native V-HUNT system resides. User data directories are automatically created – transparent to the user – alleviating the need for a system administrator to create a new data directory and files for each new user.

6. The System Must Employ Open-Systems Architecture

V-HUNT, as with its predecessor MITAVES II, is a system designed from the ground up with allowances for adaptability, expandability and up-gradability. Executing well-known, COTS applications on IT-21 compliant COTS hardware yields a system capable of evolving into a multifunctional device. Through an open programming development environment, making changes or enhancements to the underlying software applications for increased capabilities is simple.

With the technological advancements in hardware – more memory, faster processors and better graphics cards – combined with the ever increasing capabilities of computer graphics software, it is logical and feasible that this narrowly scoped navigation trainer can eventually be transformed into an affordable, full-blown mission planning/rehearsal tool. One example of a way in which to accomplish this is to bring together, in a single application, the functionalities of a route planning tool like Falcon View, and the capabilities of the Navy Portable Flight Planning Software (N-PFPS). The mission planning output files from Falcon View could be easily incorporated into the V-HUNT trainer by plotting the planned route, and through playback mode, allow the user to conduct a 3-D fly-thru of the intended route of flight prior to the actual mission.

Standard NIMA mapping products are used in the model development and in the creation of the digital maps, and the data format for the terrain model utilizes the industry-wide OpenFlight standard. This allows users familiar with common NIMA products and tools to manipulate the data, and consideration for future database expansion.

B. INTERFACE REQUIREMENTS

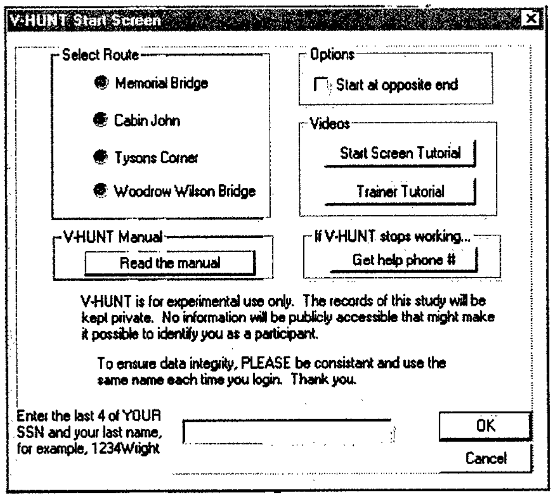
1. The Trainer Must be Easy to Use

In many modern applications, the interface is the only part of the system users actually use or manipulate to interact with the system. As was mentioned in an earlier section, from the user perspective, the interface *is* the system.

For applications such as V-HUNT, TOPSCENE™, Falcon View™, etc. – computer-based trainers used by non computer experts – the goal of the design should be a device that optimizes productivity, with a very shallow learning curve for new users and high memorability for return users. In order for V-HUNT to be effective, it must be easy to use and reuse, with minimal familiarity training required for operation.

McLean conducted a series of usability tests (McLean, 1999) on students using the MITAVES II device that showed it to be a near *walk-up-and-use* system, requiring little or no formal training prior to use. Using simple Graphical User Interface (GUI) displays written in C++ programming language, help menus and on-screen tutorials adapted from the MITAVES II design, this system has a very shallow learning curve with high memorability. Double-clicking on the V-HUNT icon, entering a user name, and selecting the desired route is all that is required to launch the program (Figure 13).

The user's name is used to create an individual folder to track user data created as the system is flown. Users are asked to enter the same name each time they use the system so that data pertaining to that individual is filed in the same folder, making the data collection, organization and analysis process simpler. Once the directory and filename are created for a user, the path to this file is passed to the simulation as an argument, and appropriate data such as route, path, and functions activated during the



V-HUNT is for experimental use only. The records of this study will be kept private. No information will be publicly accessible that might make it possible to identify you as a participant.

To ensure data integrity, PLEASE be consistant and use the same name each time you login. Thank you.

Enter the last 4 of YOUR SSN and your last name, for example, 1234Wright

Figure 13. V-HUNT Graphical User Interface (GUI).

simulation are stored in the file.

Once the simulation has begun, most of the application-user interaction is performed via the joystick. For on-screen help or map references, a single key-stroke for the help menu type map desired is required – "H" for help, "M" for map and "S" for Satellite image. The joystick buttons are clearly marked with an intuitively obvious label for quick reference so that users aren't required to look-up or memorize the function of each button. The video provides the user with an on-screen version of the user's manual. The manual can be accessed in a standard paper version, and an electronic copy is available via the interface in Adobe Acrobat Reader format. In the design of the V-HUNT interface, every effort has been made to simplify its use by reducing barriers to rapid learning and easy access.

2. The Trainer Must Employ a Basic Control Device

This system is neither designed nor meant to teach users how to fly. The trainer assumes its users are skilled in the fundamentals of aviation and have a basic knowledge of helicopter aerodynamics, although these are not pre-requisites to its use. A simple joystick manipulating a virtual helicopter over terrain mounted on a basic motion model was used in the V-HUNT implementation. A joystick was chosen as the main interface because of its familiarity to pilots and design simplicity. The motion model focused on simulation stability and straightforwardness, allowing the user to gain and maintain spatial orientation, while main effort and attention is on the task of helicopter urban navigation training.

a. Joystick Control

Based on a usability study conducted by McLean (1999) that indicated pilots using a flight training system preferred simplistic control devices that called for minimum adaptation to new environments, a very basic joystick that allowed users to manipulate the simulation with one hand was chosen. A Microsoft Sidewinder 3-D Pro® was used in the latest implementation of the system (Figure 14).

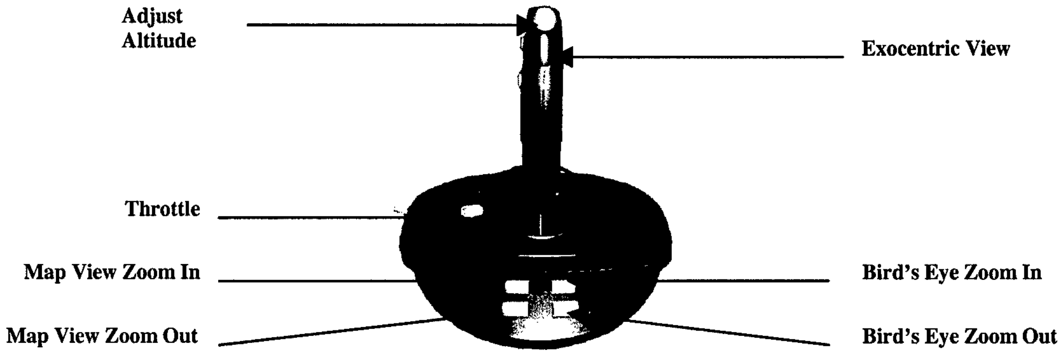


Figure 14. Microsoft Sidewinder® Joystick.

The joystick interface is very similar to a typical helicopter's cyclic stick, with control in the pitch and roll axes. For experimental purposes, the V-HUNT system is intended to be flown at a fixed altitude, therefore, pulling back or pushing forward on the cyclic stick only has the effect of changing the user's perspective view of the terrain – either more sky or more ground. If desired, the user has the ability to increase or decrease the altitude, by moving the thumb-controlled hat switch on top of the grip. The throttle lever on the joystick's base is used to increase or decrease the forward speed of the virtual helicopter, or move the helicopter in reverse, or bring it to a stable hover. The buttons on the lower base are used for on-screen map magnification, with the ability to zoom in and out of views for both the standard map and the satellite image. A thumb button on the top of the grip is used to enter a controlled exocentric view, with the ability to exit the virtual helicopter, and rotate about the helicopter's last position. This gives the user a chance to take a look around from a "bird's eye" perspective, and can be used to assist in gaining or maintaining orientation. The joystick is "self-centering", so releasing the stick will automatically level the aircraft following a turn, and returns the user from the exocentric to the egocentric view.

3. The Trainer Must Have a Wide Field of View

Based on the fact that helicopter pilots depend on peripheral vision for orientation and precise navigation, most aircraft cockpits offer a wide FOV. It only follows that computer-based trainers, particularly those that train in visually oriented tasks such as navigation, should offer to the users a FOV perspective comparable to that experienced in the aircraft.

In its current triple-screen configuration, V-HUNT offers a 140-degree physical FOV from a fixed-distance. As previously mentioned, achieving this wide FOV does not come without a cost – namely, a relatively large footprint. Each monitor provides a measured FOV of 42 degrees when seated 27 inches from the center screen. Although the monitors physically touch one another, there are two 7-degree areas that had to be accounted for in the model to compensate for the plastic frames around each screen in order to give the appearance of a smooth motion-flow from one screen to the next. The center channel has the normal one screen viewing volume with a horizontal FOV of 42 degrees. The left channel is skewed 49 degrees to the left, and the right channel is skewed 49 degrees to the right (Figure 8).

A resolution of 1360 x 766 is provided to take advantage of the 16:9 aspect ratio monitors. In the 3-screen configuration, a total usable screen space of 4080 x 766 is offered. In order to increase the display performance, each monitor is allocated a separate simulation window, and therefore, its own graphics channel. Instead of having one large 4080 x 766 window, three separate windows are created, one for each screen. Performance suffers in single screen outputs that overlap multiple screens because of a drop in frame-rate when the application has to perform redundant rendering – once for each monitor. To overcome this degradation in display performance, a 1360 x 766 window is created for each monitor. Windows for two additional views are created and rendered in the left and right channels to offer views of the map and satellite image. These two views are created as orthogonal viewing volumes because they are top-down views of flat surfaces. This configuration makes it possible to move the perspective viewpoint closer and farther away from the surface of the texture, giving the user the sense of "zooming" in and out.

4. Relative Flight Information Must Be Displayed

Pilots need certain relative flight information available in order to remain spatially oriented during a flight, regardless of geographical location, mission or operating environment. Additionally, for accurate navigation along a specified route, a pilot must have certain information that assists geospecific navigational reference.

In the V-HUNT implementation, the following flight information is available to the user during every flight:

- Aircraft heading – in degrees relative to magnetic north
- Barometric altitude – based on height above mean sea level
- Radar altitude – actual height above the ground
- Angle of bank (Turn) Indicator
- Artificial Horizon
- Airspeed Indicator – in knots (nautical miles per hour)

This information is presented on a Heads Up Display (HUD) on the lower portion of the center monitor (Figure 15). A HUD allows the user to absorb all the relative flight information with a brief scan.

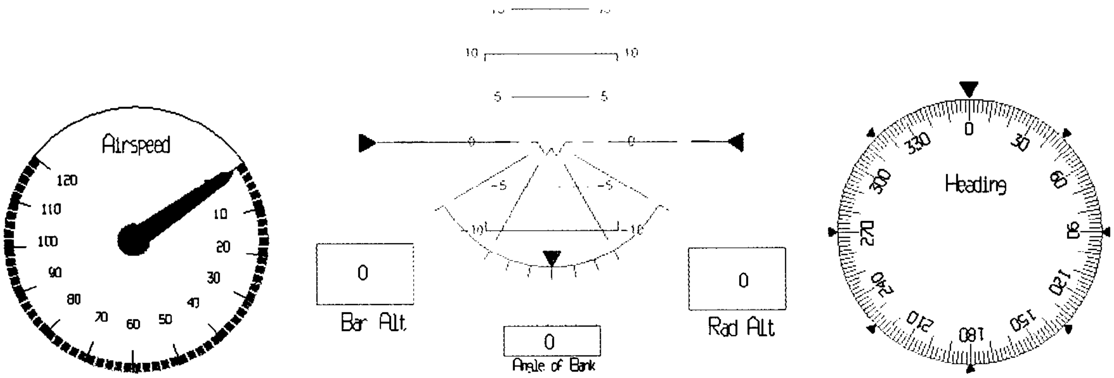


Figure 15. V-HUNT Heads-Up Display (HUD).

The dial-like airspeed indicator, similar to those in modern aircraft, gives the user a instant readout of the aircraft's velocity relative to the terrain. The indicator's maximum velocity is portrayed as 120 knots because this is the normal maximum airspeed for most helicopter navigation missions. A typical navigation mission is flown at 90 or 120 knots because it is simple for the pilot or navigator to determine ground speed at these velocities – at 90 knots the pilot knows he is traveling 1.5 nautical miles (NM) every minute, and 120 knots he travels exactly 2 (NM) per minute. Because most novice pilots would find it very difficult navigating from a helicopter at low altitudes traveling 2 NM per minute, the user has the ability to travel at much slower airspeeds by adjusting the throttle control on the joystick. The airspeed indicator will accurately reflect adjustments to velocity as they are made. The dial around the airspeed indicator is color-coded just as most are in actual aircraft for immediate scanning feedback. Green indicates normal or acceptable airspeed, and red indicates the airspeed above the normal limits of the aircraft.

Aircraft heading is also displayed on a rotating compass digital instrument. This heading, displayed in 30-degree increments from 0 to 360 degrees, helps keep the user oriented in relation to magnetic north. As the aircraft's heading changes, the dial rotates so that heading is always displayed at the top of the dial. This graphically depicted compass helps the user maintain situational awareness better than a digital numeric readout.

Two types of altitude are offered by way of digital readouts (Figure 15). The aircraft's height above mean sea level (MSL) is displayed on a barometric altimeter, and an accurate reading of the aircraft's actual height above the ground (AGL) is displayed on a radar altimeter. These instruments, along with an artificial horizon and a turn indicator, comprise the V-HUNT HUD, and are the essential elements of flight information used by pilots flying in both the virtual environments and the real world to remain spatially oriented.

C. TERRAIN MODEL REQUIREMENTS

1. The Virtual Environment Must Use a High-Resolution Database

The virtual environment used in the trainer must be of sufficient fidelity and level of detail for users to perform the task of terrain association. The terrain model must have the visual clarity to provide for terrain feature proportionality, adequate contrast and proper height and velocity perception.

a. Terrain

Construction of the terrain model begins with Digital Terrain Elevation Data (DTED). This product is a uniform matrix of terrain elevation values, and provides basic quantitative data for systems that seek terrain elevation, slope or surface roughness information. In short, it provides the terrain relief to the model. DTED is produced in a variety of unclassified levels as described below (NIMA, 1998):

- <u>DTED Level 0</u> – Thinned elevation values extracted from DTED level 1. Where that information isn't available, it is derived from contour information on Vmap level 0. Post spacing is 30 arc seconds (approximately 1,000 meters). This corresponds to contour information represented on a 1:1,000,000 scale map.
- <u>DTED Level 1</u> – Post spacing is three arc seconds (approximately 100 meters). This corresponds to contour information represented on a 1:250,000 scale map, and is the basic medium resolution data source.
- <u>DTED Level 2</u> – Post spacing is 1 arc second (approximately 30 meters). This is about equal to the contour information represented on a 1:50,000 scale map, and is the highest resolution unclassified data source.

The terrain database was created using MuliGen-Paradigm, Inc.'s Creator application. If using DTED for the underlying skin, the dàta must be in a format compatible with the application. Creator accepts only its proprietary Digital Elevation Data (DED) format. For geographical areas that are uniformly level or flat, this step can be omitted, for if there is no relief in the terrain, including DTED is of little value. For the V-HUNT model, DTED provided no appreciable value and, therefore, was not used.

Once the data is in the proper format, the desired area must be defined and extracted from the media. The geographical area used for purposes of this research needed to be representational of a typical urban or metropolitan area. For that reason, a section of northern Virginia was chosen. This area provided almost all of the usual man-made and cultural features found in metropolitan areas, yet was not immediately recognizable to test participants who were not very familiar with the specific location. The exact latitudes and longitudes for the modeled area are shown in Table 1.

These latitudes/longitudes correspond to an area of Fairfax County, Virginia west of the Potomac River, and includes parts of the District of Columbia and Bolling AFB, Maryland. The size of the grid is approximately 12 miles by 12 miles, yielding a total area of approximately 144 sq. miles.

NW Corner	NE Corner
38 57.5 N 077 15.0 W	38 57.5 N 077 00.5 W
SW Corner	SE Corner
38 47.5 N 077 15.0 W	38 47.5 N 077 00.5W

Table 1. Latitudes/Longitudes for V-HUNT Terrain Model.

Next, a determination is made for the number of polygons to use in the construction of the terrain model. The number of polygons used depends on the size and the amount of peaks and valleys, and directly effects relief definition of the terrain model – the sharpness of high and low points in the terrain. Since the area of Virginia chosen for this research is relatively level terrain, the number of polygons remained quite small – approximately 2,500. In contrast, the desert terrain model of Ft. Irwin used in MITAVES II used 50,000 polygons. The number of polygons will also have an impact on the amount of time it takes the computer to perform the geometric conversion of the model. For example, a four-processor SGI Onyx Infinite Reality computer worked over eight hours to construct the Ft. Irwin model. By comparison, had DTED been incorporated in the Virginia model, the conversion from elevation data to polygonal terrain would have taken a matter of minutes.

b. Texture

The next step in the model construction process is to add a layer of texture. Texture is provided by draping Controlled Image Base (CIB) five-meter black-and-white satellite imagery (Figure 16), obtained from NIMA, over the DTED skin. Five-meter CIB is an unclassified, limited distribution, seamless dataset of orthophotos made from rectified grayscale aerial images collected from national sensors and degraded, resulting in a ground sampling distance of five meters. CIB data is produced from digital source images and compressed and reformatted to conform to the Raster Product Format (RPF) standard. CIB files are physically formatted within the National Imagery Transmission Format (NITF) message. Applications for CIB include overviews of areas of operations, map substitutes for emergencies and crises, positionally correct images for draping in terrain visualization, and image backgrounds for mission planning and rehearsal (NIMA, 1998).

Retrieving the raw data from the media is best accomplished by using NIMA's MUSE tools. Raster Importer and Fusion takes the raw data and produces a digital photograph in standard graphics format. Since the data is CIB5, every pixel represents five meters on the ground. By measuring the area of the rectangle used and dividing by five, the correct number of pixels can be determined for an RGB formatted image. However, for the application used in the construction of this model, image size needed to be defined in even powers of two for best results. Therefore, a 1024 x 1024 image was used. Adobe Photoshop version 4.0 software was then used to artificially color the CIB image to give it a more realistic appearance (Figure 17). The main emphasis for coloring was green for the land, blue for the rivers, lakes and reservoirs, and black for the roads and highways.

Creator was the tool used to fuse the finished CIB image to the DTED through a method referred to as a "four-point-put", which essentially aligns the lat/longs of the terrain skin with those of the texture on a giant grid for manipulation. Except for minor cleanup corrections around the river shoreline using Photoshop, the match was extremely close. An individual with familiarity using commercial applications like Creator and Photoshop can easily accomplish these steps in the model building process in a matter of hours.

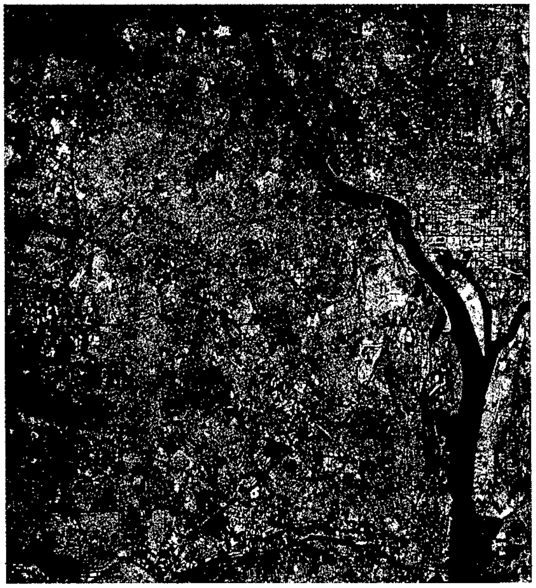


Figure 16. Original 5-meter CIB Satellite Image.

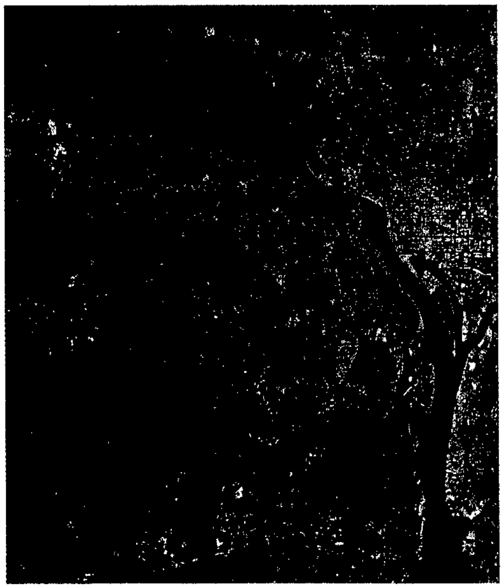


Figure 17. Artificially colored Image.

c. *Cultural Features*

The final step in the process is to add the urban cultural features to the geospecific locations on the model. This is the most complicated and time-consuming step. The construction of buildings requires expert knowledge of a realtime 3-D modeling tool and some artistic qualities. Designing the buildings for the V-HUNT model relied again on Creator. Creator, as mentioned in previous sections, is a three-dimensional graphics editor designed for general purpose modeling that allows its user to create and modify visual databases in a "what you see is what you get" (WYSISYG) environment. Creator has a rather steep learning curve, requiring many hours of use for user comfort and familiarity of its many varied functions.

For the skilled individual who is very familiar with this application, creating a generic structure that has very little texture or architectural detail takes but several minutes. For this same user to create a structure of complex architectural design could take several hours. Figures 18 and 19 show examples of structures with varying degrees of modeling detail and complexity.

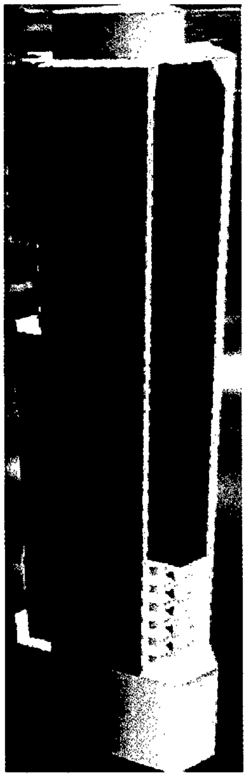


Figure 18. Complex Building Construction

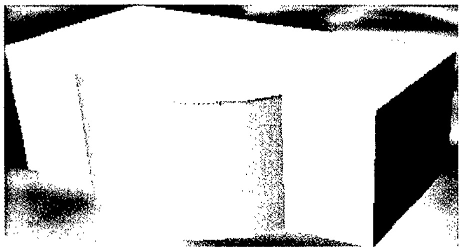


Figure 19. Simple Building Construction

2. System Features and Functionality

Interviews conducted during the original MITAVES implementation suggest that the exocentric viewpoint and the "you are here" (YAH) map features were key to helping students gain and maintain spatial orientation during virtual navigation training (Sullivan, 1998). For this reason, the main features and functionalities incorporated in the first and second generation systems design, including the ability to perform an exocentric view, and to reference the on-screen "YAH" map feature and bird's eye satellite view during the simulation, were preserved in the V-HUNT design to provide the user with this invaluable source of feedback.

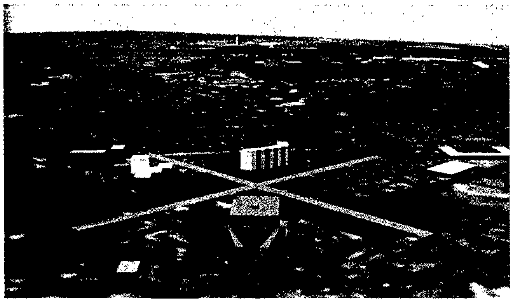
When activating the exocentric view feature, the user simply holds continuous pressure on a thumb button on top of the joystick, while gently pulling the stick aft. The camera is then detached from the normal position inside the cockpit, and moved up and away from the helicopter in a slow, fluid and animated motion. To minimize the potential effect of disorientation, the camera maintains a constant view towards the last position of the helicopter. While detached from the helicopter, the user can rotate in a circular pattern about the helicopter, and view the surroundings from all angles and altitudes. The exocentric view is demonstrated in Figure 20.

The "You Are Here" (YAH) map functionality is implemented identical to MITAVES and MITAVES II, with the exception of the differences in the types of maps used. This feature can be referenced at any time with the stroke of a single key on the keyboard. By pressing the "S" key, the user can select a bird's eye satellite view of the terrain model, which is displayed on the left monitor screen. Alternatively, pressing the "M" key brings to the right screen a digital representation of the city map covering the modeled area. Both maps may be displayed simultaneously or referenced separately. A city map, vice a contour map, is used in the V-HUNT implementation. While the ability to interpret contour intervals is critical when operating in open, natural, desert type terrain, contour map interpretation is virtually a useless skill in urban areas. Therefore, a city map, as seen in Figure 21, is used because it is more appropriate and more useful for terrain association in city and urban environments.

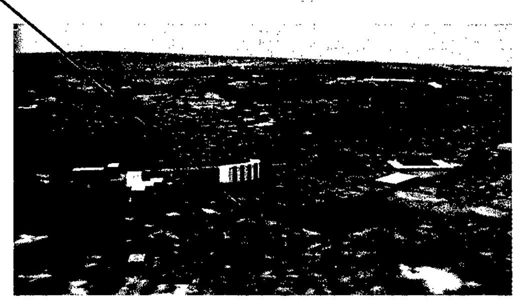
A black line is used to indicate the intended route of flight. The helicopter's current location is represented by a triangle-shaped abstract symbol. A red line displays the path the user has actually flown over the model. By comparing the two colored lines, the user has instantaneous feedback for their performance. The perspective views can be adjusted through a zoom in/out button located on the base of the joystick. This will give a close-up, detailed view of the current location, or a "big picture" view of the entire route of flight.

1. Inside the aircraft (egocentric view).

2. Just outside the aircraft (thumb-button depressed and pulling back on stick).



3. Further away (pulling back more on stick).



4. Abstract symbol (pulling back more on stick).

Figure 20. Demonstration of the Exocentric View.

Figure 21. On-Screen Satellite View (left) and On-Screen City Map (right).

With either satellite or map displayed, all simulation motion is frozen. This affords the user an opportunity to take plenty of time to study the navigation route or on-screen displays without the worry of continuing to fly and navigate. Additionally, it prevents the user from using the trainer as a crutch by simply attempting to match the two colored lines while the simulation runs, whereby no beneficial training is received.

While either the satellite view or city map is displayed, the user may rotate the map(s) to any orientation desired by simply moving the joystick in the direction of intended rotation. This can be useful in determining an intercept heading to get back on course. Once the maps are turned off, the user is automatically returned to the last heading in which the helicopter was oriented, and the motion of the simulation resumes. Although, by allowing the motion to continue while the assist maps are displayed on-screen would certainly cause the user to correctly navigate from point-to-point, it could instill a false sense of security in the user that reinforces negative feedback behavior.

D. SYSTEM VERIFICATION AND VALIDATION

As mentioned, system verification *is the process of determining that the system works as the developer expected.* For the purposes of this study, the strict formalities of verification, validation, and accreditation, as defined in most modeling and simulation textbooks, will not be performed. Instead, the verification and validation process will involve evaluation and assessment of the V-HUNT system based on user input, experimentation and feedback.

Since previous research indicates that virtual environments can be effective tools for training skills and tasks such as helicopter navigation (Sullivan, 1998; McLean, 1999) using a system such as MITAVES II, and fundamentally V-HUNT is identical to MITAVES II, we now must verify that the V-HUNT design, using its urban model, remains an effective tool. One of the key questions this thesis attempts to address is: *what must be modeled in order for the virtual environment to be an effective, credible tool for helicopter urban navigation*? Therefore, model validation through experiments with real end-users will be the primary focus of the system evaluation.

Initial research indicates that the number of objects, and the detail and fidelity of the objects in the model are user-perspective dependent. That is, a model designed for a user to virtually stroll down a city sidewalk and window-shop must contain more objects of greater detail than a model designed for a jet pilot conducting an over-flight of an area at 35,000 feet and traveling at mach 2. From these examples, it should be clear that the perspectives are completely different. The individual who is enjoying virtual window-shopping is covering far less ground at a much slower speed than the jet pilot, and is, therefore, able to absorb more information over less area, but at a higher level of detail.

The helicopter pilot's perspective, in many ways, is unique in that the detail and fidelity of the model must strike a balance between the two aforementioned examples. Since helicopters typically operate in an environment that includes ground-level perspectives as well as views from higher altitudes, the model must have sufficient detail when in close proximity to the earth, yet not saturate the user with insignificant detail when viewed from higher altitudes.

For the TOPSCENE™ system, which primarily serves the needs of the U.S. Naval jet aircraft community, the convention is to include as much detail as possible in the models, based on the amount of raw data available for the area and the given time constraints for the finished product. A team from the TOPSCENE™ database generation unit devotes many man-hours constructing models of high detail, and since these models run on high-end computer systems, TOPSCENE™ is not overly concerned with the processor and memory limitations imposed by a PC. Since one of the more critical points of TOPSCENE™ is its limited database coverage, it is worthwhile investigating methods to increase the amount of global coverage in the databases. One means of accomplishing this is through *selective modeling* – to include those items necessary for accomplishing the mission, disregarding those items that add no significant value, and giving higher level of detail to significant objects and less detail to objects of less importance.

When one visually conceptualizes a major city, there are certain cultural features that stand out from the rest. Although there may be dozens of other buildings or man-made objects in the same geographical location, they aren't unique or distinctive enough to leave a lasting impression. These distinctive features are precisely the same ones that helicopter pilots use for spatial orientation, visual recognition and positive checkpoint identification when navigating in urban environments.

Empirical data, collected from a survey of 86 Army, Navy, and Marine helicopter pilots, clearly indicates that there are certain man-made and cultural features that are more valuable than others in providing visual cues to navigation and maintaining spatial orientation in an urban or metropolitan area (Appendix B).

For example, Chart A on the following page represents the results of those pilots surveyed who indicated whether the given terrain features should be included in a sketch or diagram of an urban area for purposes of helicopter navigation orientation and checkpoint recognition/identification. From the list shown in Table 2 of 14 natural and man-made terrain features commonly found in urban and metropolitan areas, pilots were asked to rank the importance of each with regards to its relevance in helicopter navigation in urban environments.

Roads & Highways	Residential Homes
Railroad Tracks	Parking Lots
Rivers, Lakes, Reservoirs	Trees & Shrubbery
Power Lines	Ball Fields (Football, Baseball, Soccer, etc.)
High-rise Buildings	Water Towers
Sports Stadiums	Bridges
Cemeteries	Radio Antennas / Microwave Towers

Table 2. Natural & Man-made Features in Urban Areas.

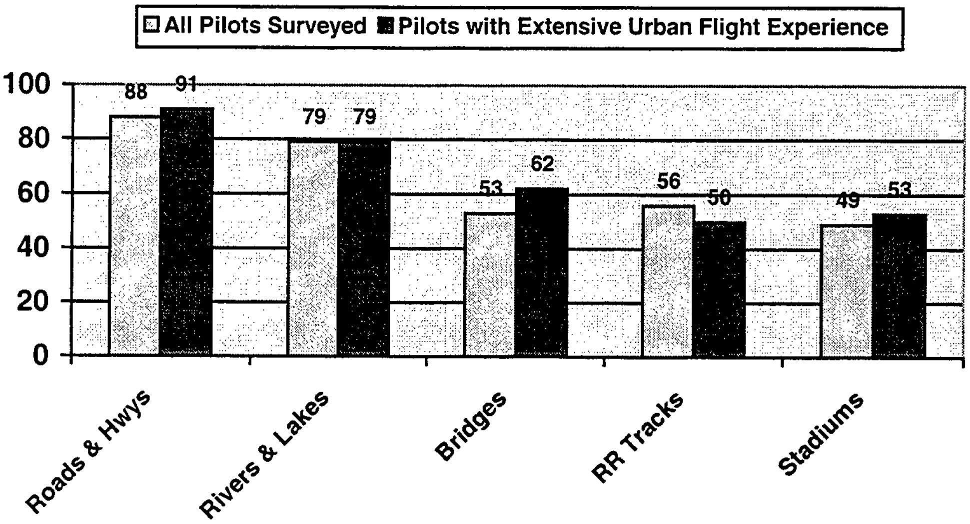


Chart A. Essential Terrain Features

The top five features from the survey are shown in Chart A. The column on the left shows the results of all pilots surveyed, and the column on the right is the results of those pilots who had self-described moderate or extensive flight experience in urban or metropolitan areas.

Chart B on the following page represents the results of those pilots surveyed who indicated the given terrain feature did not add significant value to positive checkpoint recognition/identification and route navigation orientation, and could therefore be omitted from a sketch or diagram to be used for navigation in an urban area.

From the list of 14 natural and man-made terrain features in Table 2, pilots were asked to select those terrain features that were of little or no value, and could therefore be omitted from a sketch, diagram or graphical representation without loss of effectiveness. The four features chosen most often as insignificant from the survey are displayed in Chart B.

Additionally, there are certain characteristics of man-made features, such as uniquely shaped buildings, that clearly distinguish them from their surroundings. Table 3 is a listing of nine characteristics commonly found in man-made objects in urban and metropolitan areas, pilots were asked to give a ranking from 1 to 9 of each characteristic's importance with regard to its relevance to visual recognition and/or positive identification.

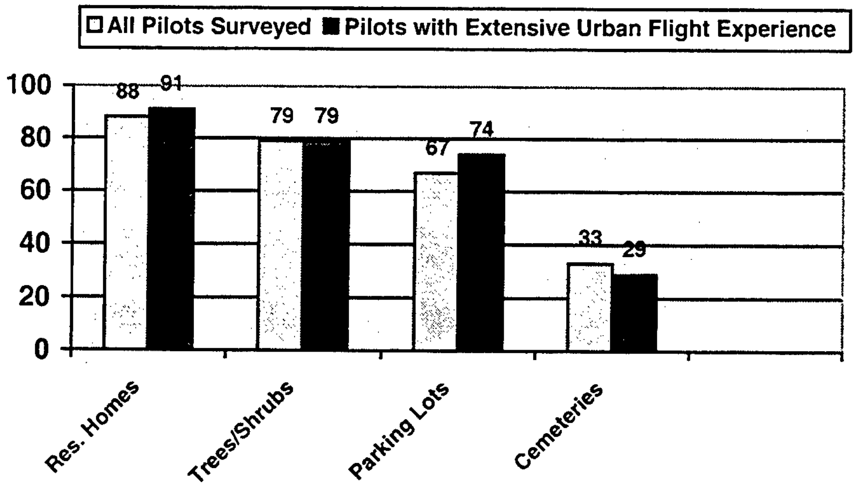


Chart B. Non-Essential Terrain features

Actual Size	Relative Size
Shape	Color / Texture
Construction Material	Number of Stories
Distinctive Markings	Relative Position
Immediate Surroundings	----------------

Table 3. Characteristics of Man-made Features Common to Urban Areas.

The complete results of the survey can be found in Appendix B. The data regarding the importance of characteristics of certain man-made features indicates that relative size, relative position, shape, and distinctive markings are more important than the actual number of stories, color/texture, type of material and immediate surroundings. The results indicating the importance of actual size showed a wide variance of pilot opinion.

Based on the results of this research, a "recipe" for constructing virtual models of urban terrain employing selective modeling techniques can be formed. An example of selective modeling can be seen using the Pentagon. Because of its size, geographical location and distinctive five-sided shape, it is unnecessary to spend a lot of time modeling the intricate details of its architectural design. For those vaguely familiar with this very recognizable structure would logically associate any large, circular building with a hole in its center located near the Potomac River between Washington National Airport and Arlington National Cemetery with the Pentagon. The same is true for most of the more famous buildings and monuments in the downtown Washington D.C. area. However, in certain areas of northern Virginia, as well as other metropolitan areas, there are many buildings with very unusual shapes or distinctive markings that aren't popular or famous, and aren't as readily recognizable to the casual observer. Therefore, these structures are prime candidates for detailed modeling.

Using both aerial and ground-level photographs combined with satellite imagery of key structures, the significant buildings and cultural features can be identified and targeted as candidates for high-detailed modeling. Other buildings and features may need to be included in the terrain model, although they may be given less attention to detail. There are certain structures that may exist in reality that are so insignificant that they can be omitted from the model altogether.

For the model used in the V-HUNT implementation, satellite imagery, augmented with city maps and tourist maps was used to determine the geospecific location for the structures. Using recent aerial and ground level photographs, Creator was used to construct the polygons to give shape to the buildings, and Photoshop to add color, texture and other important architectural details such as windows. An example of the selective modeling technique employed in the V-HUNT terrain model can be seen in Figure 22, which compares an aerial photograph of a portion of Tysons Corner, Virginia, to the virtual environment.

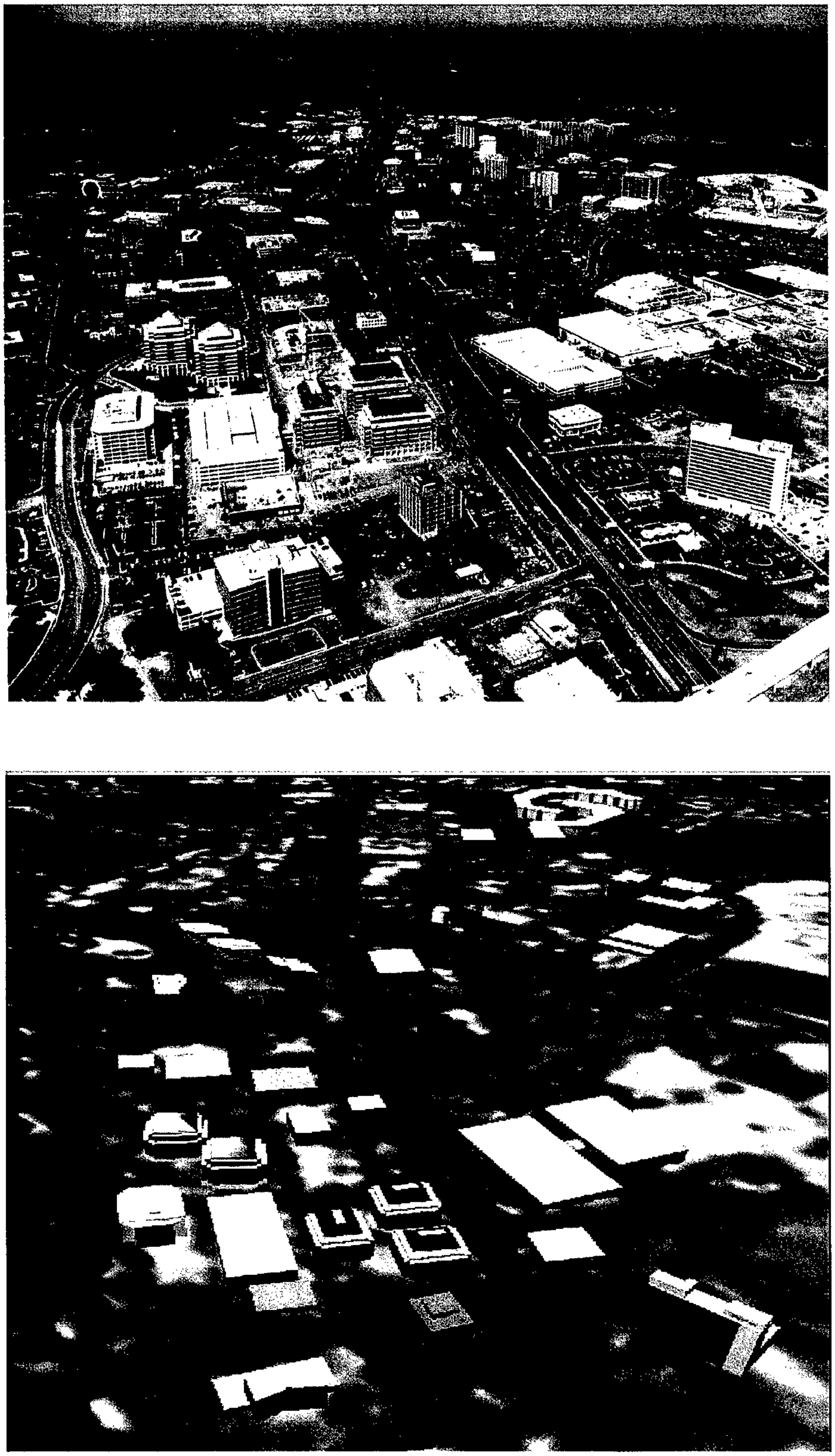


Figure 22. Aerial Photo vs. Virtual View of Tysons Corner, Virginia

The buildings and structures selected for detailed modeling in the V-HUNT urban terrain model were based on the results of subject matter input from the pilot surveys. The key recognizable urban features that added significant value to helicopter navigation, spatial orientation and checkpoint identification were modeled with a high degree of detail, while those structures and features that were not as significant to helicopter urban navigation were either omitted or included with little regard to details.

Selective modeling can be effective and beneficial for several reasons. By choosing not to model everything, time-to-build is drastically reduced. Secondly, the amount of data to be stored and manipulated by the computing device is significantly less, thus a large geographical area can be modeled and flown on PC's with the appropriate hardware configuration and running the appropriate software applications, alleviating the requirement for large, expensive computers. Thirdly, the insignificant clutter normally associated with major metropolitan areas is culled out of the model, reducing the amount of distractions to users training in the virtual environment, while focusing user attention on those key landmarks and features that are fundamental to helicopter urban navigation.

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V. SYSTEM TEST AND EVALUATION

An experiment was conducted to evaluate the V-HUNT system design and the effectiveness of the virtual terrain model as a tool for training helicopter pilots in the task of urban terrain navigation. The subject pool consisted of twenty volunteer pilots from various helicopter communities in the U.S. Army, Navy, Coast Guard and Marines. The military ranks of the test participants ranged from O-2 to O-4, with total helicopter flight time ranging from 500- 2500 hours.

A. METHOD

1. Experimental Design

The experiment consisted of a helicopter route/checkpoint navigation test. The subject pool was divided into two groups – a control group that was exposed only to conventional 2-D navigation maps, charts and photos, and an experimental group that was exposed to those same products and the ability to conduct a virtual fly-thru using the V-HUNT trainer.

2. Experimental Protocol

a. Administration

The navigation test was administered to only one test participant at a time. Information gathered from each participant included branch of service, military rank, aircraft type, and total flight hours. There was no personal information collected that could potentially relate the participant to his/her responses or test results. A pre-established route of flight through several urban sections of northern Fairfax County, Virginia, was briefed to members of both control groups. Test participants with prolonged pre-exposure to the test area – lived, worked, previous flight experience, or otherwise had extensive familiarity with the gaming area – were disqualified from participation. The flight route was approximately twenty-five nautical miles in length, and was comprised of thirteen checkpoints.

b. Preparation

The test participants were given ninety minutes to conduct a thorough pre-flight study of the route using typical maps, charts & photos including a city map, a helicopter route chart, a VFR sectional, a VFR Terminal Area Chart, a several aerial and ground-level photographs (Table 4). The group that had at their disposal the V-HUNT virtual environment (VE) trainer was instructed to divide the allotted ninety minutes in any manner they desired. Additionally, this group was given a brief (5-minutes) familiarization instruction period on how to fly and utilize the various functions of the V-HUNT trainer.

Group	Available Tools	Duration
Control Group	2D Maps, Charts & Photos	90 min. (max)
Experimental Group	2D Maps, Charts, Photos AND V-HUNT	90 min. (max)

Table 4. Experimental Design

During the pre-flight route study, each test participant was monitored to observe which products were used, and the length of time spent preparing for the flight. The complete results of the evaluation are shown in Tables 5 and 6.

c. Evaluation

At the completion of the allotted ninety minutes, each test participant was given the same navigation evaluation. Due to Department of Defense (DoD) and Office of the Chief of Naval Operations restrictions for civilians and non-crewmembers flying in DoD aircraft (OPNAV 3710.7R), geographical distance to the test area, and economical constraints, the evaluation could not be conducted using test participants flying over the terrain in actual helicopters. The inability to validate research through realistic means has been a recurring problem at NPS for research in the area of helicopter navigation training, as evidenced by the methods used by Sullivan and McLean, who were forced to conduct very limited and loosely controlled studies and evaluations in validating their research (Sullivan, 1998; McLean, 1999).

Therefore, a suitable alternative was chosen as the metric for this evaluation. The navigation test consisted of watching an aerial videotape of a helicopter flying the pre-described route of flight at altitudes between 700 and 1,300 feet and airspeed ranging from 65-90 knots. During the navigation evaluation flight, the test participants were allowed to use any maps, charts and photos they would typically expect to carry along for an actual flight.

Once the videotape began playing, the evaluator clearly indicated the precise starting location, both on the map, and on the television screen, to each test participant. The task for the test participant was to positively identify the twelve remaining checkpoints along the route of flight before they disappeared below the bottom of the T.V. screen. Since this was a non-interactive evaluation, the tape ran continuously from beginning to end. Once the helicopter flew over a checkpoint, it did not return or circle back – the test participant either identified the checkpoint correctly or missed it. If a test participant flew past a checkpoint without realizing it, the evaluator would mark it as missed checkpoint, and indicate the helicopter's current location on the map in order to keep the test participant oriented for the remaining checkpoints.

3. Medium

There are artificialities inherent to using videotape as a substitute for an actual flight, some of which tend to make the evaluation less difficult for the participant, and some which clearly increase the difficulty of the evaluation. These include, but are not limited to the following:

- Videotape is non-interactive by nature – Helicopter flies the correct route without pausing or stopping.
- No peripheral cues – Single, large-screen (42 inch) television.
- No heading indications
- Slant-view perspective – 1,000 feet altitude viewing straight ahead, without the ability to look down beneath the helicopter.

- Slant-view perspective – 1,000 feet altitude viewing straight ahead, without the ability to look down beneath the helicopter.

The fact that the helicopter flies the correct course can be viewed as an artificiality that makes the test easier. During an actual flight, the navigator would typically be expected to alert the flying pilot to upcoming turns and heading corrections to stay on course. Obviously, in a non-interactive video, the test participant is relieved of this task. The fact that the helicopter flies the route without pausing or stopping forces the test participant to "get it right the first time", making the test a bit more difficult.

The inability of the pilot to look beneath the aircraft and peripherally for visual cues makes this navigation test more difficult. The absence of a heading reference indicator can be viewed as a hindrance. However, since the helicopter remains on course for the entire route of flight, the test participant does not need to make adjustments to the aircraft's heading.

B. RESULTS

The results of the navigation experiment indicate that the test group that had the opportunity to virtually fly the route as a supplement to a thorough map study consistently performed better than the test group who used only the 2-D map products and aerial photographs. Table 5 shows the results of the group of ten test participants who were not exposed to the virtual environment prior to the evaluation. Although two subjects were able to identify all twelve checkpoints along the route, and three test participants identified eleven checkpoints.

Table 6 shows the results of the test group that was afforded the opportunity to virtually fly the route prior to the navigation evaluation. Every test participant from this group was able to positively identify all twelve of the checkpoints in this study.

C. DISCUSSION

Some of the data collected during the course of this study reinforced portions of the data collected previously in the pilot questionnaires. Consistent with the results of the pilot surveys, all test participants in the navigation evaluation chose to use the city map and aerial photographs as the primary products for the route study. Although some test participants looked briefly at the helicopter route chart as a reference, none of the subjects spent more than two or three minutes studying this chart. Only a handful of the test participants took time to look at the VFR sectional or Terminal Area Chart, and even those curious subjects quickly refolded them and placed them aside. This information helps to validate the results of the portion of the pilot questionnaire dealing with flight planning products that decisively indicated that *city maps* and *aerial photographs* are the most useful products for planning helicopter operations in an urban setting.

Non-VE Test Group

Test Subject	Time Spent Preparing (min/90)	Number of Checkpoint's Correct (x/12)
1	70	11
2	50	11
3	30	12
4	30	9
5	30	10
6	30	11
7	30	12
8	30	8
9	35	10
10	35	9

Table 5. Results of Navigation Experiment for Non-VE Group.

V-HUNT TEST GROUP

Test Subject	Time Spent Preparing (min/90)	Number of Checkpoint's Correct(x/12)
1	72	12
2	65	12
3	70	12
4	50	12
5	50	12
6	50	12
7	45	12
8	70	12
9	40	12
10	45	12

Table 6. Results of Navigation Experiment for V-HUNT Group.

The overall performance of the V-HUNT group is noteworthy in that it clearly indicates that having to perform a mental transformation from 2-D flight-planning products to the 3-D world is a very challenging task. The noticeable increase in performance for the V-HUNT participants may be explained by the trainer's ability to assist the user in the transfer of spatial knowledge from the virtual world to the "real world", or in the case of this particular experiment, from the virtual world to a video recording of a real environment. Additionally, this data indicates that using the VE trainer reduces the user's mental workload when preparing for a complex task such as helicopter route navigation by eliminating the user's need to perform a mental transformation from 2-D maps to 3-D perspective view.

It is interesting to note the various techniques used by different test subjects during the pre-flight preparation. While all the test participants chose to fly the virtual route twice – one slow, methodical flight, and one at real-time, which is consistent with previous data collected during similar VE experiments (Goerger, 1998) – some subjects chose to utilize the exocentric view to observe each checkpoint from different subjects during the pre-flight preparation. While all the test participants chose to fly the virtual route twice – one slow, methodical flight, and one at real-time, which is consistent with previous data collected during similar VE experiments (Goerger, 1998) – some subjects chose to utilize the exocentric view to observe each checkpoint from different angles, while others never used the exocentric view. Also, some test participants utilized a combination of the VE and paper map, while referencing the on-screen maps to confirm their location, while others flew the VE and barely used the on-screen map functionality at all (Table 7).

It is also worth noting the number of references each user made to the on-screen maps. Some subjects mainly used the satellite picture, while others mainly used the on-screen version of the city map. For example, test participant three referenced the on-screen satellite map 39 times during a 40 minute fly-thru, yet never referenced the on-screen city map. Conversely, test participant six referenced the satellite map only three times, and the on-screen city map 38 times during a 35 minute fly-thru. As is evidenced by the end results, both of these test participants were properly prepared for the evaluation, even though their preparation methods were not the same. This example lends credibility to the argument against "one-size-fits-all" type training. These differences may be a reflection of the navigation training methodology used during the pilots' flight training, and with which mapping products each user is most comfortable using while planning flight routes. Since the two products offer different, yet complimentary information, it would seem logical to assume that the most benefit could be gained through a balanced combination of reference to both products.

In the non-VE group, the amount of time spent in pre-flight preparation ranged from 30-70 minutes, with an average time of 37 minutes. In the VE group, the time spent in pre-flight preparation ranged from 40-72 minutes, with an average time of 55.7 minutes. The disparity in preparation time between the two groups of test participants can be explained by the fact that, when using the trainer to virtually fly the route, the user is forced to conduct a disciplined, thorough, and methodical route review, at a speed not to exceed the maximum speed of the virtual helicopter. Conversely, the group that used only maps and photos could conduct a route review at any speed, or simply glance at each of the twelve checkpoints without ever really conducting a thorough route study.

If this procedure is performed more than once, the training time increases, but so does the benefits of the repetitious practice. On the other hand, the undisciplined individual may be tempted to conduct a hasty a map study, or take ill-advised short-cuts, and proclaim his/her readiness prematurely. This will, most likely, result in degraded performance in the actual flight.

Test participant	Map Study Time (min)	VHUNT Study Time (min)	Total Time Planning (min/90)	Number Times Route Flown	Number Exocentric Views	Number References To Sat. Map	Number References To City Map
1	35	37	72	2	3	22	0
2	30	35	65	2	3	4	9
3	30	40	70	2	8	39	0
4	15	35	50	2	2	9	34
5	25	25	50	2	2	3	20
6	15	35	50	2	2	3	38
7	20	25	45	2	6	12	8
8	45	25	70	2	12	3	14
9	20	20	40	2	3	4	17
10	20	25	45	2	3	8	13

Table 7. Observations of V-HUNT Group During Evaluation Preparation.

VI. CONCLUSIONS

A. V-HUNT IS AN EFFECTIVE TOOL FOR THE STATED TASK

Based of the results of the navigation experiment, one can conclude that having a CBT with the ability to conduct a thorough 3-D route study is an enabling tool that enhances navigational performance. Although no formal modeling and simulation accreditation was conducted, V-HUNT – system and model – has been shown to be an effective resource in training pilots the task of helicopter urban navigation through exposure to the virtual environment prior to the mission. The data collected during the course of this study is consistent with, and helps to confirm the results obtained during previous research in the area of helicopter navigation training using virtual environments (McLean, 1999). Since the configuration of the hardware, as outlined in Chapter IV, was preserved from the MITAVES II setup, the results from this research are compelling evidence that this particular hardware configuration is effective.

The design for MITAVES (Sullivan, 1998), MITAVES II (McLean, 1999), and V-HUNT were all *user-centered* – the interface and system functionality were designed based on input and feedback from actual users. Having subject matter experts participate in the research and controlled experiments lends credibility to the findings, and helps to support our theories with regard to helicopter-specific requirements. Although there are some consistencies and similarities among the three studies, there are also some differences between previous studies and this study that warrant some attention. First, as mentioned previously, the basic hardware setup remains intact from the MITAVES II setup. This system provides a fundamental user interface to a functional computer-based platform that looks, feels and behaves enough like an actual helicopter for familiarity, yet is not so complex as to be an impediment to training the intended task – helicopter terrain navigation. Secondly, the V-HUNT terrain model includes many major 3-D features not used in first and second generation designs. The urban environment necessarily adds a new dimension to the virtual model. The methods used in the creation of the urban model were primarily based on input, in the form of a pilot questionnaire, from subject-matter experts (Appendices A and B). Helicopter pilots from all branches of the U.S. military, from various aircraft communities, and with varying levels of military flight experience, provided invaluable research data that was used to formulate a "recipe" for building the V-HUNT urban terrain model.

The results of the experiment validate the effectiveness of the system design and terrain model. Every test participant that was exposed to the virtual trainer had a perfect score on the evaluation. Additionally, many of the test participants commented that they felt very confident in their ability to perform the navigation task after the first fly-thru of the VE. These test participants chose to conduct a second fly-thru at a speed comparable to that expected during the evaluation flight, with minimum pausing and stopping, as positive memory reinforcement.

Another recurring comment from the VE group was that their level of confidence was so high during the navigation evaluation that could have performed the task at a faster airspeed and a lower altitude. In general, this group of test participants was able to identify most checkpoints far earlier than test participants from the non-VE group.

B. SYSTEM HARDWARE CONFIGURATION

1. Performance

The current hardware configuration as detailed in Chapter IV provides adequate performance for the run-time applications used given the size of the urban terrain model for V-HUNT. The three-screen configuration offers a realistic wide field of view, with frame rates between 9 and 13 Hz. For single-screen configurations, it is possible to achieve frame rates as high as 55 Hz, depending on the graphics subsystem used (McLean, 1998).

The system configuration is summarized below:

- Unclassified
- IT-21 Standards Compliant
- Affordable / COTS
- Requires Minimal Maintenance
- Employs Open-Systems Architecture

- Near "Walk-up and Use" Functionality – Minimal Familiarity Training Required
- Wide Field of View
- Basic Interface / Joystick Control Device
- Heads-Up Display for Relative Flight Information

As of this writing, the age of the V-HUNT system hardware configuration is approaching 3 years. With the advancements in technology, it is feasible to field a better, faster, and more capable system at a reduced cost from the original setup. Faster processors, improved graphics cards and more memory would allow for higher resolution data to be rendered and processed faster and more efficiently, yielding a higher quality virtual environment training system.

2. Affordability

Affordability is a relative term. When compared to the cost of a standard PC with its standard single monitor setup, the V-HUNT system may not seem so affordable. However, in terms of cost versus functionality, many V-HUNT systems can be purchased and implemented compared to the cost of a full motion-based simulator or a TOPSCENE™ system. When viewed in this light, V-HUNT is most affordable.

In its current configuration, the V-HUNT system can be commercially acquired for under $30K. For the price of a single TOPSCENE™ model 400, three V-HUNT trainers can be purchased. Hardware components costs continue to decline, while performance continues to rise. This addresses the issue of effectiveness of training through access of technologically advanced systems. Affordability breeds access – the more systems there are, the more training can be conducted.

3. Deployability

The deployability of the V-HUNT system in its current configuration is questionable. Deployability of this system equates to space requirements. In its three-monitor configuration, wide-screen, high-aspect ratio monitors are too large for space-conscious units, particularly ship-based commands. With a single monitor, this system occupies the space comparable to a standard desktop PC. The major drawback to the single-monitor configuration, however, is the lack of a peripheral view perspective. Therefore, a deployable configuration could include three flat-panel screens for a wrap-around view that occupies an acceptable amount of desktop space, or optimally, a configuration with a Head-Mounted Display (HMD) that eliminates the space requirements for desk-top monitors altogether.

C. URBAN TERRAIN MODEL

1. Data Resolution

Although the results from the navigation evaluation indicate that the resolution of the V-HUNT terrain model is sufficient to perform the task, improving the data resolution may increase the trainer's effectiveness. Pixelation effects caused by the five-meter CIB data result in a distorted image at lower altitudes, making it difficult for the user to discern details when flying through some areas of the terrain model. Many test participants were able to overcome the distortion by exercising the exocentric view feature at critical checkpoints where higher levels of detail were required for positive identification. This adaptation works because as the user's distance from the terrain increases, there is less pixelation, and therefore, the image appears clearer. The higher the resolution of the initial image, the sharper the details in the model will be.

It is possible to use a higher resolution image in this system configuration, however, it may not be possible to use a piece of terrain as large as the one used in this research. The size of the terrain model for V-HUNT was approximately 144 sq. miles, and mostly level ground. As the terrain size increases, so does the amount of data. The real-world hardware limitations – processor power and memory -- prevent us from using high-resolution imagery over large areas of terrain. In order to increase the resolution of the model, some compromises will have to be made. Feasible solutions include:

- Reduce the size of the terrain model.
- Increase the hardware capabilities.
- Use data-scaling technique (see Chapter VII).

2. Selective Modeling

The procedures used in the creation of the terrain model for the V-HUNT trainer were designed to answer the following research question:

> *What needs to be modeled, and at what level of fidelity and detail, in order to produce an effective, credible training aid for helicopter urban navigation?*

Using the data collected from the pilot questionnaires, an urban terrain model was constructed using selective modeling techniques for use in this research. *Selective modeling* involves modeling and/or texturing only those items and features necessary to create an effective 3-D terrain model for accomplishing the task, disregarding items and features that do not add significant value, and modeling with greater detail those items and features essential for the task. According to the data collected from the pilot surveys (Table 4, Appendix A), the most prominent terrain features for conducting urban helicopter navigation are roads and highways, rivers and lakes, bridges, railroad tracks, sports stadiums and high-rise buildings. Accordingly, these natural and man-made features are modeled to a higher level of detail than the items deemed *non-essential* in the survey. Those items that were deemed non-essential by an overwhelming majority of pilots surveyed included residential homes, trees and shrubbery, parking lots and cemeteries. Therefore, these items were either modeled with less details, or omitted from the terrain model altogether.

Regarding the level of detail applied to specific features such as buildings, the data indicates that the relative size, relative position, shape and distinctive markings are the most important characteristics for visual recognition and positive identification. Actual size, actual number of stories, color or texture, and type of material used are the least important factors for visual recognition and/or positive identification of urban man-made objects such as buildings (Tables 8 & 9, Appendix A). The *recipe* for selective modeling of urban terrain in virtual environments is summarized as follows:

Essential Features

- Roads and Highways
- Rivers, Lakes and Reservoirs
- Bridges
- Railroad Tracks
- Sports Stadiums
- High-Rise Buildings

Discretionary Features

- Power Lines
- Radio Antennas / Microwave Towers
- Water Towers
- Ball Fields

Non-Essential Features

- Residential Homes
- Trees / Shrubbery
- Parking Lots
- Cemeteries

It is important to emphasize that these guidelines are general, not unconditionally universal in nature. The relevance or significance of these features is conditionally qualified with respect to helicopter route navigation and/or checkpoint visual identification. It is conceivable, under certain scenarios, that the relevance or significance of these features could shift. For example, in an area that has an unusually high concentration of power lines or radio antennas that could have a dramatic effect on helicopter operations with regard to safety issues, their significance would need to be promoted. In another example, for helicopter operations in the vicinity of residential neighborhoods may demand the need to model, with greater detail, residential homes, parking lots, cemeteries, trees, etc., and reduced detail on high-rise buildings. Therefore, under certain situations, those items categorized as “Non-essential” could become “Essential”, and those “Essential” items could become relatively insignificant.

A similar recipe can be formulated when modeling features or characteristics used in the visual recognition and/or positive identification of man-made structures, such as buildings. Although the complete data can be found in Appendix B, the general guidelines are given in the recipe below:

Most Significant Characteristics

- Relative Size
- Relative Position
- Shape
- Distinctive Markings
- Actual Size

Least Significant Characteristics

- Number of Stories
- Color / Texture
- Construction Material
- Immediate Surroundings

As with the recipe given for features, this recipe for characteristics is general, rather than unconditionally universal in nature, and can change based on the situation or scenario. It is conceivable that the color, texture, or construction material of a particular building can cause it to “stand out”, giving it the type of distinction needed for navigational orientation or positive identification. In this instance, the relevance of this particular characteristic may need to be promoted during the modeling process.

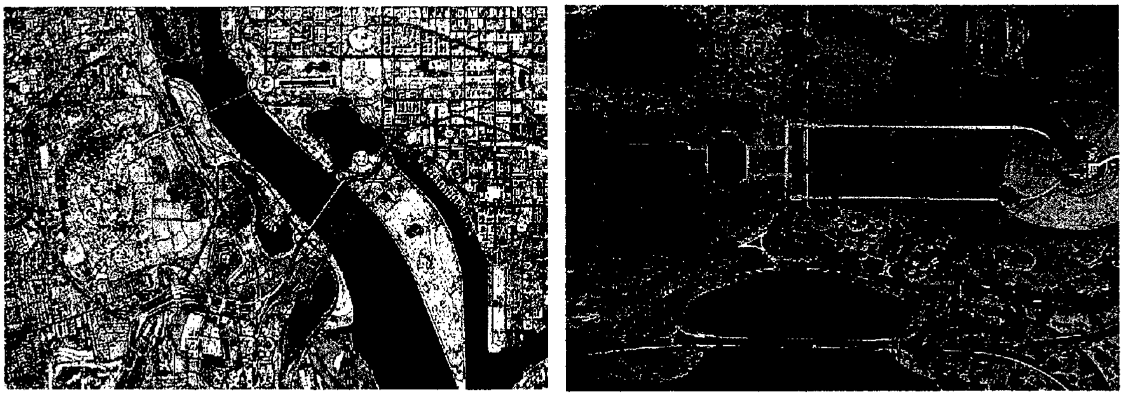
Based on the results of the navigation evaluation, selective modeling is an effective means of designing a terrain model for urban navigation training. By using selective modeling techniques, two very important points are made. First, dozens, even hundreds of unnecessary buildings and other features can be culled from the model, eliminating many distractions to training. Secondly, applying higher levels of detail to the most important features highlights and reinforces those key landmarks and aids to navigation that will need to be recalled during the actual flight mission. This recollection is crucial to performing the task of route navigation. According to the data collected in the research for this thesis, selective terrain modeling, when applied correctly in a 3-D virtual environment, can be an effective instrument in the transfer of spatial knowledge for helicopter route navigation.

VII. FUTURE WORK

A. IMPROVED DATA RESOLUTION

One of the limitations of the V-HUNT system is the distortion of the images at lower altitudes caused by the pixelation effects inherent to five-meter CIB satellite imagery. With an increasing number of both public and private earth-orbiting satellites, combined with NASA Space Shuttle global mapping missions, comes increased mapping of the earth's surface. These state-of-the-art orbital resources are providing researchers and scientists with global imagery coverage with unprecedented resolution. As these products become more available, applications such as V-HUNT will have the ability to take advantage of the high-quality data, and provide users with virtual models at much higher resolutions, making it an even more effective training device. Although there is still a requirement to convert selected 2D images to 3D structures, using higher resolution imagery reduces the overall number of urban cultural features required to be constructed by human hands.

Figure 23 shows a side-by-side comparison of a standard NIMA five-meter CIB satellite image compared to a one-meter resolution image acquired commercially from Space Imaging, Inc.'s Ikonos satellite.



Space Imaging, Inc.

Figure 23. NIMA's 5-meter CIB (left) and Space Imaging's 1-meter imagery (right).

One-meter resolution data provides a sharper image with much greater detail, and with less pixelation effect than the five-meter data as magnification increases.

A feature offered by TOPSCENE™ is the ability to scale the resolution of the terrain model based on user perspective view. When the user is operating at higher altitudes, a larger area of terrain needs to be viewed, so TOPSCENE™ loads in a lower resolution data. As the user's perspective gets closer to the terrain, a smaller area of terrain is required, so higher resolution data is seamlessly and transparently loaded in, using a windowing or caching effect. This gives the user the level of detail and resolution required, while employing an efficient memory management routine. TOPSCENE™ is able to use higher resolution data and imagery because of the high-end hardware used. This functionality can be incorporated in the V-HUNT trainer by exploring ways to use a large area database management (LADBM) system at run-time.

B. FULLY DEPLOYABLE SYSTEM

In order for this system to be completely portable and fully deployable, a reduction in system footprint must be made. This can be accomplished by replacing the three 24-inch monitors with more space efficient flat-panel monitors, or a single wrap-around monitor that offers a comparable peripheral view perspective. Another alternative is to replace the monitors altogether with a single projector, or a head-mounted display. Experiments would be needed to determine if a single-screen configuration is as effective as a multi-screen configuration, and to determine the effectiveness, capabilities, and limitations of head-mounted displays. As technology advances, hardware components will reduce in size and cost, making systems such as V-HUNT more feasible for remote-area use and shipboard deployability.

C. PLAYBACK MODE

During the evaluation phase of V-HUNT, several test participants commented that a useful functionality would be to allow the user to plan the route, then watch a "hands off" play-back of the route in a 3-D VE. Tests and experiments would need to be performed to determine if it is even possible, and if it is an effective means to train the task. The users' comments centered on the fact that a play-back mode would allow the user more time to study the route, and not have to devote time to actually manipulating the controls. This seems logical, since, in actuality, the navigating pilot would not normally be controlling the aircraft, but primarily focused on the navigation route. McLean suggested one such method of accomplishing this in the future works section of his thesis (McLean, 1999).

> *A batch file that creates a VRML position and orientation interpolator can be assembled from the data file that MITAVES II creates. The X, Y, Z, H, P, R, and velocity data can be used to create the interpolators. The interpolators would then control the viewpoint as the animation progresses. This would play back the exact route the user flew while they were trying to navigate the route.*

Experiments would need to be conducted in this area comparing the performance of pilots who train using the play-back functionality with those who do not.

D. IMPLEMENT ENVIRONMENT ENHANCEMENTS

Most tactical helicopter missions are flown during the hours of darkness or inclement weather. In order for V-HUNT to be universally accepted from the armed services as a credible training tool to helicopter navigation, it needs to have the ability to train pilots the task of navigating in all-weather conditions. MultiGen-Paradigm Vega Lynx® offers some environment enhancement tools such as fog, smoke, and haze. Incorporating the ability to darken the environment and conduct a virtual fly thru of a city at night is a most realistic expectation. This would involve modeling a city at night, with all the positive and negative effects caused by ambient lights.

To take this a step further, almost all tactical night missions are flown using visual aids – namely, night vision goggles (NVG's). As is the case with all other training devices, flight operations using NVG's require practice for proficiency. Therefore, it is only natural that virtual trainers for helicopter operations must incorporate NVG scenery mode to be effective in training the task. In order for an NVG-compatible VE trainer to be credible and effective, it must include, not only a representative visual scenery, but also a FOV comparable to that afforded by NVG's.

E. EXPANDED DATABASE COVERAGE

While this research is narrowly scoped, and includes a terrain model of a specific landmass in Virginia, the possibilities for expansion are virtually endless. The basic functionality of V-HUNT can be applied to any area on the globe, limited only by the size of the terrain, and the processing power and memory capabilities of the PC hardware.

One method of incorporating an expanded terrain database is to mount the NIMA world-wide DTED and CIB files on a machine configured as a file server. With a centralized database, users can simply input latitudes/longitudes of the desired geographical area via a GUI interface, and access the specific piece of terrain for the mission. This will aid tremendously in the model building process. Additionally, a centralized repository of global data in a common format will allow for increased applicability for systems such as V-HUNT.

F. AUTOMATED RAPID DATABASE GENERATION PROCESS

Ultimately, it would be most beneficial for the terrain generation process to be automated. A conceptual design is shown in Figure 24.

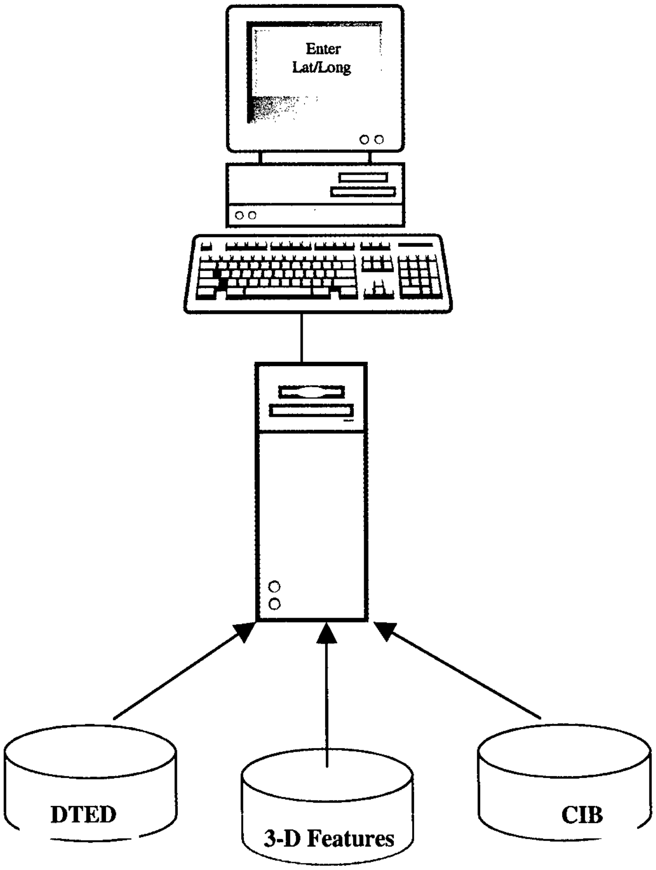


Figure 24. Conceptual Model of Automated Terrain Generation System.

The DTED and CIB data, in some standardized format, would reside in the database, along with a library of 3-D cultural features. The user need only enter the latitudes and longitudes for the area of interest, and the terrain model is generated. A software application would need to be written that combines the functionality of NIMA's MUSE tools and MultiGen-Paradigm's Creator®. Although adding the 3-D features may require some manual manipulation, it will be a more efficient process if all the data and tools are collocated. Through the process of selective modeling, generic features can be easily added through a point-and-click, cut-and paste feature from the library. Those areas that require more detail will still demand more time to create. As the library grows, future models can take advantage of feature reusability, reducing the overall time-to-build.

Cambridge Research Associates, Inc. has been exploring the possibilities in this area of research, and has produced a product called PowerScene II for PFPS. This system offers real-time, geo-specific, 3-D visualization capability by ingesting standard products from NIMA such as Controlled Image Base (CIB), Compressed Arc Digitized Raster Graphics (CADRG), and Digital Terrain Elevation Data (DTED), along with several commercial formats such as National Imagery Transmission Format (NITF) 2.0, Geo-referenced Tagged Image File Format (GeoTiff) and Open Flight. The fully automated data loaders perform dynamic tessellation, level-of-detail management, and run-time data caching (PowerScene, 2000).

Evans and Sutherland, Inc. have also made great strides in the area of scene visualization and rapid database generation. Their product, RapidScene®, is capable of rendering high-resolution and large area photo-specific databases on a desktop computer system. RapidScene includes typical simulation functions for increased texture capacity, moving model scenario generation, and video creation including motion picture expert group (MPEG) output. It also allows simple, fast creation of 3-D databases from satellite imagery, bypassing the traditional "hand-built" methods. It also provides automatic texture application on features, and supports hand-held photos (Faust, 1996).

It is a logical extension of the basic V-HUNT design to move towards automated terrain model generation. In order for this application to meet the needs of operational commands, its scope of applicability as well as the terrain database coverage, must be expanded, and the time to create the models must be reduced through automation. By incorporating known features, functions and existing applications, the V-HUNT system is capable of being transformed into a complete mission rehearsal system, with world-wide applicability, and rapid database generation functionality.

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APPENDIX A. PILOT QUESTIONNAIRE

Questionnaire

This is a voluntary questionnaire. A student at the Naval Postgraduate School in Monterey, Ca, will use data collected by this questionnaire for thesis research. The statistical results of the data may be published and may be shared with other educational institutions and professional and military organizations. No personal information such as name, social security number, address, phone, etc. will either be requested or disseminated.

Your valued input to this questionnaire is greatly appreciated. Thank you for your participation.

APPENDIX A. PILOT QUESTIONNAIRE

For each category below, completely fill in the bubble adjacent to the response that best describes you.

Branch of Service

○ Army
○ Navy
○ Air Force
○ Marines
○ Coast Guard

Rank

○ O-2
○ O-3
○ O-4
○ O-5
○ O-6

Flying Experience

○ < 2 yrs.
○ 2-4 yrs.
○ 5-7 yrs.
○ 8-10 yrs.
○ > 10 yrs.

Total Flight Time (All Models)

○ < 500 hrs.
○ 500 – 1,500 hrs.
○ 1,500 – 2,500 hrs.
○ 2,500 – 3,500 hrs.
○ > 3,500 hrs.

Flight Experience in Urban / Metro Areas

○ None
○ Very Little
○ Moderate
○ Extensive

Instructions

The focus of this questionnaire is helicopter navigation in an urban environment. You have been asked to participate in this study because of your experience flying in urban and metropolitan areas. Our goal is to determine what information is important to helicopter pilots when navigating in urban settings. Your input will help us determine what information should be included in computer graphics models of urban areas that can be used for flight planning and preparation products, such as Virtual Navigation Training and Rehearsal Tools.

Please read each question carefully. There is no time limit. Please use a #2 lead pencil to fill in the bubble(s) corresponding to the most appropriate response(s) for each question. For those questions that ask for written responses, please print neatly and legibly. Use only the space provided in the questionnaire.

Notes: **1.** Although we are aware of the usefulness, accuracy and reliability of onboard precision navigation products such as Loran and GPS, your responses to the questions contained herein should be based solely on *visual* recognition and identification techniques.

2. Flight Conditions: Daylight VFR, normal helicopter altitudes and airspeeds (Below 1000' AGL, 60 – 120 KIAS).

APPENDIX A. PILOT QUESTIONNAIRE

1. Assuming <u>all the products listed below are available</u>, fill in the bubbles corresponding to the *five* MOST USEFUL products when conducting pre-flight route planning for helicopter missions in an urban environment: (Choose only 5)

○ City Map (tourist maps showing streets, major landmarks, parks, ball fields, etc.)
○ VFR Sectional – 1:500,000
○ VFR Terminal Area Chart – 1:250,000
○ Helicopter Route Chart – 1:125,000
○ Contour Maps – 1:50,000
○ Aerial (Still) Photographs
○ Aerial Video
○ Satellite Imagery

2. If you were restricted to only *three* of the five route planning products you selected in question #1, which products would you choose: (Choose only 3)

○ City Map (tourist maps showing streets, major landmarks, parks, ball fields, etc.)
○ VFR Sectional – 1:500,000
○ VFR Terminal Area Chart – 1:250,000
○ Helicopter Route Chart – 1:125,000
○ Contour Maps – 1:50,000
○ Aerial (Still) Photographs
○ Aerial Video
○ Satellite Imagery

3. When conducting pre-flight route planning in a metropolitan area, certain landmarks along the intended route of flight are helpful for maintaining orientation, while other features are not as important. From the list below, select *seven* of the natural and man-made terrain features commonly found in an urban setting that should be included in a flight planning diagram, sketch or graphical representation that would be most helpful in maintaining navigational orientation: (Choose only 7)

○ Roads & Highways
○ Railroad Tracks
○ Rivers, Lakes & Reservoirs
○ Power Lines
○ High-rise Buildings
○ Sports Stadium
○ Residential Homes
○ Bridges
○ Parking Lots
○ Trees & Shrubbery
○ Cemeteries
○ Radio Antennas/Microwave Towers
○ Ball Fields (Football, Baseball, Soccer, etc.)
○ Water Towers
○ Other ____________________
○ Other ____________________

APPENDIX A. PILOT QUESTIONNAIRE

4. When conducting a route study for a mission in an urban area, there may be many natural and man-made terrain features that actually exist that do not add significant value to positive checkpoint identification and route navigation orientation, and therefore, do not need to be included in the route planning diagram, sketch or graphical representation. From the list below, <u>select those features that you feel could be omitted</u>:

○ Roads & Highways
○ Railroad Tracks
○ Rivers, Lakes & Reservoirs
○ Power Lines
○ High-rise Buildings
○ Sports Stadium
○ Residential Homes
○ Bridges
○ Parking Lots
○ Trees & Shrubbery
○ Cemeteries
○ Radio Antennas/Microwave Towers
○ Ball Fields (Football, Baseball, Soccer, etc.)
○ Water Towers
○ Other ______________________
○ Other ______________________

5. Using the list of items *remaining* from question #4 <u>that you felt were too important to omit</u> from a diagram, sketch, or graphical representation, write them in the blanks below in order or importance, from most important to least important: (List *only* those items you *did not* select in Question #4)

______________________ **(Most Important)**

____

____

____

____

____

____

____

______________________ **(Least Important)**

APPENDIX A. PILOT QUESTIONNAIRE

6. When attempting to identify a particular man-made structure such as a building, certain features or characteristics are more important for positive visual recognition/identification than others. Place the following in order of significance, assigning 1 to the most significant characteristic and 9 to the least significant:

_____ Actual Size (Height, Width, Length, etc.)
_____ Relative Size (As compared to neighboring buildings)
_____ Shape
_____ Color / Texture
_____ Construction Material (Wood, Stone, Glass, Brick, etc.)
_____ Number of Stories
_____ Distinctive Markings (Name on side, objects on rooftop, exterior architectural details, etc.)
_____ Relative Position to other key landmarks (Roads, Rivers, Lakes, Towers, etc.)
_____ Immediate Surroundings (Trees, Side Walks, Parking lots, etc.)

APPENDIX A. PILOT QUESTIONNAIRE

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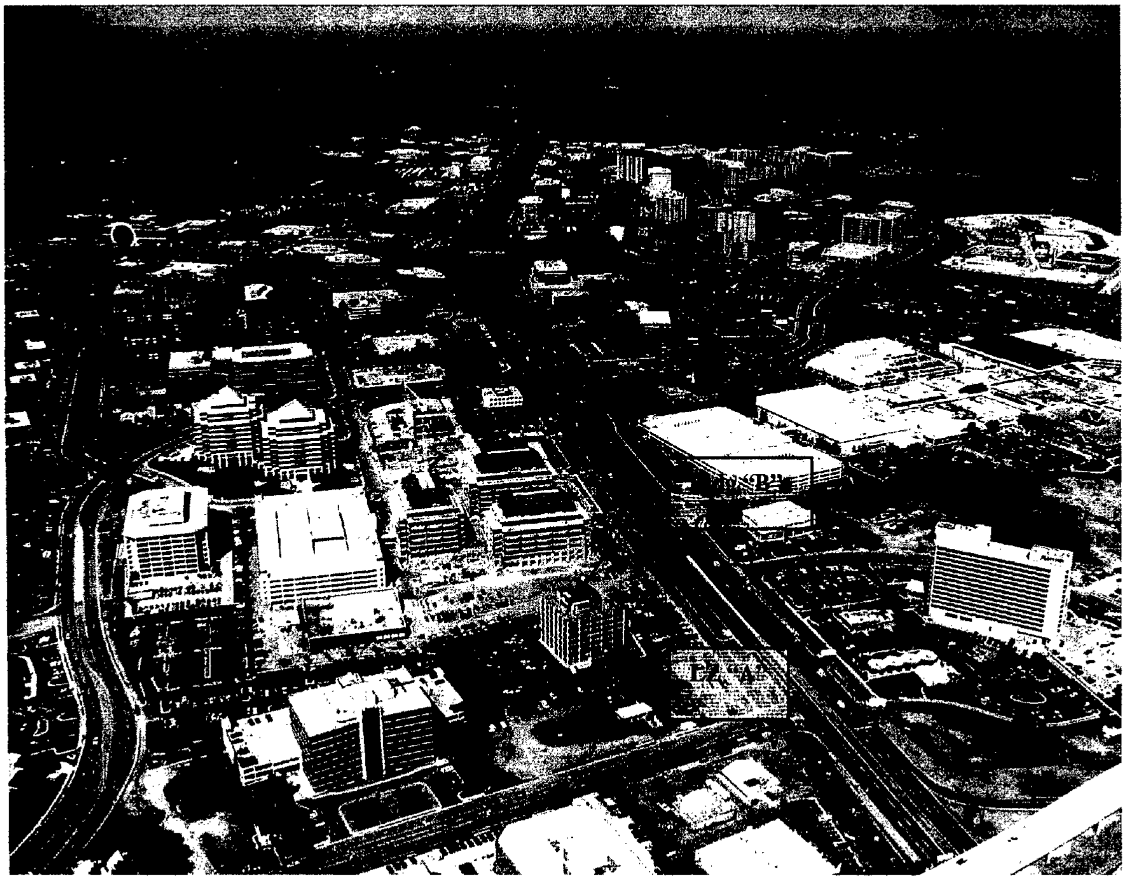
APPENDIX A. PILOT QUESTIONNAIRE

7. You are given a mission to fly to LZ "A" for an evacuation of civilians located in building "B" in the urban area depicted in the photo. Study this photo for as long as you need to become familiar with the mission area. Make a mental "snapshot" of the mission area, concentrating on those natural and man-made features that you will be able to recognize during the flight. When you are done, go to the next page and carefully sketch a diagram that accurately depicts and defines LZ "A". Your sketch should include everything you feel is necessary for visually recognizing/identifying the mission area, as it will be the *only product* you will have in the aircraft to use for identifying LZ "A".



APPENDIX A. PILOT QUESTIONNAIRE

Note: **You should attempt to sketch this diagram from memory as much as possible; however, you may refer back to the photo if necessary. Your sketch should be confined to the space provided. No time limit.**

APPENDIX A. PILOT QUESTIONNAIRE

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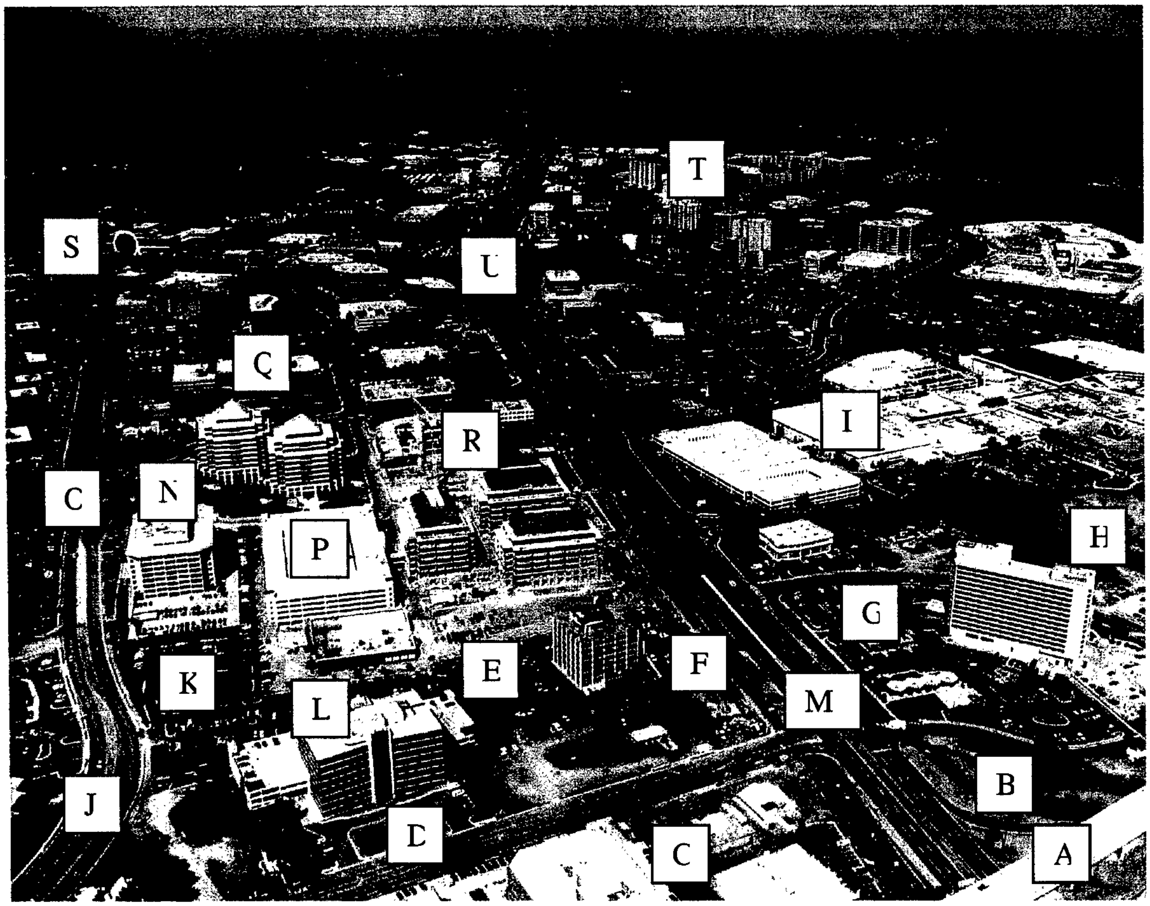
APPENDIX A. PILOT QUESTIONNAIRE



Compare the items labeled in the photo above with those items you chose to include in *your* diagram. Indicate with a Yes or No whether you included the item, and state the reason why you chose to include/omit each item in the blank provided. If you included items in your diagram that are not labeled in the photo, add them to the end of the list and explain why you chose to include them.

Y N
○ ○ A. Highway Overpass ____________________
○ ○ B. Off-Ramp ____________________
○ ○ C. Bldgs ____________________
○ ○ D. "U" Shaped Driveway ____________________
○ ○ E. Parking Lot ____________________
○ ○ F. Shrubbery ____________________
○ ○ G. Parking Lot ____________________
○ ○ H. Red Letters on Bldg. ____________________
○ ○ I. Group of Bldgs ____________________

Continued ⟶

APPENDIX A. PILOT QUESTIONNAIRE

Y N

○ ○ J. 4-Lane Hwy______________________________

○ ○ K. Parking Lot______________________________

○ ○ L. Bldg.______________________________
○ ○ M. Intersection______________________________
○ ○ N. Bldg.______________________________
○ ○ O. Intersection______________________________
○ ○ P. Bldg.______________________________
○ ○ Q. Twin Bldgs.______________________________
○ ○ R. Triplet Bldgs.______________________________
○ ○ S. Circular Entrance on Bldg Front
____
○ ○ T. Radio Tower______________________________
○ ○ U. 4-Lane Hwy______________________________

Other______________________________
Other______________________________
Other______________________________

**************************** END OF QUESTIONNAIRE ****************************

THANK YOU

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APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

A survey, in the form of a questionnaire (Appendix A), was conducted to gather data and information for designing computer graphics 3-D models depicting urban terrain for virtual helicopter navigation flights. The results of data collected from 86 pilots are contained herein.

The subject pool consisted of helicopter pilots from varying aircraft communities from the U.S. Army, Navy and Marine Corps. The ranks of the subjects ranged from O-2 to O-6, with flying experience ranging from 2 to more than 10 years, and total flight time from 500 hours to more than 3,500 hours.

The subjects were placed into one of two categories: those pilots who had self-described "moderate" or "extensive" flight experience in urban or metropolitan areas, and those pilots who had very little or no flight experience in urban areas.

The pilots were instructed that their responses to the questions were to be based solely on visual recognition and identification techniques, in daylight VFR flight conditions, at typical helicopter altitudes and airspeeds.

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

This data represents those pilots surveyed who indicated which products were the most useful for conducting pre-flight route planning for helicopter flights in urban areas.

From a list of eight (8) products * commonly available for flight planning, pilots were asked to select the five (5) most useful. They were then asked to select those products most useful (or desired) if restricted to only three flight planning products.

Column A shows the results (expressed as a percentage) of surveyed pilots among the group that had self-described "moderate" or "extensive" experience flying in urban or metropolitan areas. Column B shows the results of all pilots surveyed.

* Map Descriptions:

- City Map – tourist map with streets, landmarks, parks, ball fields, etc.
- VFR Sectional – 1:500,000 scale
- VFR Terminal Area Chart – 1:250,000 scale
- Helicopter Route Chart – 1:125,000 scale
- Contour Maps – 1:50,000 scale
- Aerial (Still) Photographs
- Aerial Video
- Satellite Imagery

5 Most Useful Flight-Planning Products	A	B
1. Aerial (Still) Photographs	100	95
2. City Map	97	95
3. Helicopter Route Chart	94	81
4. Aerial Video	65	70
5. VFR Terminal Area Chart	65	61
Satellite Imagery	53	54
Contour Maps	32	42
VFR Sectional	15	16

3 Most Useful Flight-Planning Products	A	B
1. City Map	91	88
2. Aerial (Still) Photographs	68	65
3. Helicopter Route Chart	59	51
VFR Terminal Area Chart	35	33

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Aerial Video	24	23
Contour Maps	21	28
Satellite Imagery	12	14
VFR Sectional	6	9

Chart D gives a graphical representation of column A from the preceding page. Correspondingly, Chart E is a graphical representation of column B.

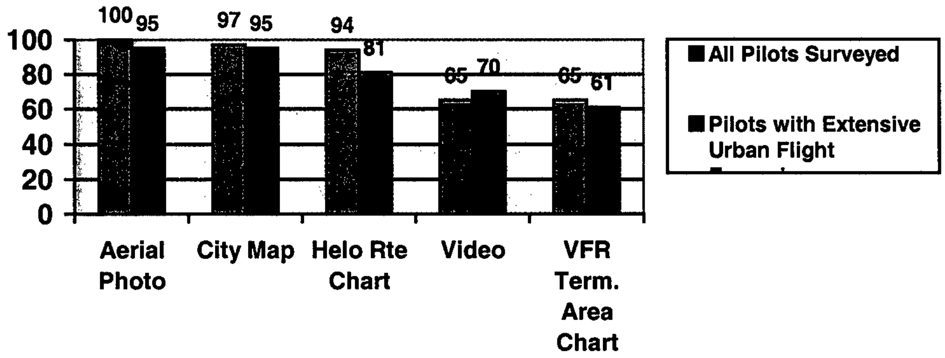


Chart D. Five Most Useful Flight-Planning Products

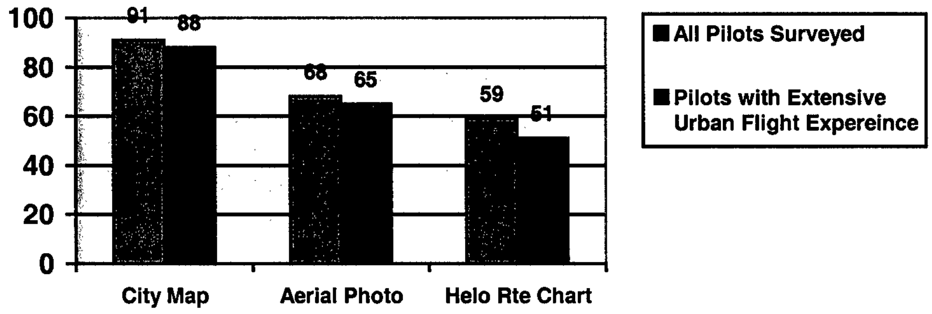


Chart E. Three Most Useful Flight-Planning Products

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Table 8 represents the results of those pilots surveyed who indicated the given terrain feature shown in the first column should be included in a sketch or diagram of an urban area for purposes of helicopter navigation orientation & checkpoint recognition/identification.

From the list below of 14 natural or man-made terrain features commonly found in urban and metropolitan areas, pilots were asked to rank the importance of each with regards to its relevance in helicopter navigation in urban terrain. The top ten features from the survey are displayed in this table.

Columns 2 through 4 show the percentage of pilots that ranked the given feature among their top 3, top 5 and top 7 choices. The first number in each box indicates the percentage of pilots who had self-described "moderate" to "extensive" experience flying in urban or metropolitan areas. The second number is the percentage of all pilots surveyed.

* List of natural and man-made terrain features commonly found in urban areas:

Roads & Highways
Railroad Tracks
Rivers, Lakes, Reservoirs
Power Lines
High-rise Buildings
Sports Stadiums
Cemeteries
Residential Homes
Parking Lots
Trees & Shrubbery
Ball Fields (Football, Baseball, Soccer, etc.)
Water Towers
Bridges
Radio Antennas / Microwave Towers

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Terrain Feature	Top 3	Top 5	Top 7
Roads & Highways	76/77	91/88	91/93
Rivers, Lakes & Reservoirs	59/56	79/79	85/84
Bridges	32/28	62/53	82/74
RR Tracks	18/26	50/56	68/72
Sports Stadiums	35/30	53/49	76/70
High-Rise Bldgs.	29/26	38/37	68/70
Power Lines	6/9	32/35	44/47
Radio Antennas & Microwave Twrs.	21/21	29/30	44/42
Water Towers	15/16	35/40	53/56
Ball Fields	0/5	12/14	29/30

Table 8. Top Terrain Features.

Chart F provides a graphical representation of Table 8.

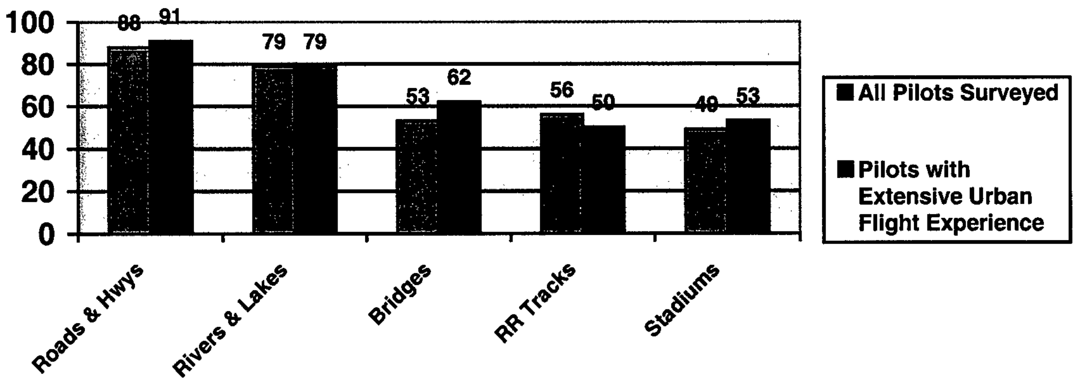


Chart F. Ranking of Top 5 Terrain Features

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Table 9 represents the results of those pilots surveyed who indicated the given terrain feature shown in the first column did not add significant value to positive checkpoint recognition/identification and route navigation orientation, and could therefore be omitted from a sketch or diagram of an urban area.

Terrain Feature	**A**	**B**
Residential Homes	91	88
Trees & Shrubbery	79	79
Parking Lots	74	67
Cemeteries	33	29

Table 9. Non-essential Terrain Features.

From the list below of 14 natural or man-made terrain features commonly found in urban and metropolitan areas, pilots were asked to select those terrain features that could be omitted from a sketch, diagram or graphical representation. The top four (4) features from the survey are displayed in Table 9.

Column A represents the results (expressed as a percentage) of surveyed pilots who had self-described "moderate" or "extensive" experience flying in urban or metropolitan areas. Column B shows the results of all pilots surveyed.

* List of natural and man-made terrain features commonly found in urban/metro areas:

Roads & Highways
Railroad Tracks
Rivers, Lakes, Reservoirs
Power Lines
High-rise Buildings
Sports Stadiums
Cemeteries
Residential Homes
Parking Lots
Trees & Shrubbery
Ball Fields (Football, Baseball, Soccer, etc.)
Water Towers
Bridges
Radio Antennas / Microwave Towers

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Chart G provides a graphical representation of Table 9.

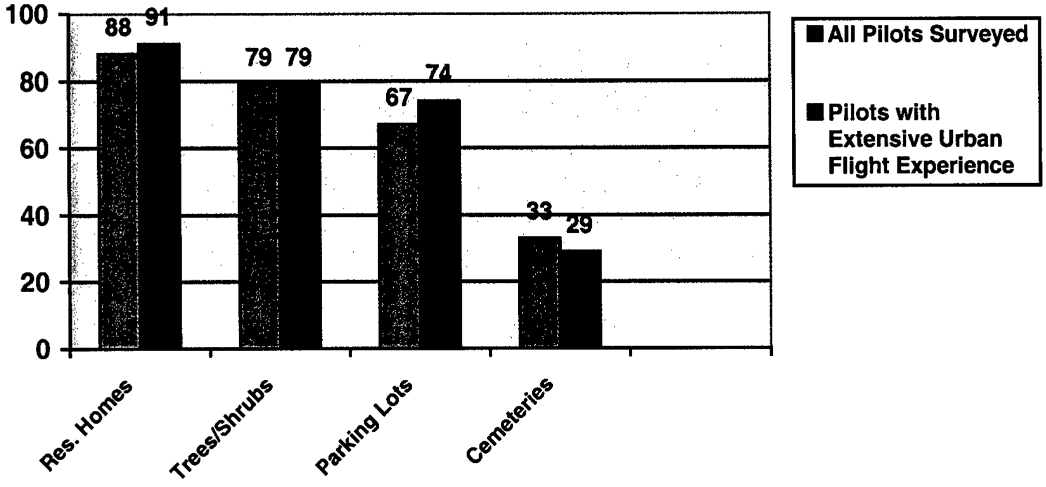


Chart G. Top Three Non-Essential Terrain features

Tables 10 & 11 represent the results of those pilots surveyed who indicated whether the given characteristic of a man-made terrain feature (ex. building) was important for positive visual recognition/identification. The histograms on the following page give a graphical representation of the data contained in these charts, with column A corresponding to Table 10, and column B corresponding to Table 11.

From a list of nine (9) characteristics commonly found in man-made objects in urban and metropolitan areas, pilots were asked to rank from 1 to 9 its importance with regard to its relevance to visual recognition and/or positive identification.

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Rankings

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Actual Size	**28**	**15**	**12**	**0**	**6**	**12**	**15**	**6**	**6**
Relative Size	**28**	**32**	**12**	**16**	**12**	**0**	**0**	**0**	**0**
Shape	**9**	**24**	**26**	**18**	**6**	**12**	**5**	**0**	**0**
Color / Texture	**0**	**3**	**9**	**6**	**3**	**15**	**18**	**26**	**20**
Construction Material	**0**	**0**	**0**	**0**	**12**	**6**	**12**	**38**	**32**
# of Stories	**3**	**0**	**8**	**10**	**14**	**15**	**17**	**14**	**18**
Distinctive Markings	**8**	**12**	**15**	**26**	**18**	**15**	**0**	**3**	**2**
Relative Position	**24**	**12**	**15**	**12**	**20**	**5**	**12**	**0**	**0**
Immediate Surroundings	**0**	**3**	**3**	**12**	**9**	**20**	**21**	**13**	**20**

Table 10. Figures expressed as a percentage of those pilots surveyed who had self-described "moderate" or "extensive" experience flying in urban areas.

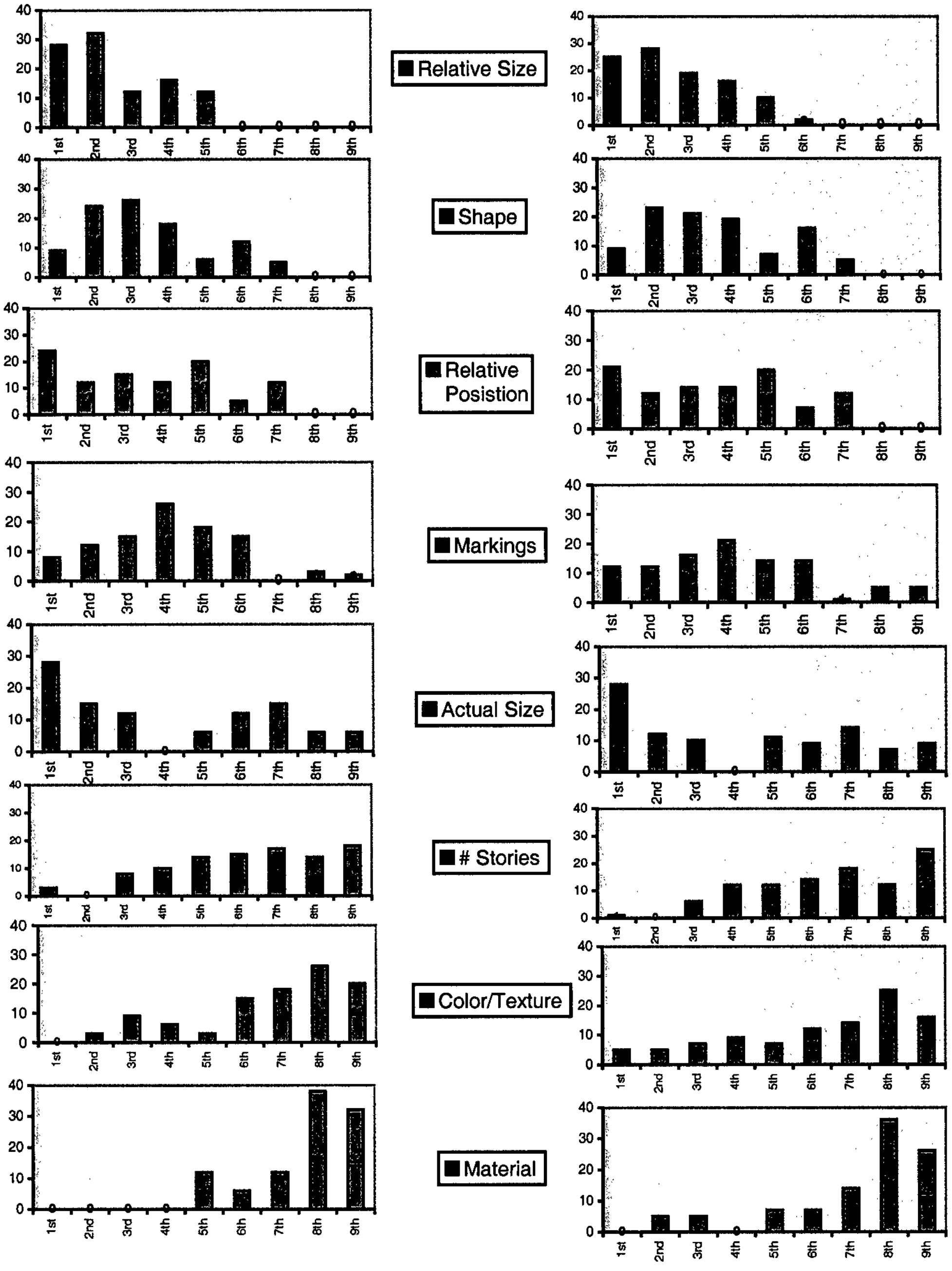
Rankings

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Actual Size	**28**	**12**	**10**	**0**	**11**	**9**	**14**	**7**	**9**
Relative Size	**25**	**28**	**19**	**16**	**10**	**2**	**0**	**0**	**0**
Shape	**9**	**23**	**21**	**19**	**7**	**16**	**5**	**0**	**0**
Color / Texture	**5**	**5**	**7**	**9**	**7**	**12**	**14**	**25**	**16**
Construction Material	**0**	**5**	**5**	**0**	**7**	**7**	**14**	**36**	**26**
# of Stories	**1**	**0**	**6**	**12**	**12**	**14**	**18**	**12**	**25**
Distinctive Markings	**12**	**12**	**16**	**21**	**14**	**14**	**1**	**5**	**5**
Relative Position	**21**	**12**	**14**	**14**	**20**	**7**	**12**	**0**	**0**
Immediate Surroundings	**0**	**3**	**1**	**9**	**12**	**19**	**21**	**15**	**19**

Table 11. Figures expressed as a percentage of all pilots surveyed.

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Column A **Column B**



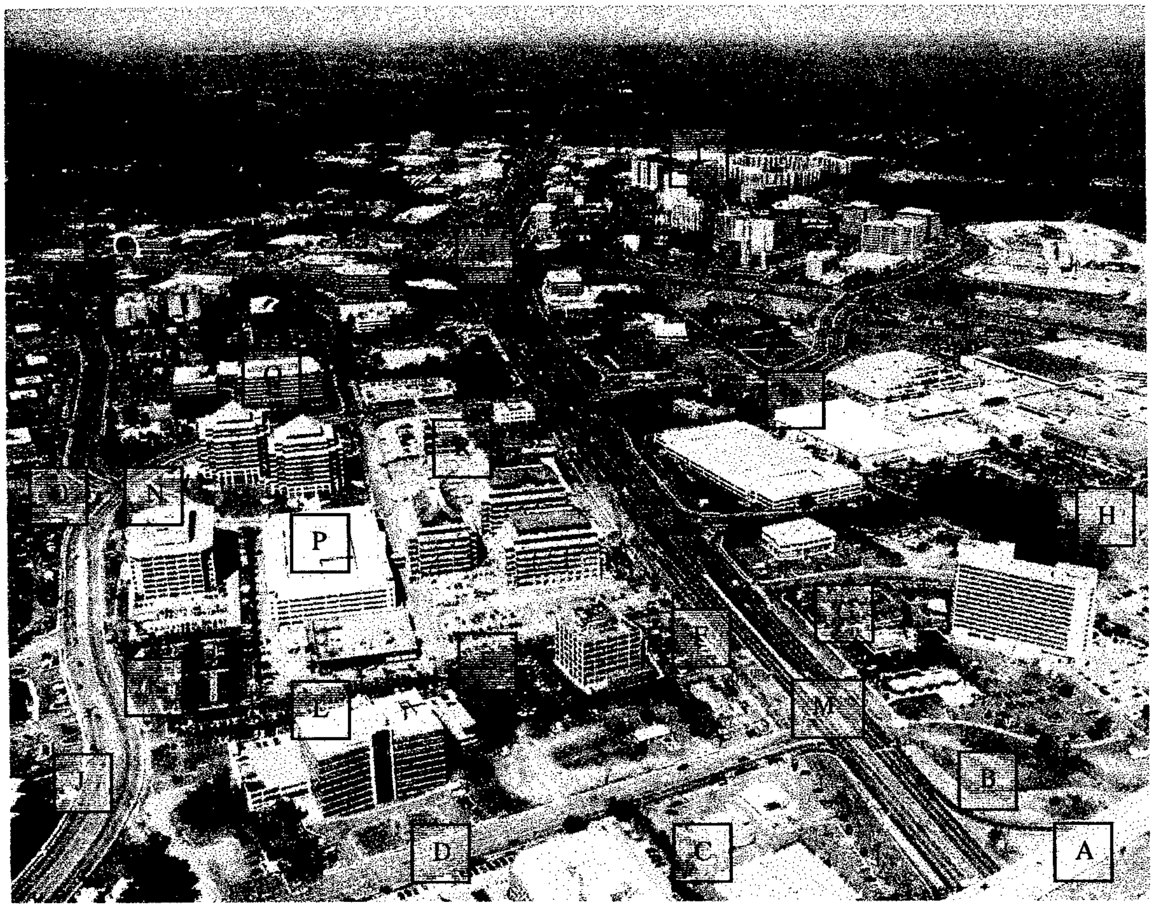
APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

Pilots were asked in the questionnaire to study the photo below, depicting a typical urban area, with no limit on the amount of time with which to become familiar with the photo, and to form a mental "snap-shot" of the area.

They were then asked to complete a sketch of the same area, and include in their sketch those natural and man-made features they felt would be necessary in order to visually recognize and positively identify Landing Zone (LZ) "A" during an actual flight.

Although the pilots were instructed to construct their sketch primarily from memory – not to copy the picture directly, and not to look at the picture while sketching – they were allowed to refer back to the photo if necessary. The pilots were told that their sketch would be the only product they would have in the aircraft to use in identifying the Landing Zone.

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE



		A	B
A	Highway Overpass	56	58
B	Off Ramp	3	5
C	Buildings	32	30
D	"U" Shaped Driveway	18	14
E	Parking Lot	59	60
F	Shrubbery	21	21
G	Parking Lot	12	14
H	Red Letters on Marriott	53	53
I	Group of Buildings	38	40
J	4-Lane Highway	82	86
K	Parking Lot	21	16
L	Building	77	79
M	Intersection	82	86
N	Building	38	40
O	Intersection	47	30
P	Building	41	44
Q	Twin Buildings	53	63
R	Triplet Buildings	47	53
S	Circular Entrance on Bldg.	3	12
T	Radio Tower	24	30
U	4-Lane Highway	74	77

Table 12. Items Pilots included in LZ sketches.

APPENDIX B. DATA FROM PILOT QUESTIONNAIRE

The pilots were then asked to compare the items labeled in the photo with those items they chose to include in their sketch. The results are shown in Table 12.

The data depicted in column A of the Table 12 represents the results (expressed as a percentage) of those pilots surveyed who had self-described “moderate” or “extensive” experience flying in urban areas. The data depicted in column B is the results from all pilots surveyed.

Assumptions: It was assumed that all sketches, diagrams or graphical representations would include LZ “A” and building “B”, therefore pilots were not asked in the questionnaire whether they had included these two features in their sketch. Furthermore, it was assumed that most (if not all) sketches, representations or diagrams would include the Marriott Hotel, due to its unique shape, position and proximity to LZ “A”. As a footnote, 100% of those pilots surveyed chose to include in their sketch all three aforementioned features.

APPENDIX C. NAVIGATION EVALUATION FOR NON-VE TEST PARTICIPANTS

Instructions: You are tasked with navigating along a pre-determined route of flight from a helicopter. You will be given the type of standard maps, charts, and photographs you could expect for pre-flight route planning and study when preparing for actual helicopter flights. You will have 90 minutes to prepare for the flight, using any or all of the products provided to you, at which time you will begin the navigation test.

Evaluation Flight: The navigation test will consist of viewing a videotape of the route you have studied, taken from a helicopter at altitudes ranging from 700 to 1,300 feet agl, and at airspeeds between 65 – 90 knots. The flight will be flown during daylight hours, under VMC flight conditions.

Your evaluator will clearly identify your starting position, both on the video, and correspondingly, on your map. You are tasked with positively identifying the twelve (12) checkpoints along the route listed below and circled on your map. The flight is approximately 15 minutes duration, and ends at the Pentagon.

Thanks for your participation, and Good Luck !

===

Start -> Quaker Church

1 -> I-395
2 -> Bailey's Crossroads
3 -> Seven Corners
4 -> I-66
5 -> Tysons Corner
6 -> McLean
7 -> Langley Fork
8 -> Glebe Elbow
9 -> Glebe / I-66
10 -> Shirlington
11 -> Navy Annex
12 -> Pentagon -> End of flight

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APPENDIX D. NAVIGATION EVALUATION FOR V-HUNT TEST PARTICIPANTS

Instructions: You are tasked with navigating along a pre-determined route of flight from a helicopter. You will be given the type of standard maps, charts, and photographs you could expect for pre-flight route planning and study when preparing for actual helicopter flights. You will also have an opportunity to virtually fly the route on a computer navigation trainer. You will have 90 minutes to prepare for the flight, using any or all of the products provided to you, at which time you will begin the navigation test.

Evaluation Flight: The navigation test will consist of viewing a videotape of the route you have studied, taken from a helicopter at altitudes ranging from 700 to 1,300 feet agl, and at airspeeds between 65 – 90 knots. The flight will be flown during daylight hours, under VMC flight conditions.

Your evaluator will clearly identify your starting position, both on the video, and on your map. You are tasked with positively identifying the twelve (12) checkpoints along the route listed below and circled on your map. The flight is approximately 15 minutes in duration, and ends at the Pentagon.

Thanks for your participation, and Good Luck !

==

Start -> Quaker Church

1 -> I-395
2 -> Bailey's Crossroads
3 -> Seven Corners
4 -> I-66
5 -> Tysons Corner
6 -> McLean
7 -> Langley Fork
8 -> Glebe Elbow
9 -> Glebe / I-66
10 -> Shirlington
11 -> Navy Annex
12 -> Pentagon -> End of flight

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APPENDIX E. NAVIGATION EVALUATION GRADING CARD

Test participant #____
○ VE
○ Non-VE

Rank________________
Service ________________
Aircraft ________________

Total Flt Time __________Hrs

Total time spent preparing for flight ____________

Map Study Time ____________

V-HUNT Time ____________

Times route flown ____________

Exocentric Views ____________

Sat Image Call-ups ____________

City Map Call-ups ____________

Checkpoint		**Y**	**N**	**Notes**
I – 395	1:42			
Bailey's X-Roads	2:52			
Seven Corners	3:57			
I – 66	5:25			
Tysons Corner	6:30			
McLean	7:52			
Langley Fork	8:50			
Glebe Elbow	10:30			
Glebe / I – 66	11:50			
Shirlington	13:40			
Navy Annex	14:45			
Pentagon	15:00			

Notes

____

____

____Score /12

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