To the Graduate Council:

I am submitting herewith a thesis written by Donald James Hunter entitled "Identification Of Aircrew Tasks For Using Direct Voice Input (DVI) To Reduce Pilot Workload In The AH-64D Apache Longbow." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Ralph D. Kimberlin

Ralph Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Peter Solies

Richard J. Ranaudo

Acceptance for the Council:

Vice Provost and Dean of Graduate Studies

# IDENTIFICATION OF AIRCREW TASKS FOR USING DIRECT VOICE INPUT (DVI) TO REDUCE PILOT WORKLOAD IN THE AH-64D APACHE LONGBOW

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Donald James Hunter
December 2003

# DEDICATION

This thesis is dedicated to all the men and women that support, fly, and maintain the AH-64 Apache. Attack!

# ACKNOWLEDGEMENT

I would like to express many thanks to the faculty and staff of the Aviation Systems Department who have made my stay here at the University of Tennessee Space Institute challenging and enjoyable. I am grateful to my thesis committee, Dr. Ralph Kimberlin, and Dr. Peter Solies, for their wisdom and guidance, and to Professor Rich Ranaudo for the many air miles and hours spent helping me prepare this thesis.

I would also like to acknowledge the technical support of Tim Roderick and Ty Crowder whose years of expertise flying the Apache proved invaluable. Special thanks to Matt Hannen, Crew Systems and Human Factors Engineer for Boeing Co. Mesa, Arizona, for his assistance in directing the focus of this thesis and answering the many questions I posed. Additionally, I would like to thank the wonderful Allison Schmidt for her understanding and support in helping me write this thesis.

# ABSTRACT

Advances in helicopter design continue to saturate the pilot's visual channel and produce remarkable increases in cognitive workload for the pilot. This study investigates the potential implementation of Direct Voice Input (DVI) as an alternative control for interacting with onboard systems of the AH-64D Apache, in an attempt to reduce pilot workload during a "hands on" the controls and "eyes out" condition. The intent is to identify AH-64D cockpit tasks performed through Multi Purpose Displays (MPDs) that when converted to DVI will provide the greatest reduction in task execution time and workload. A brief description of applicable AH-64D audio and visual displays are provided. A review of current trends in state-of-the-art voice recognition technology is presented, as well as previous and current voice input cockpit identification studies. To identify tasks in the AH-64D, a methodology was developed consisting of a detailed analysis of the aircraft's mission and on-board systems. A pilot questionnaire was developed and administered to operational AH-64D pilots to assess their input on DVI implementation. Findings indicate DVI would be most useful for displaying selected MPD pages and performing tasks pertaining to the Tactical Situation Display (TSD), weapons, and communications. Six of the candidate DVI tasks were performed in the AH-64D simulator using the manual input method and a simulated voice input method. Two different pilots made objective and subjective evaluations. Task execution times and workload rating were lower using a simulated means of voice input. Overall, DVI shows limited potential for workload reduction and warrants further simulator testing before proceeding to the flight environment.

# TABLE OF CONTENTS

**CHAPTER 1**

INTRODUCTION ....... 1

Preface ....... 1

Statement of the Problem ....... 1

A Proposed Solution ....... 3

Thesis Statement ....... 3

Structural Overview of Thesis ....... 4

**CHAPTER 2**

BACKGROUND ....... 6

Introduction ....... 6

The Evolution of the AH-64D Attack Helicopter ....... 6

Background Conclusion ....... 19

**CHAPTER 3**

SYSTEM DESCRIPTION ....... 21

AH-64D: General Description ....... 21

Data Management System ....... 22

Warning, Caution and Advisory System ....... 32

**CHAPTER 4**

LITERATURE REVIEW ....... 34

Multiple Resource Theory ....... 34

Acoustic Theory ....... 36

Speech Recognition Technology .......... 39

Speech Recognition In The Flight Environment .......... 47

Direct Voice Input Cockpit Research .......... 50

Voice Input Task Identification Studies .......... 52

**CHAPTER 5**

METHODOLOGY .......... 58

Introduction .......... 58

Description of the Test Simulator .......... 59

Module One: Mission Analysis .......... 61

Module Two: Task Identification .......... 64

Module Three: Pilot Questionnaire .......... 68

Module Four: Simulator .......... 69

**CHAPTER 6**

FINDINGS AND DISCUSSION .......... 73

Module One Findings: Mission Analysis .......... 73

Module Two Findings: Task Identification .......... 75

Module Three Findings: Pilot Questionnaire .......... 75

Module Four Findings: Simulator .......... 88

**CHAPTER 7**

CONCLUSION & RECOMMENDATIONS .......... 94

Conclusion .......... 94

Recommendations .......... 96

**LIST OF REFERENCES** .......... 98

**APPENDICES** ........................................ 104

APPENDIX A: MISSION OUTLINE ........................................ 105

APPENDIX B: MODULE TWO DATA ........................................ 114

APPENDIX C: PILOT QUESTIONNAIRE ........................................ 125

APPENDIX D: BEDFORD SCALE ........................................ 138

APPENDIX E: SLALOM COURSE ........................................ 140

APPENDIX F: SIMULATOR DATA ........................................ 142

**VITA** ........................................ 149

# LIST OF TABLES

Table 1. WCA Categories and Definitions ..... 32

Table 2. Example Switch Action History ..... 62

Table 3. Test and Test Condition Matrix ..... 72

Table 4. Pilot Questionnaire Results, Questions 1-43 ..... 77

Table 5. Pilot Questionnaire Results, Question 44 ..... 80

Table 6. Pilot Questionnaire Results, Question 45 ..... 81

Table 7. Pilot Questionnaire Results, Question 46 ..... 82

Table 8. Additional Pilot Responses to Question 46 ..... 82

Table 9. Pilot Questionnaire Results, Question 48 ..... 84

Table 10. Bedford Workload Ratings for Simulator Sessions ..... 91

Table A1. Mission Task Categorization ..... 110

Table B1. Task Analysis From Module Two Of Methodology ..... 115

# LIST OF FIGURES

Figure 1. AH-64D Apache ........ 7

Figure 2. Photo of Copilot Gunner/Cockpit AH-64A ........ 11

Figure 3. Photo of Pilot Cockpit AH-64A ........ 11

Figure 4. Copilot/Gunner Cockpit AH-64D ........ 15

Figure 5. Pilot Cockpit AH-64D ........ 16

Figure 6. Experimental RPA Cockpit ........ 20

Figure 7. MPD with Menu Page ........ 24

Figure 8. MPD Page Layering ........ 28

Figure 9. Wickens Multiple Resource Model ........ 35

Figure 10. Plot of the acoustic waveform and spectrogram of the utterance *jump the lines.* ........ 38

Figure 11. Dynamic time warping of the word *one*, being aligned with the *one* template. ........ 43

Figure 12. Two-state Hidden Markov Model ........ 45

Figure 13. Apache Longbow Crew Trainer (LCT) ........ 60

Figure 14. Direct Voice Input Criteria ........ 66

Figure 15. Response Time for Simulator Sessions 1 & 2 ........ 89

Figure D1. The Bedford Scale developed by Roscoe and Ellis at the Royal Aircraft Establishment in Bedford, England ........ 139

Figure E1. Slalom Course ........ 141

Figure F1. Subject Pilot One Slalom Course Baseline ........ 143

Figure F2. Subject Pilot One "Hands Busy" FM & VHF Frequency Changes ............... 144

Figure F3. Subject Pilot One Using Voice Input ............................................................ 145

Figure F4. Subject Pilot Two Slalom Course Baseline .................................................. 146

Figure F5. Subject Pilot Two "Hand Busy" Entering A Target ...................................... 147

Figure F6. Subject Pilot Two Using Voice Input ........................................................... 148

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AI | Artificial Intelligence |
| AAH | Advanced Attack Helicopter |
| ABF | Attack By Fire |
| ABR | Abbreviation |
| A/C | Aircraft |
| ACT | Active |
| ADF | Automatic Direction Finder |
| ANN | Artificial Neural Networks |
| AMPS | Aviation Mission Planning System |
| APU | Auxiliary Power Unit |
| AQC | Acquisition |
| ASE | Aircraft Survivability Equipment |
| ASR | Automatic Speech Recognition |
| ATHS | Automatic Target Handover System |
| AVRADA | Army Avionics Research and Development Activity |
| BDA | Battle Damage Assessment |
| BUCS | Back-Up Control System |
| CHAN | Channel |
| CL | Checklist |
| COM | Communications |
| CPG | Copilot Gunner |
| CRT | Cathode Ray Tube |
| DA | Density Altitude |
| DEL | Delete |
| DIR | Direct |
| DMS | Data Management System |
| D/NAW | Day/Night All Weather |
| DP | Display Processor |
| DTU | Data Transfer Unit |
| DTW | Dynamic Time Warping |
| DTU | Data Transfer Unit |
| DVI | Direct Voice Input |
| ECCM | Electronic Counter Counter-Measure |
| ENG | Engine |
| ERF | ECCM Remote Fill |
| EVMPI | Eye/Voice Mission Planning Interface |
| EXC | Exceedence |

| | |
|---|---|
| FAARP | Forward Aerial Arming and Refueling Point |
| FAB | Fixed Action Button |
| FARM | Fuel Ammo Rockets Missiles |
| FCR | Fire Control Radar |
| FFAR | Folding Fin Aerial Rocket |
| FFT | Fast Fourier Transform |
| FH | Frequency Hop |
| FH/M | Frequency Hop Master |
| FLIR | Forward Looking Infra-Red |
| FLT | Flight |
| FM | Frequency Modulation |
| FMC | Flight Management Computer |
| FUEL | Fuel |
| GOMS | Goals, Operations, Methods, and Selections |
| HDU | Helmut Display Unit |
| HEDP | High Explosive Dual Purpose |
| HMD | Helmet Mounted Display |
| HMM | Hidden Markov Model |
| HOCAC | Hands On Collective And Cyclic |
| HQ2 | Have Quick 2 |
| HST | History |
| IAT | Image Auto Tracker |
| IBIT | Initiated Built In Test |
| IHADSS | Integrated Helmet and Display Sight Subsystem |
| IMELDA | Integrated Mel Scaled Linear Discriminant Analysis |
| IR | Infra-Red |
| KU | Keyboard Unit |
| LCT | Longbow Crew Trainer |
| LDA | Linear Discriminant Analysis |
| LHG | Left Hand Grip |
| LHMMS | Longbow Hellfire Modular Missile System |
| LPC | Linear Predictive Coding |
| LRU | Line Replaceable Unit |
| M | Menu |
| MM | Millimeter |
| MAN | Manual |
| MANPRINT | Manpower and Personnel Integration |
| MBE | Management By Exception |

| | |
|---|---|
| MPD | Multi-Purpose Display |
| MSG SEND | Message Send |
| MSIP | Multi-Stage Improvement Plan |
| MSL | Missile |
| MTF | Maintenance Test Flight |
| | |
| NASA | National Aeronautics and Space Administration |
| NAVAIR | Naval Air Systems Command |
| NF | No-Fire |
| NOE | Nap-Of-Earth |
| NRC | National Research Council |
| NVG | Night Vision Goggles |
| | |
| ORT | Optical Relay Tube |
| | |
| PA | Pressure Altitude |
| PERF | Performance |
| PFZ | Priority Fire Zone |
| PNVS | Pilot Night Vision System |
| PP | Present Position |
| PRI | Priority |
| PTR | Push To Recognize |
| | |
| REC | Receive |
| RF | Radar Frequency |
| RFHO | Radar Frequency Handover |
| RHG | Right Hand Grip |
| RJAM | Radar Jammer |
| RKT | Rocket |
| RPA | Rotorcraft Pilot's Associate |
| RQST | Request |
| RTE | Route |
| RTM | Route Menu |
| RTS | Remote Transmit Select |
| RVW | Review |
| | |
| SC | Single Channel |
| SEG | Segment |
| SINC | Single Channel Ground & Airborne Radio |
| SOI | Signal Operating Instructions |
| STBY | Standby |
| SYS | System |
| | |
| TADS | Target Acquisition Designation Sight |
| TDANN | Time Delay Artificial Neural Networks |

| | |
|---|---|
| TGT | Target |
| THRT | Threat |
| TSD | Tactical Situation Display |
| TSTT | TADS Selected Task Trainer |
| TSET | Training Set |
| UFC | Up Front Controller |
| UFD | Up-Front Display |
| UHF | Ultra High Frequency |
| USAALS | United States Army Aviation Logistics School |
| USAAVNC | United States Army Aviation Center |
| UTIL | Utility |
| VAB | Variable Action Button |
| VCR | Video Recorder |
| VERS | Version |
| VHF | Very High Frequency |
| VID | Video |
| WCA | Warning, Caution, and Advisory |
| WL | Workload Level |
| WP | Weapon Processor |
| WPN | Weapons |
| XMIT | Transmit |
| XPNDR | Transponder |
| ZN | Zone |

# CHAPTER 1

# INTRODUCTION

## Preface

The proliferation of advanced electronics and digital computers in helicopter design has led to remarkable increases in mission capabilities. The AH-64D Apache Longbow is at the leading edge of advanced helicopter cockpit design. Evolution of the aircraft has led design engineers toward the optimization of the limited visual and manual capacities of the pilot. This goal has been pursued through the use of helmet display units, multi-purpose displays, voice-synthesized warning messages, caution tones, and control switches on the cyclic and collective sticks.

A potential addition to these techniques is currently being explored; voice recognition technology is being examined as a potential input mode for the AH-64D Apache. The benefits of using voice as a means of control input in aircraft have been well documented (Henderson, 1989; Swail & Kobierski, 1997; Vidulach & Bortolussi, 1988). The question remaining is how to effectively apply voice recognition technology to the difficult environment of the AH-64D helicopter. More specifically, to which tasks would Direct Voice Input (DVI) be most beneficially applied?

## Statement of the Problem

The increasing complexity of helicopter design and cockpit instrumentation has perpetuated the need for flexible multi-purpose displays. The multi-purpose display, by definition, presents an enormous amount of information to the aircrews, but in doing so has aggravated a very real problem. A pilot has a limited capacity for receiving and processing information.

The use of MPDs as a man/machine interface is not necessarily the most efficient method of performing cockpit tasks (Downey, 1995). The AH-64D Apache Longbow uses four Multi-Purpose Displays (MPDs), two in each cockpit. The MPDs display flight critical information and facilitate aircrew/helicopter interface of mission tasks. The accomplishment of many of these tasks require several buttons to be pushed, and, in some cases, data to be entered via a keyboard. During night Nap-Of-Earth (NOE) flying, it is critical for the pilot and copilot gunner (CPG) to remain "eyes-out" and with their "hands on" the controls. This constraint is in direct conflict with the current input modality of pushing buttons and viewing displays. As a result, the manual method of pushing buttons makes it difficult to safely perform necessary tasks and has increased manual workload. Bucher, Karl, Voorhees, and Werner (1984), describe this conflict best: " . . . current cockpit design has incorporated multifunction CRT [cathode ray tube] displays in an attempt to provide the maximum amount of information to the pilot while reducing sensory overload. The problem with multi-function CRTs is that information must be accessed manually and then read by the pilot. Both tasks can interfere with the visual and motor demands of ... flight, so the reduction of sensory clutter introduces cognitive clutter."

## A Proposed Solution

A proposed solution to this problem is using an alternative mode of control to issue commands. A natural way of communicating a command is through voice[1]. The rapid advances in Automatic Speech Recognition (ASR) make it possible to apply that technology to the noisy, complex environment of the AH-64D Apache cockpit. The use of Direct Voice Input (DVI), through ASR, to execute commands and display information can provide measurable benefits in workload reduction, safety, and mission effectiveness. Using DVI to perform tasks that require high cognitive and motor workloads will enhance crew effectiveness only if it is applied to the correct tasks. Obviously, due to practicality and safety concerns, not all of the over 200 tasks currently performed through the MPDs can be executed using DVI, nor should they be. Therefore, a balance must exist between the number of tasks proposed, the size of the ASR vocabulary, the aircrew memory, and the overall effectiveness of using DVI as opposed to the manual method.

## Thesis Statement

This thesis will identify key tasks performed by AH-64D aircrews that would benefit from using DVI as an alternative means to accomplish the task. This selection was achieved through the following procedures:

1) A literature review of voice recognition technology and its application to the flight environment.
2) Development of a methodology used to identify potential voice input tasks.
3) Collection of pilot input on the role of DVI obtained through a questionnaire.

---

[1] Voice and speech are considered synonymous for this study.

4) A limited flight simulation of selected tasks to validate workload reduction.

The results of this study are important to design engineers choosing an ASR platform and developing the vocabulary associated with DVI. In keeping with current design methods, this thesis provides aircrew input on which tasks should be performed by DVI, thus reducing implementation time and increasing aircrew acceptance. Secondary benefits include the identification of tasks that need to be redesigned to require fewer motor commands and the identification of those tasks that need to be addressed for critical crew coordination timing.

## Structural Overview of Thesis

The following chapters intend to provide the reader with the necessary background and understanding of applying DVI to AH-64D cockpit. In chapter two, background information is provided on the evolution of the AH-64 series and its cockpit design. The reader should gain an understanding of how increasing technology has affected the Apache pilot's visual and manual workload.

A description of relevant aircraft systems are provided in chapter three. The intent of chapter three is to explain the complexity of the MPD paging hierarchy and its operation. Additionally, descriptions of the voice synthesis warning system and auditory caution tones are provided. The implementation of DVI in the AH-64D would conflict with these auditory displays if DVI auditory feedback were not adjusted.

In chapter four, a literature review is presented. The areas covered include multiple-resource theory, acoustic theory, voice recognition technology, and flight research using DVI.

The remaining chapters conclude the study. They explain the methodology used and present the results of the study.

# CHAPTER 2

# BACKGROUND

## Introduction

The AH-64D Apache Longbow, the latest version of the original AH-64A Apache, is the platform chosen by the U.S. Army and armed forces throughout the world to perform deep strikes, to conduct close air support, and to provide armed reconnaissance. The 21$^{st}$ century brought the digital battlefield, and the Apache Longbow is an integral player in this new age of warfare. The Apache is a tandem seat, twin engine, multi-mission attack helicopter built by the Boeing Company. Figure 1 presents a three-view picture of AH-64D Apache. The aircraft is designed for day or night combat missions in weather conditions and temperatures ranging from artic cold to desert heat. This advanced combat-proven machine was developed from the lessons learned in previous conflicts and from the successful performance of its predecessors. A brief review of these pertinent historical facts is discussed hereafter.

## The Evolution of the AH-64D Attack Helicopter

### The Origin of the Attack Helicopter

The role of the attack helicopter in the U.S. Army has expanded and evolved over the last 50 years. Attack helicopter design during this period has undergone a metamorphosis. The inception of the attack helicopter in the U.S. Army occurred during the Vietnam conflict to satisfy the ground force commander's need for close air support when operating outside of friendly direct fire support. The ever-growing role of the Bell UH-1 Huey quickly expanded to fulfill that requirement. Armed UH-1s known as "Huey

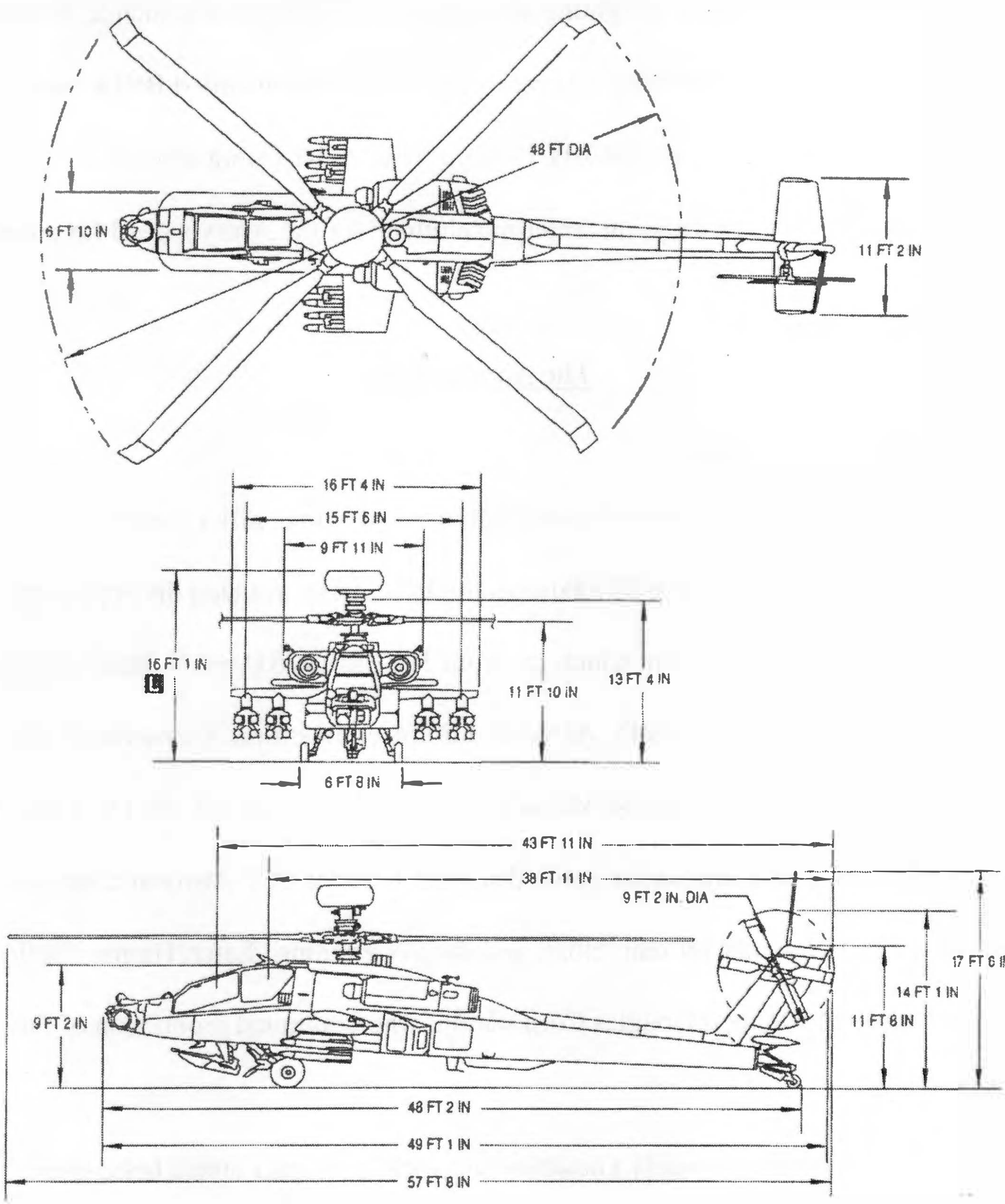



**Figure 1.** AH-64D Apache.

Source: Department of the Army. (2002). *Operator's Manual for Helicopter, Attack, AH-64D Longbow Apache* (TM 1-1520-251-10). Washington, D.C.: Author.

Gunships" proved essential in fighting an enemy on difficult terrain such as the jungles of Vietnam. Because of the Huey's success, the U.S. Army awarded Bell a contract to build its first attack helicopter, the AH-1 Cobra. The AH-1 Cobra entered service in 1967 and was widely known as an "interim solution" for the Army's need for an attack helicopter.

## The Apache Series

### The AH-64A is Introduced

As a result of the lessons learned from the Vietnam conflict and of the massive build up of Soviet armor in Eastern Europe, the U.S. Army initiated the Advanced Attack Helicopter (AAH) competition, which ran from 1973 to 1976 (United States Army Aviation Logistics School, 1994). At the end of the competition, the contract was awarded to Hughes Helicopters for the production of AH-64 design. In 1984, the AH-64A, the first aircraft in the series, entered service with the U.S. Army and became the primary attack helicopter for rear, close, and deep operations. Later, Hughes Helicopters was bought by McDonnell Douglas Corporation, who continued production of the AH-64A.

The AH-64A was widely known as the world's premier attack helicopter, representing a giant leap in technology as well as pilot workload. Previous attack helicopter cockpits were elementary in design compared to the Apache. Pilot workloads in these earlier aircraft were acceptable despite numerous modifications that cluttered the cockpit with poor ergonomic switches and dials. Conversely, design considerations for the Apache cockpit involved extensive human factors engineering and benefited from the lessons learned from its predecessor, the AH-1 Cobra. However, the increasing demand on the pilots to control all these new sensors required Apache crewstation designers to design the cockpit to conform with the prevalent philosophy of the time: The Hands On Collective and Cyclic (HOCAC) concept states that cockpits should be configured such that time-critical and frequently used operations are placed on the flight controls at the pilot's fingertips to promote speed in execution and safety.

Airframe design considerations of the AH-64A centered on enhancing survivability through ballistic hardening and crashworthiness. A digital multiplex system was used to integrate the aircraft systems, provide fault isolation, and facilitate digital data transfer. The primary armament system consists of 16 laser-guided Hellfire anti-armor missiles hung from wing-mounted pylons and sighted through the Target Acquisition Designation Sight (TADS), mounted on the nose. To counter light-skinned vehicles and personnel, wing-mounted rocket pods hold 38 2.75 inch Hydra 70 rockets, and a chin-mounted 30mm cannon is armed with 1,200 rounds of High Explosive Dual Purpose (HEDP) bullets. Pilots fly the Apache using a helmet-mounted display (HMD). This display shows a Forward Looking Infra-Red (FLIR) image generated from either the Pilot Night Vision System (PNVS) or TADS with superimposed flight and target symbology. A FLIR image is used in all poor visibility conditions, and flying with these images in low light represented a departure from the traditional method of flying with Night Vision Goggles (NVGs). This advance permitted flight in adverse weather and low illumination conditions, settings in which the reliance on NVGs is hazardous. The FLIR capability produced a dramatic increase in not only the visual capacity of the pilot, but also the visual workload of the pilot.

## Workload Issues in the AH-64A

The impetus for the evolution of the AH-64A Apache helicopter has been to increase combat survivability and enhance performance. During these developments, however, few improvements were made in cockpit design to reduce crew workload. For instance, shortly after the introduction of the AH-64A, a new variant of the "A" model Apache emerged equipped with a Back-Up Control System (BUCS). The BUCS is a single-channel, non-redundant, fly-by-wire flight control system, which operates the control actuators during a flight control severance, jam, or mistrack. Concurrent with the BUCS upgrade, a stronger General Electric T701C engine was fielded, yielding an increase in the performance at high-density altitudes. Aside from these alterations, the cockpit hardware and design of the AH-64A remains largely unchanged since 1984.

The pilot and copilot/gunner (CPG) cockpits, as shown in Figures 2 and 3, differed from each other in both capability and design. The CPG occupies the front seat, which was primarily designed for employing the Hellfire weapon system and performing tactical navigation.

This cockpit features an Optical Relay Tube (ORT) for viewing the FLIR image, and attached to the sides of the ORT are a Right Hand Grip (RHG) and Left Hand Grip (LHG) that place critical weapons and sensor controls at the CPG's fingertips using the HOCAC philosophy. In addition, the CPG had exclusive control over the VHF radio, navigation system, and laser. The pilot occupies the rear seat, which contains most of the radios, aircraft system displays, and piloting information. The engines are started solely from the pilot cockpit. In addition, control of the rocket system is exclusive to the pilot station; however, the crew stations share the use of the 30 MM cannon. Because the

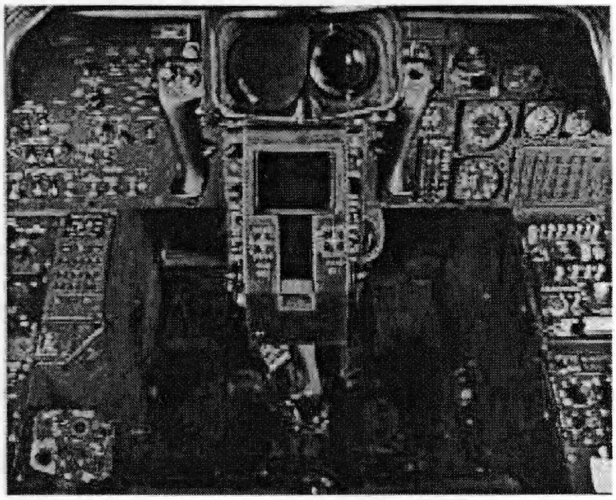


**Figure 2.** Photo of Copilot/Gunner Cockpit AH-64A.

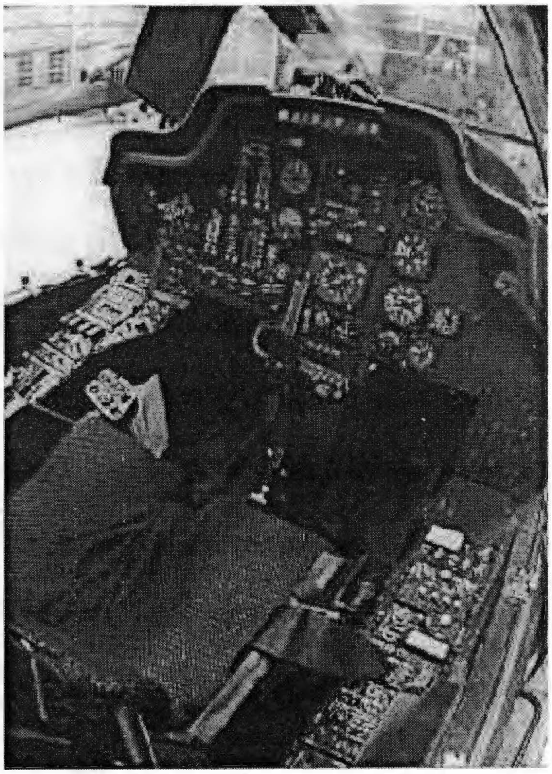


**Figure 3.** Photo of Pilot Cockpit AH-64A.

CPG possessed control over some functions that the pilot required for flight safety and ordnance delivery, target engagement times and workload increased. For example, if the pilot wanted to change the selection of the fly-to waypoint in the navigation system, the CPG would have to pause his actions, understand the pilot's intent, and then make the selection. As a result, crew coordination became essential for flight safety and mission effectiveness, and recurrent training for proficiency became paramount. Recognizing the importance of coordination, the U.S. Army implemented a program called "aircrew battle rostering". In contrast with policies for previous aircraft, such as the AH-1, in which pilots were able to fly in either seat, this program required Apache crews to be designated undeviatingly to either the pilot or CPG cockpit and further recommended that battle-rostered crews qualify together during semi-annual gunnery training.

Any attempt by McDonnell Douglas to make the crew stations identical for redundancy would not only be cost prohibitive, but such a design also would overcrowd each cockpit, creating additional workload. Despite the exclusive placement of some controls, when compared to previous aircraft, both cockpits represent an dramatic increase in the number of switches and buttons used to control sighting systems and employ the on-board weapons.

Proficiency was difficult to maintain in the CPG cockpit. The HOCAC philosophy was necessary to employ for the sake of aircraft safety and efficiency, but pilots were indicating that it became difficult to remember where all the RHG and LHG switches were positioned. Although the variety of different shapes and locations of the switches assist the pilot with tactile cues, performing some cockpit tasks require the selection of buttons in a sequence that varies from left hand to right hand. Besides the confusion of constantly switching hands, task completion is further hampered when the dexterity continually required for control manipulation is worsened by wearing flight gloves or, even worse, chemical protective gloves. Not surprisingly, the amount of time required by aircrews to acquire and engage targets increased in comparison to that of earlier attack helicopters. Consequently, many pilots spent extra time in the hangar "ground flying" the cockpit to develop the "blind cockpit" skills necessary to operate the aircraft without having to look at the grip switches. The U.S. Army alleviated the plight of the aircrews with a CPG cockpit mock-up called the TADS Selected Task Trainer (TSTT), which provided the copilot with "switchology" tutorials, increasing the overall effectiveness of the crew. The TSTT proved very effective, and Apache pilots finally realized the HOCAC benefit. Two lessons were learned through the development of the AH-64A cockpit: First, the increase in capability provided by the HOCAC philosophy can be negated if not accompanied by appropriate training, and secondly, there is a limit to the number of switches that can be successfully associated with control grips.

## The Arrival of the AH-64D

The AH-64D, the latest version in the Apache series, evolved from the U.S. Army's scheduled Multi-Stage Improvement Plan (MSIP) for the AH-64A. The initial phase was the development of a commitment by McDonnell Douglas Corporation and other industry partners in 1985. This commitment included a new baseline design of the crewstations and avionics architecture. Phase two efforts of the MSIP included the Airborne Adverse Weather Weapons System program, which resulted in the Longbow Hellfire Modular Missile System (LHMMS). The LHMMS included the "fire and forget" launching of radar-guided missiles for use in high-threat situations and conditions under which lasers are ineffective and the option of switching between the two guidance methods. The Longbow Fire Control Radar (FCR) was integrated in 1990 after successful demonstration of the concept in prototype aircraft (Boeing, 1998). Once again, a giant leap in technology and capability presented a human factors challenge to design engineers.

**Workload Issues Evolve**

To keep pace with the new technology, the new crewstation design included a "MANPRINT" (Manpower and Personnel Integration) cockpit with large displays (see Figures 4 and 5). At first glance, the cleaner looking cockpit appears to have less capability than the AH-64A, when in fact just the opposite is true. The total number of cockpit switches decreased from 1,200 in the AH-64A to 200 in the AH-64D. Since additional systems were added, more grip switches were necessary to control the additional systems, so the LHG, RHG, cyclic, and collective were re-designed accordingly. Between the AH-64A and AH-64D, the number of switches on the grips increased from 8 to 13 on each the LHG and the RHG. The number of switches on the collective increased from 10 to 18, and the collective was organized into two separate grips: flight control grip and mission control grip. Some pilots, in fact, complained that Boeing just relocated the old AH-64A panel switches to the grips. This was testament to the fact that adding even a few grip switches causes a drastic increase in cognitive workload. Unfortunately, despite the increases in grip switch complexity, the Apache Longbow crews have yet to receive a TSTT for the new RHG, LHG, and grip switches unique to the AH-64D.

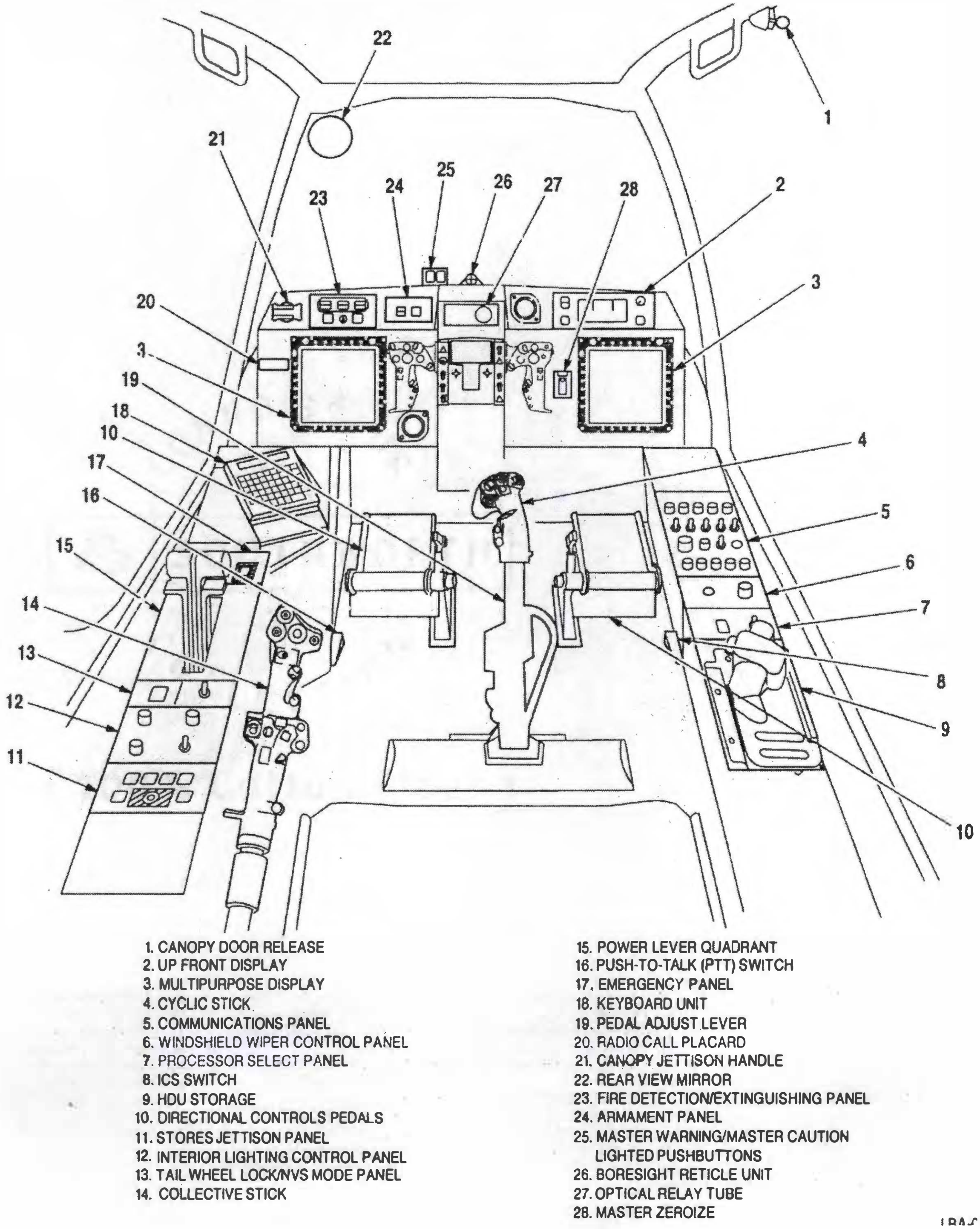
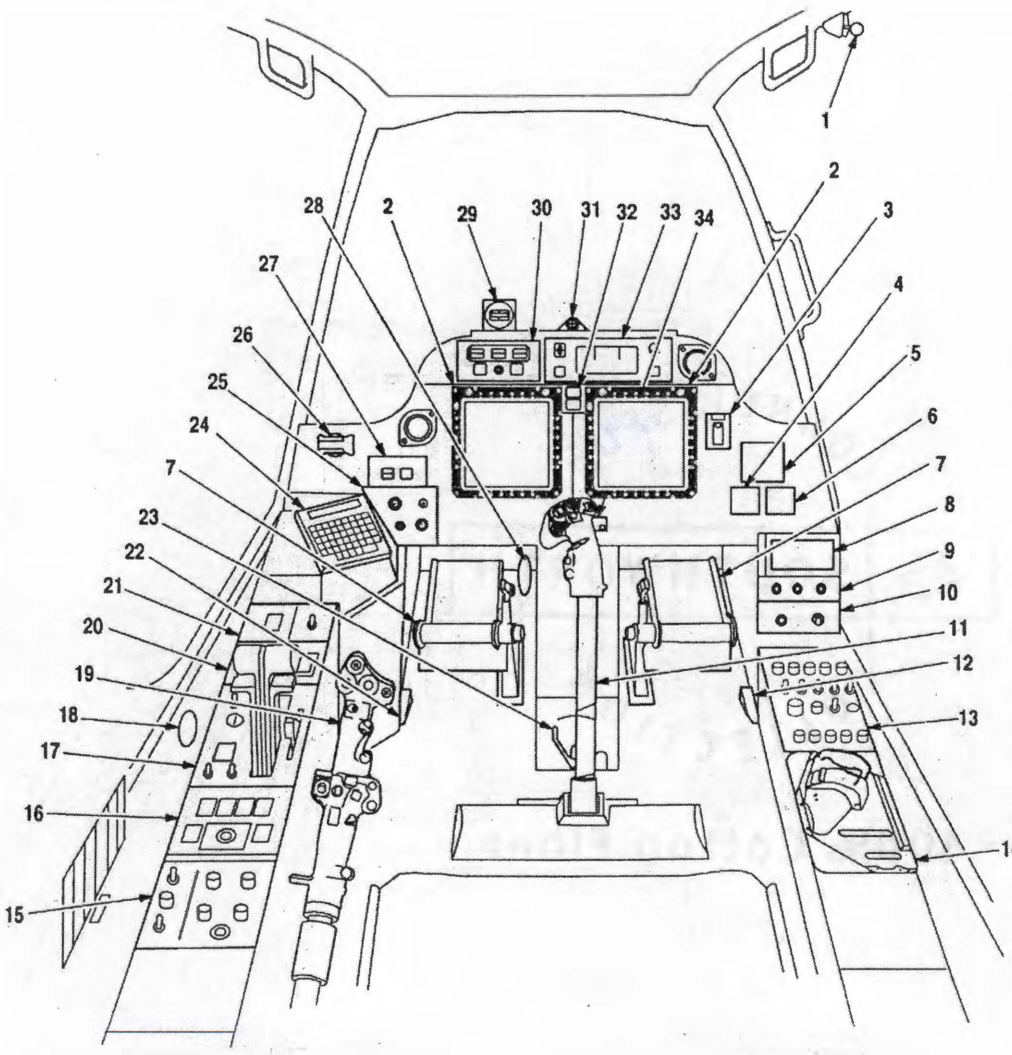



**Figure 4**. Copilot/Gunner Cockpit AH-64D.

Source: Department of the Army. (2002). *Operator's Manual for Helicopter, Attack, AH-64D Longbow Apache* (TM 1-1520-251-10). Washington, D.C.: Author.



1. CANOPY DOOR RELEASE LEVER
2. MULTIPURPOSE DISPLAY UNIT
3. MASTER ZEROIZE
4. AIRSPEED INDICATOR
5. ATITUDE INDICATOR
6. ALTIMETER
7. DIRECTIONAL CONTROL PEDALS
8. DATA TRANSFER CARTRIDGE RECEPTACLE
9. CHECK OVERSPEED TEST/ GENERATOR RESET PANEL
10. WINDSHIELD WIPER CONTROL PANEL
11. CYCLIC STICK
12. ICS SWITCH
13. COMMUNICATIONS PANEL
14. HDU STORAGE
15. EXTERIOR/INTERIOR LIGHTING PANEL
16. STORES JETTISON PANEL
17. POWER LEVER QUADRANT
18. FREE AIR TEMPERATURE GAGE
19. COLLECTIVE STICK
20. EMERGENCY PANEL
21. TAIL WHEEL LOCK/ NVS MODE PANEL
22. PUSH-TO-TALK (PTT) SWITCH
23. PEDAL ADJUST LEVER
24. KEYBOARD UNIT
25. VIDEO PANEL
26. CANOPY JETTISON HANDLE
27. ARMAMENT PANEL
28. PARKING BRAKE HANDLE
29. STANDBY COMPASS
30. FIRE DETECTION/ EXTENGUISHING PANEL
31. BORESIGHT RETICLE UNIT
32. MASTER WARNING/ MASTER CAUTION LIGHTED PUSHBUTTONS
33. UP FRONT DISPLAY
34. RADIO CALL PLACARD

**Figure 5**. Pilot Cockpit AH-64D.

Source: Department of the Army. (2002). *Operator's Manual for Helicopter, Attack, AH-64D Longbow Apache* (TM 1-1520-251-10). Washington, D.C.: Author.

Obviously, not every task could be designed around the HOCAC concept and controlled from the grips, creating the need for more displays. The cockpit space available in the AH-64A was already limited, so the addition of more displays in the AH-64D was not a viable option without a complete redesign of its predecessor's cockpit. In keeping with the current design philosophy used in other Boeing aircraft, Multi-Purpose Displays (MPDs) were adopted to replace the legacy instrumentation and provide the display flexibility and depth required to accommodate the new systems (see Figures 4 & 5). The MPDs vastly improved the display capability needed for targeting, communication, and navigation. One of the goals in the re-design was to make both cockpits as close as possible to each other in appearance and capability, thus decreasing the need for crewstation designation. With a few exceptions, the cockpits are identical in display capability. For example, the CPG retained control of firing the laser for target designation, and the pilot retained control of starting the engines. However, both crewstations were similar enough that pilots could now alternate between pilot and copilot cockpits with greater ease; therefore, the requirement for crewstation designation was relaxed.

Pilot workload required to fly the AH-64D compared to the AH-64A was reduced because of the crewstation redesign. An assessment of crew workload was made in June of 2000 based on a survey given to AH-64D pilots. The results of the survey indicated that pilot workload in the AH-64D was lower for all 21 of the surveyed flight and mission tasks (Durbin, 2000). The assessment helped support the cockpit design philosophies used and revealed the source of the reduction in workload. The pilots commented that workload was lower in the AH-64D because of the large amount of useful information presented on the crewstation displays. The amount of information and the manner in which it is presented are superior to the AH-64A (Durbin, 2000). However, the survey did not address the workload required to perform tasks unique to the AH-64D, for which a comparison with the AH-64A would not be possible. Further, the survey assessed overall workload and did not differentiate between workload reductions in one area, and increases in other areas. For instance, the audio channel workload increased because of additional radios and auditory messages.

The visual workload in the AH-64D has increased due to the addition of more displays presenting more information. A new Up-Front Display (UFD) was located conspicuously on the console of both cockpits that shows active faults, tuned frequencies, and fuel status, among other things. To provide the aircrews with FCR targeting information and sensors and weapons statuses, the number of HMD symbols superimposed on the FLIR picture was increased. In addition, only two MPD pages could be viewed at once. While each screen presents much information, the limited number of displays creates the need for the pilot to constantly switch pages to maintain situational awareness. Furthermore, on the periphery of each MPD display are 30 bezel buttons from which the pilot must select each time a display is to be changed. The aggregate effect of all these improvements further increased the already task-saturated visual channel. The helmet-mounted display is inundated with flight and mission critical information, and the MPDs give the pilot more necessary information at which to look and another reason to be heads-down during flight.

## A Prototype Solution: Rotorcraft Pilot's Associate

To demonstrate a possible remedy for the information overload associated with state-of-the-art technology on today's battlefield, the Boeing Company modified an AH-64D with a prototype cognitive decision-aiding system called Rotorcraft Pilot's Associate (RPA). Several new technologies were demonstrated, including touch screen displays, redesigned flight grips, and voice recognition for DVI commands. Flight and mission data on the RPA Apache Longbow was displayed on three large MPDs (see Figure 6), instead of two smaller ones used in the standard AH-64D (Janes Information Group, 2000). Although voice recognition technology was part of the RPA program, that component of the program was never flight tested due to interface conflicts with on-board communication hardware (M. Hannen, personal communication, May, 2003).

## Background Conclusion

Multi-modal workload is the defining limit of AH-64D effectiveness. Voice output technology is being used in the Apache Longbow to alert the pilots of systems failures and to provide increased situational awareness. Although the voice warnings are very effective, when combined with four radios and intercommunication from the other crewmember, the audio channel, like the visual channel, can become task-saturated. The tactile cues associated with the HOCAC concept are also limited by flight gloves and vibration. The number of switches on the flight grips has increased to the point at which the pilot's memory for switches' locations or purposes is limiting further reduction in workload. The requirement has arisen for an alternative control technology that is intuitive and natural, and voice commands can fulfill this need.

**Figure 6**. Experimental RPA Cockpit.

Source: Janes Information Group. (2000). *Boeing AH-64D Apache: An Article from the Boeing Company* [On-line]. Available: http://www.janes.com/defence/air_forces/news/jawa/jawa001013_1_n.shtml

# CHAPTER 3

# SYSTEM DESCRIPTION

## AH-64D: General Description

The AH-64D Apache is a twin engine, tandem seat, aerial weapons platform (U.S. Army, 2002). The airframe is all-metal with Kevlar protection for the crewstations and critical systems. Engine power is supplied by two horizontally separated free-power turbine engines, each capable of producing 1800 shaft horsepower at sea level, standard day conditions. The rotor system features a four-bladed, fully-articulated design with a rotor diameter of 48 feet. Anti-torque is provided by a conventional tail rotor design with four blades mounted on a delta hinge. The aircraft employs externally mounted armament systems that include a 30 MM chain gun, rocket pods for 2.75 inch Folding Fin Aerial Rockets (FFAR), and missile racks for the anti-armor Radar Frequency (RF) fire-and-forget missiles. Additionally, the aircraft is equipped with Forward Looking Infra-Red (FLIR), a multi-mode Fire Control Radar (FCR), state-of-the-art digital avionics, and a laser for target designation and ranging.

The centerpiece of the AH-64D mission equipment package is the FCR. This sensor is capable of detecting both stationary and moving ground-based targets for either onboard weapons systems or digital transmission to other AH-64Ds. An aircraft equipped with an FCR is called a Longbow Apache (LBA). The FCR radome, mounted above the rotor system, is its most notable feature because of the radome's size and location.

## Data Management System

The Data Management System (DMS) is the controller for the vast amount of digital information that is exchanged between components. DMS links the aircraft systems through the digital multiplex bus for managing, controlling, reporting, monitoring, and reporting (Boeing, 1998a). The DMS prioritizes 1,586 faults by a hierarchy of severity to display to the aircrew members on the MPD. DMS facilitates better information transfer to the pilot by displaying only the information needed. This concept is known as "Management By Exception" (MBE), and the DMS will not display the controls for systems that are not turned on or not installed. The system consists of:

1) Two fully-redundant System Processors. These function as the primary bus controller for the primary two data bus channels.
2) A four-channel redundant MIL-STD-1553B digital data bus.
3) Four Multi-Purpose Displays (MPD); two for each cockpit.
4) Two fully-redundant Display Processors (DP).
5) Two fully-redundant Weapon Processors (WP).
6) Four pylon interface units for weapon system interface.
7) Two Keyboard Units (KU); one for each cockpit.
8) A Data Transfer Unit (DTU). This unit provides the interface for uploading pre-planned mission data developed on the Aviation Mission Planning System (AMPS).

### Multi-Purpose Displays

The Multi-Purpose Display (MPD) is a square, 8.84 inch, color, active-liquid-crystal display that provides the capability for controlling most of the on-board systems and serves as a display for targeting sensors (U.S. Army, 2002). The MPD receives video information from the DP, which can independently supply four different images. Both crewmembers can select and view the same page simultaneously. The displays are interactive, allowing the control of systems via 30 bezel buttons located along the periphery of the display. There are three different types of bezel buttons, differentiated based upon their functions. Figure 7 presents the MPD with the associated bezel button groupings.

The "dual action" Menu (M) button, when pressed, displays the top-level menu page from which all other selections are nicely grouped according to system. When the menu page is present, selecting the "M" button again will display the DMS page. The second type of bezel button function is the Variable Action Button (VAB). There are 23 VABs that change in function depending on which menu is displayed. The third type is the Fixed Action Button (FAB), which is labeled on the face of the button, and provides instant access to the applicable system. The following systems are assigned FABs:

1) FCR; Fire Control Radar page.
2) WPN; Weapons page.
3) TSD; Tactical Situation Display.
4) VID; Video select.
5) COM; Communications.
6) A/C; Aircraft page. The aircraft page button is a dual-use FAB, presenting the Engine page when the aircraft is on the ground and the Flight page when airborne.

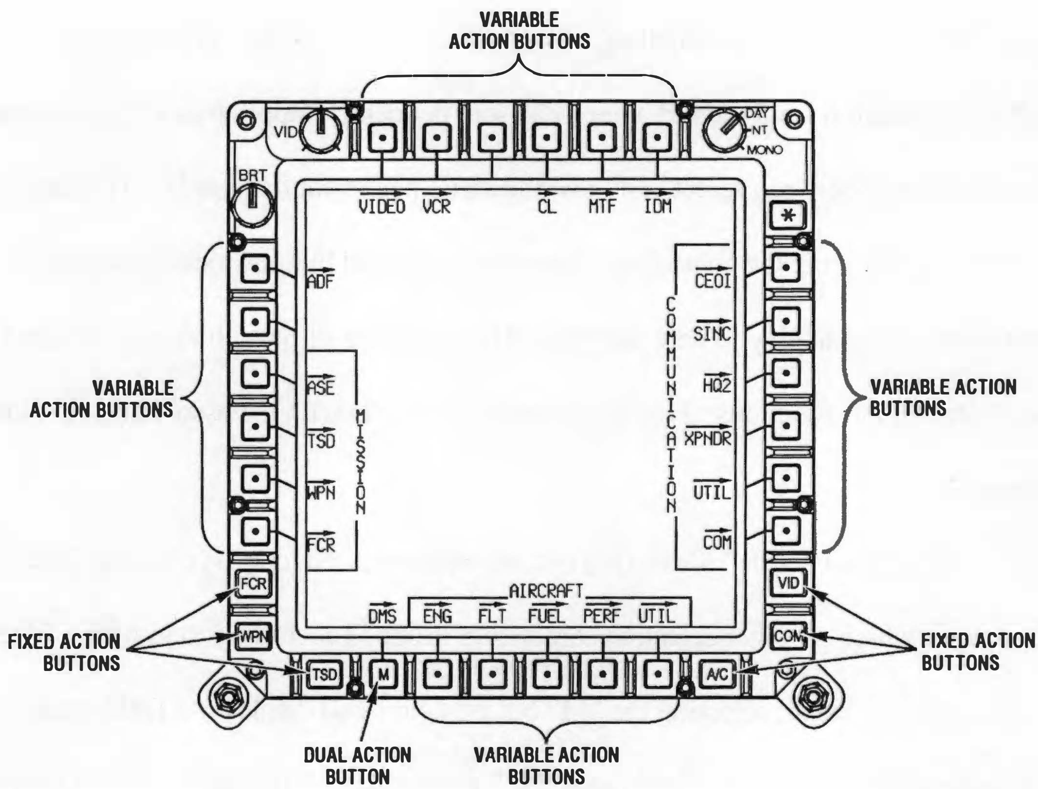



**Figure 7.** MPD with Menu Page.

Source: Boeing Co. (1998b). *AH-64D Control and Display Methodology* (PFN 4934). [Student Handout.] Unpublished text.

## Multi-Purpose Displays Page Layering

The MPDs have several layers of pages that permit access to the various options available to each system. The Menu page is a reference from which all other pages can be accessed. Selections on the Menu page are called top-level pages, which, when selected, will appear in text above the "M" button. From the top-level page, there are several second-level pages that can be selected for additional options. Each second-level page contains "hot links" to other systems' second-level pages. These "hot links", in effect, create a way to move laterally through the displays without having to return to the Menu page (Boeing, 1998b). Third-level pages are accessible only from second-level pages. When a third-level page is selected, the source second-level page name remains visible. If the second-level page name is deselected, the MPD will display the top-level page for that system. Deselecting the third-level page will return the MPD to the source second-level page. This feature provides aircrews a quicker way to return to top-level pages from which other systems can be accessed. Top-level pages are arranged in three groups: aircraft, mission, and communications. The three groups consist of the following top-level pages:

**Aircraft**

1) ENG; Engine page displays the engine status, powertrain status, and warning/emergency procedures.
2) FLT; Flight page displays the current aircraft attitude and navigational status.
3) FUEL; Fuel page provides selections for all fuel/refuel options.
4) PERF; Performance page provides current/planned/maximum performance calculations.
5) UTIL; Aircraft Utility page provides selection for aircraft sub-systems.

**Communications**

1) COM; Communications page provides access to digital communication setup and manual frequency selection.
2) XPNDR; Transponder page permits selection of the transponder mode and coding.
3) HQ2; Have Quick 2 page permits selection and setup of frequency hopping parameters.

4) SINC; Single Channel Ground & Airborne Radio page provides access to selecting/editing frequency hopping nets.

5) SOI; Signal Operating Instructions page provides the capability to authenticate communications transmissions.

6) UTIL; Communications Utility page provides setup utilities for all communication radios.

**Mission**

1) ASE; Aircraft Survivability Equipment page provides access to threat countermeasures and displays battlefield radar emitter information.

2) TSD; Tactical Situation Display page presents the ownship in an overhead view related to navigation information, threat information, and battlefield graphics.

3) WPN; Weapon page provides access to control onboard weapon systems.

4) FCR; Fire Control Radar page displays FCR targets and provides access to modes and status.

**Additional Selections on the Menu Page**

1) DMS; The Data Management System page provides a listing of all faults and provides access to initiated built-in-tests.

2) ADF; Automatic Direction Finder page provides controls for tuning, presetting, and viewing ADF functions.

3) VIDEO; Video page contains controls for real time video source information.

4) VCR; Video Recorder page contains controls for video recorder operation.

5) MSG SEND; Message Send page provides controls to send digital data.

The MPD paging arrangement is very user friendly because most pages are only a few bezel button strokes away. Page layering is more horizontal than vertical, meaning that pages are more evenly dispersed throughout several top level categories instead of chains of subordinate pages. As a result, the 289 total pages are distributed such that there are 20 top-level pages and several second and third level pages. A paging tree diagram of the Main Menu and its associated sub-systems is presented in Figure 8.

Pilots usually configure their MPD pages with the Flight page on the left and the TSD page on the right. Typically, a video underlay (TADS, FCR, or PNVS) is selected that is continuously visible regardless of which page is displayed. A common configuration for the CPG during target engagement is the FCR page on the left with a TADS video underlay and the TSD page on the right with a TADS video underlay. The pilot might have a Weapon page on the left and the TSD page on the right with a TADS underlay. Selected MPD pages are continuously displayed until removed by one of the following actions:

1) The paging button is deselected.
2) Either the Menu or a subsystem button is selected.
3) A subordinate page button is selected.
4) An autopage or switch page occurs.

**Multi-Purpose Displays Automatic Page Switching**

Automatic MPD page switching occurs in response to a DMS triggered event, threat information, or cockpit switch selections. Auto-paging instantly displays an MPD page to both crewmembers based on a hierarchical list of importance. During all engine warnings, the engine page emergency format is automatically displayed by the DMS.

**Figure 8.** MPD Page Layering.


MENU PAGE
1 PAGE
VIDEO PAGE
3 PAGES
COMMUNICATIONS PAGE
38 PAGES
COMM. UTILITY PAGE
2 PAGES
TRANSPONDER PAGE
1 PAGE
HAVE QUICK PAGE
9 PAGES
SINC PAGE
15 PAGES
SOI PAGE
3 PAGES
MSG SEND PAGE
5 PAGES
DMS PAGE
88 PAGES
VIDEO RECORDER PAGE
1 PAGE
FLIGHT PAGE
2 PAGES
ENGINE PAGE
8 PAGES
FUEL PAGE
3 PAGES
PERFORMANCE PAGE
6 PAGES
AIRCRAFT UTILITY PAGE
1 PAGE
ADF PAGE
2 PAGES
ASE PAGE
2 PAGES
TSD PAGE
84 PAGES
WEAPON PAGE
12 PAGES
FCR PAGE
5 PAGES

When a threat radar emitter is detected by onboard sensors, the TSD page is automatically displayed.

Switch paging occurs when a crewmember selects a cockpit switch and the associated MPD display is not already present. This feature obeys the same list of importance as the auto-paging feature. The intent of switch paging is to provide the aircrews with the most useful information at the proper time. A discussion of this switching logic can be obtained from the AH-64D Operator's Manual.

There are five switch paging actions that consist of:

1) Symbology select switch. The Flight page is automatically displayed in response to pressing the cyclic symbology select switch in the "Z" axis position. Once the Flight page is displayed, pressing the symbology select switch again will return the display to the MPD page which was active prior to switch paging. Unfortunately, this return function is exclusively available on the left MPD, and the function can only be used in the ten minutes following the initial switch paging.
2) Hydraulic push button. This button will automatically display the Engine Page.
3) Engine power levers. If the Engine page is displayed, the format of that page will change when the power levers are advanced from the idle position to the fly position.
4) Engine start switch. When either of the engine start switches is actioned, the Engine page will automatically be presented if it is not already displayed.

5) FCR sight select switch. When either crewmember selects the FCR as a sensor, the FCR page, if not already selected, is automatically displayed on the crewmember's left MPD.

## Cursor Operation

The MPD cursor is a movable symbol generated through DMS that provides aircrews an alternative way of selecting MPD options. The intent of each cursor is to provide aircrews with a HOCAC way of interacting with the MPDs. Each cockpit has one cursor available for use that works independently of the other cursor. During normal operations, each crewmember's cursor cannot be viewed from the other crewstation.

Cursor controllers are multi-directional force transducers that provide a method of controlling cursor movement (Boeing, 1998b). The cursor controllers are located on the mission portion of each crewmember's collective grip. In addition, the CPG has a redundant cursor controller located on the LHG that provides cursor operation when the CPG is not flying the aircraft. To select an MPD option, the cursor is moved over the desired option, and the cursor controller is pressed to select the highlighted option. There are two methods of moving the cursor between the crewstation displays. First, a cursor may be moved by "bumping" it to the other display. This is accomplished by moving the cursor to the inboard edge of the MPD before the cursor controller force is momentarily relaxed and reapplied. This action causes the cursor to "bump" over to the other MPD. A second means of moving the cursor is through the cursor display select switch on the collective mission control grip.

## Warning, Caution and Advisory System

The Warning, Caution, and Advisory (WCA) system provides the aircrews with visual and aural feedback to an aircraft or aircraft systems malfunction. The WCA system prioritizes malfunctions according to the three categories shown in Table 1.

Warnings are announced to the aircrew visually on the MPD, UFD, and a flashing Master Warning pushbutton. There are 13 separate warnings, all of which are accompanied by a digitized female voice heard through the aircrew headsets (U.S. Army, 2002). When activated, each voice warning will repeat until either there is no longer cause for that warning or the aircrew acknowledges the warning by depressing the illuminated Master Warning pushbutton. In addition, the MPD will automatically change to the ENG page so that the aircrew can quickly assess the situation. The ENG page automatically displays the warning and its associated emergency procedure in the lower portion of the MPD.

Cautions are announced to the aircrew visually on the MPD, UFD, and a flashing Master Caution pushbutton. There are 66 caution messages. All cautions are

**Table 1.** WCA Categories and Definitions.

| Category | Definition |
|---|---|
| Warnings | The existence of a hazardous condition that requires immediate action and correction to prevent possible death or injury to the crew. |
| Cautions | The existence of a impending hazardous action requiring attention, but not necessarily immediate action |
| Advisories | An indication of a safe or normal configuration, condition, or performance, the operation of essential equipment, or attraction of attention and impartation of information for routine action. |

accompanied by a caution tone given through the aircrew headset. The caution tone is a concurrent low (2.0 kHz) then high (2.7 kHz) frequency that will sound for 1.5 seconds with pause intervals of 10 seconds (United States Army Aviation Center USAAVNC, 2000).

Advisories are announced to the aircrew visually on the MPD and UFD. There are 139 advisory messages. Some advisories are announced with an accompanying advisory tone given once through the aircrew headset. The tone is a single mid-frequency (500 Hz) tone of a half-second duration (USAAVNC, 2000).

The extensive use of auditory displays in the AH-64D presents an engineering challenge for DVI implementation. Fortunately, only one voice warning, "*Altitude Low*", occurs on a regular basis; however, during an emergency, several voice messages may be present. A particular concern is ensuring that the auditory feedback for DVI commands does not desensitize the pilots to hearing voice synthesis in their headset. In effect, this desensitization could cause reduced reaction time during emergency conditions when immediate action is required by the pilot. Further research of DVI implementation should address audio clutter created by the combination of the effects of cockpit intercommunications, radio transmissions, voice warnings, and caution tones.

# CHAPTER 4

# LITERATURE REVIEW

## Multiple Resource Theory

Flying a helicopter imposes multiple simultaneous demands on the pilot. Some of these demands are measurable, such as manipulating the flight controls and pressing MPD bezel buttons. Other demands are concealed from direct observation, such as planning, problem solving, and decision making. However, these cognitive tasks demand just as much of the pilot's attention (Stokes, Wickens, & Kite, 1990). Consequently, there is interference among demands and competition for the pilot's limited resources.

Wickens and Flach (1988) identified two major variables that affect the pilot's ability to time-share among tasks, or perform dual-tasks concurrently: their difficulty and their structure. For the purpose of this study, the competing tasks in the cockpit of Apache Longbow are flying eyes-out (manipulating flight controls) and interfacing with the systems through the MPDs (pushing bezel buttons). First, the task difficulty of flying night NOE missions requires extensive use of the pilot's hands. Difficulty can be reduced through recurrent training and simulator flying, both of which are currently used in the U.S. Army. Conversely, the task difficulty involved in pushing MPD bezel buttons is described as quite easy, and any further reduction in the workload of this task is not likely. The second variable, task structure, involves the competing information processing structures required to perform tasks. For example, performing two tasks that are relatively simple, but which are competing for the same resources, will be perceived as difficult. Since flying and pushing buttons compete for the same resources (visual and manual), a reduction in workload could be achieved by restructuring the tasks to utilize different resources.

A more detailed model of information processing resources was developed by Wickens (1990). See Figure 9. This multiple resource model labels and identifies the processing structures within the brain that correspond to the separate resources. The model is three dimensional and categorizes resources along three axes: (a) processing modalities, (b) processing codes, and (c) processing stages.

The processing modalities represent the relationship between auditory versus visual tasks and manual versus vocal responses. The model postulates that time-sharing an auditory and a visual task is easier than time-sharing two auditory or two visual tasks (Stokes et al. 1990). Processing codes separate spatial versus verbal information and manual versus vocal responses. Accordingly, a task that uses both manual and vocal

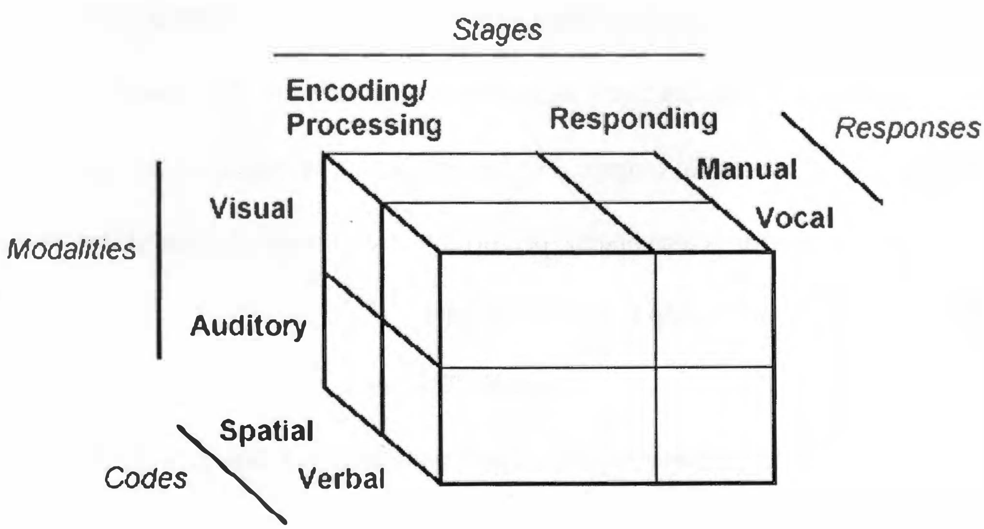



**Figure 9.** Wickens Multiple Resource Model.

Source: Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention.* New York: Academic Press.

responses will result in less workload compared to an exclusively manual task of the same overall magnitude. Processing stages separate encoding/processing operations from manual and vocal responses. For example, two tasks requiring cognitive operation (instrument scanning and calculating) will result in greater workload than performing one task requiring a cognitive operation and another requiring a manual/vocal response (instrument scanning and speaking) (Wickens & Flach, 1988).

The multiple resource theory predicts that some tasks are best performed using speech, others using vision, and others with motor/kinesthetic or tactile modes. Another group of multi-modal tasks exist that is best performed using multiple modes (Weinschenk & Barker, 2000).

In research done by Wickens (1984), subjects performed one of two tasks; one of these tasks required verbal resources, and the other's requirements were spatial. The type of input and output mode was varied. Input for some subjects was auditory, while others' was visual. The output mode was either spoken or manual. For verbal tasks, performance was best with auditory input and spoken output. Performance was worst with visual input and manual output. For spatial tasks, performance was best with visual input and manual output. Conversely, performance was worst in spatial tasks when auditory input and spoken output were combined.

**Acoustic Theory**

Automatic Speech Recognition (ASR) systems use a series of sounds that represent an acoustic wave. A speech signal, when examined over a short time frame, such as one-two-hundredth of a second (5 ms), has a relatively stationary acoustic waveform. If the signal is analyzed over a longer time period, such as one-fifth of a second (200 ms), a pattern appears that reflects changes in sound. The simplest way to classify speech is using the accepted convention of a three-state representation. The states are *silence*, in which no speech is produced, *unvoiced*, in which the vocal chords are not vibrating but the waveform is aperiodic, and *voiced*, in which the vocal chords are vibrating and the waveform is quasi-periodic (Wiley, 2000). Because voice recognition engines must first filter out the silence and unvoiced states before they can analyze the voiced portions of a waveform, a problem arises when the waveform includes more than one state due to the difficulty in determining where one state begins and another ends. An example speech waveform is presented in Figure 10.

## Speech Parts

The study of phonetics breaks down the speech signal into elemental parts known as phonemes. For example, the *f* in "fly" is a phoneme. The importance of phonemes is that they make up the differences between utterances that make speech recognition possible. Speech recognitions software uses the distinctions between phonemes to identify vocalizations. In the English language, there are approximately 44 phonemes (Holmes, 1988). Phonetics classifies speech movements into three types: continuants, stops, and glides (Prochnow, 1987). A brief description of each movement is provided below.

1) Continuants; The extended holding of an initial phoneme. Continuants consist of vowels (*a*, *e*, *i*, *o*, and *u*), fricative consonants (e.g. *f*, *v*, *th*, *s*, *z*, *sh*, and *h*), and nasals (e.g. *m*, *n*, and *ng*).

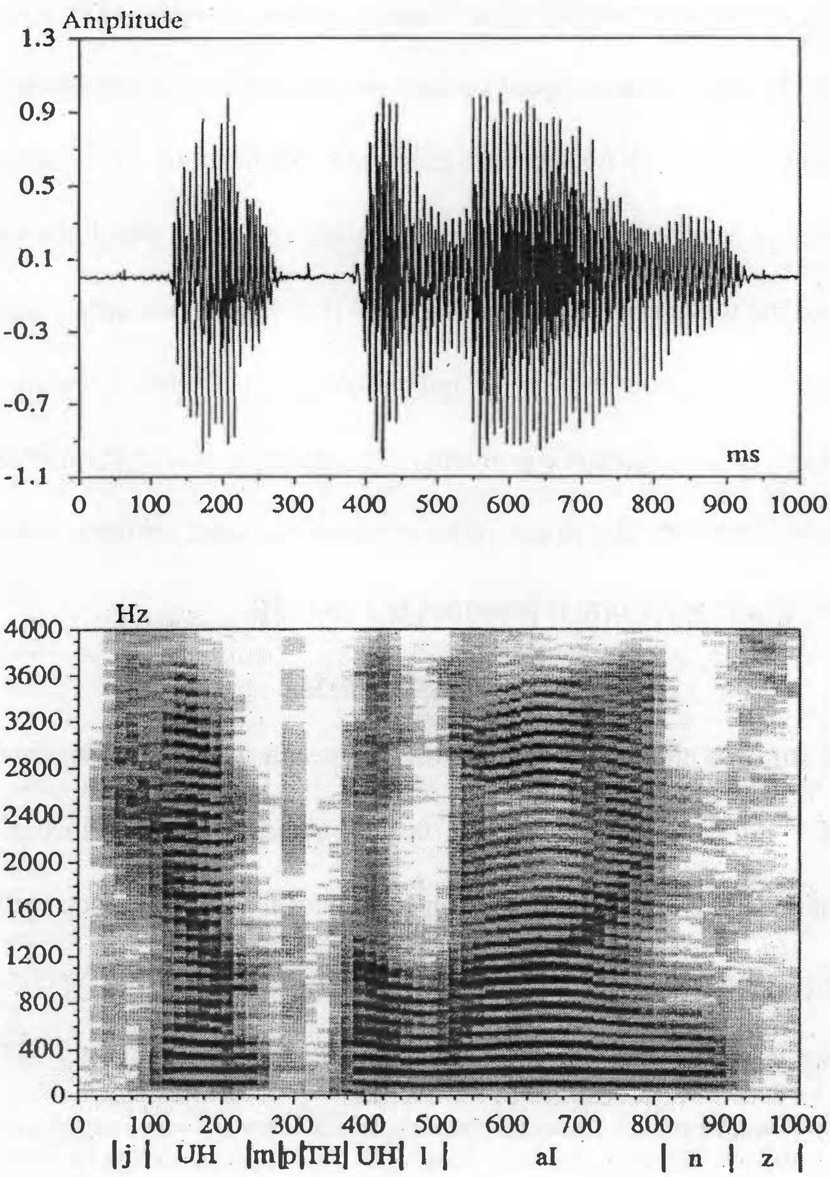



**Figure 10.** Plot of the acoustic waveform and spectrogram of the utterance *jump the lines.*

Source: Goldberg, R. & Riek, L. (2000). *A Practical Handbook of Speech Coders*. Boca Raton, FL: CRC Press.

2) Stops; The blocking and unblocking of the air flow through the larynx. Plosive consonants (e.g. *b*, *d*, *k*, *p*, and *t*) are formed when the articulation of a constant is completely stopped.

3) Glides; The transition from one phoneme to another. One example of glides, diphthongs (e.g. *au* and *oi*), are formed when gliding from one vowel to another.

## Co-articulation

During normal speech, people usually do not isolate each sound. In normal usage, most phonemes affect the articulation of each other. The spoken words *top page* provide an example of this tendency. If one were to say *top*, pause, then say *page*, there would be two stop /p/ phonemes spoken. In the normal pronunciation of the words *top page*, however, only one /p/ phoneme is spoken. This characteristic of speech is referred to as co-articulation. A major challenge for speech recognition systems is caused by the co-articulation of neighboring words (Weinschenk & Barker, 2000).

## Speech Recognition Technology

Speech recognition machines operate using one of three approaches: acoustic-phonetic, pattern recognition, and artificial intelligence. Each approach consists of a combination of functional elements including the following: signal acquisition, signal processing, and pattern matching.

The acoustic-phonetic model is based on the number of phonetic units that can be distinguished in an acoustic waveform. The process involves segmenting and labeling each unit, and then determining the uttered word from a string of units (Technical Insights, 2000). The main problem with this approach is the omnipresent variability in the speech signals of an utterance, even among samples from the same person.

Pattern recognition is the method of using speech patterns instead of distinct phonemes to recognize an utterance. The recorded speech pattern is compared to a database from a known speaker to determine a match (Technical Insights, 2000). Because any variability usually occurs at the beginning or end of a word, an advantage of this technique is that the main portion of a speech pattern is usually well-defined, thus easy to recognize.

Artificial Intelligence (AI) is the newest approach to speech recognition. This technique expands on the previous methods and attempts to mechanize the human approach to pattern recognition. AI employs the use of Artificial Neural Networks (ANN), which, over time, learn the relationships between phonetic events as well as how to discriminate between similar sound classes (Technical Insights, 2000).

## Signal Acquisition

The signal acquisition process involves collecting the speech signal to be processed. In military cockpits, the procedure usually involves the headset microphone or the oxygen mask. In the AH-64D, however, collecting the acquisition signal would involve sampling from one of two other sources, depending on situation. The first, and, likely, more common source is through the Integrated Helmet and Display Sight Subsystem (IHADSS), which is worn by all U.S. Army Apache pilots. Furthermore, the IHADSS microphone can be of two types: a normal Dynamic type or the anti-jamming Tempest type. The second source, the less desirable of the two, would be through the chemical protective mask microphone, which is worn while in chemical protective posture. During a chemical alert, the aircrews remove their helmets and don their protective masks. Once his mask is sealed, the pilot disconnects his IHADSS microphone connection and attaches that connection to the imbedded microphone in the mask. Research conducted by Malkin (1983) studied 12 Army aviators wearing M24 aviators' protective masks. The pilots spoke into a voice recognition system, and the study concluded that there existed no identifiable difference between the helmet-mounted microphone and the one on the mask. A second experiment using the M24 mask conducted by Poock, Roland & Schwalm (1983) asserted higher misrecognition rates. However, the researchers reported additional information to qualify their data. First, the study's conductors partially attributed their poor recognition rate to users' unenthusiastic attitudes, and they also presented results, which show that as subjects gained experience speaking into the mask's microphone, the software's recognition rate did improve.

## Signal Processing

In any speech recognition engine, after signal acquisition, the speech waveform is processed into meaningful and identifiable parts so pattern matching can be accomplished. The goal in signal processing is to extract those features of the speech waveform that contain information and discard those features that contain other information (unvoiced parts). This objective can be accomplished in a wide range of techniques. A few common methods are frequency representations, cepstral analysis, and Linear Predictive Coding (LPC) coefficients. Almost all techniques filter the raw waveform into identifiable parts, which represent only a short time period (5-30 ms) (Anderson, 1998)

The speech waveform can be represented by a spectrogram in numerical form in various time frames. The common method of identifying and sorting these frequencies is through a Fast Fourier Transform (FFT) algorithm. Taking FFT representations over a moderately-sized time windows (20 ms) is the method of signal processing which is most commonly used by voice recognition platforms (Klevans & Rodman, 1997).

The cepstral analysis technique is based on the assumption that speech is a convolution of an excitation function with a vocal tract impulse response (O'Donoghue, 1991). In effect, a narrow-band spectrum is transformed, using Fourier analysis, into a cepstral domain where the workings of pitch in the voice become irrelevant.

Linear Predictive Coding (LPC) is a technique, which has shown success representing the frequency-shaping characteristics of the vocal tract. In LPC, a parametric representation of speech is created by using past values of the signal to predict future values (Goldberg & Riek, 2000).

The basic signal processing techniques may be greatly improved using a subsequent processing technique known as Linear Discriminant Analysis (LDA). The best known version of LDA is the Integrated mel scaled Linear Discriminant Analysis (IMELDA) transform (Anderson, 1998). In IMELDA, the separation between words is maximized while the variance within the word is minimized. This processing method is very robust and is not easily affected by interfering noise, making it well-suited to meet the challenges presented by helicopter cockpits (Kobierski, 1997).

## Pattern Matching

Pattern matching represents each the incoming speech waveform and the word model with a sequence of vectors. In general, the relationship with respect to time between the two sets of vectors is unknown. Even if the times at which the word starts and stop are known, variability exists in the rate of speaking within the word. If the endpoint of the uttered word can be determined, linear time compression is sometimes used to perform pattern matching for waveforms. This method, however, is far from optimal and is only used for discrete word recognition. A more practical method is Dynamic Time Warping (DTW), which applies a vector optimization process to the speech model and incoming speech waveform. A distance score is calculated between the vectors of each model, and a match is found that creates the minimum cumulative distance score (Anderson, 1998.). Figure 11 presents dynamic time warping of the word *one*.

The most widely used pattern matching algorithm is the Hidden Markov Model (HMMs) (Anderson, 1998). The general structure of an HMM is a set of states with transitions between each state. For each transition, a probability of taking that transition is assigned. The sum of the probabilities of all transitions from a state must equal one.

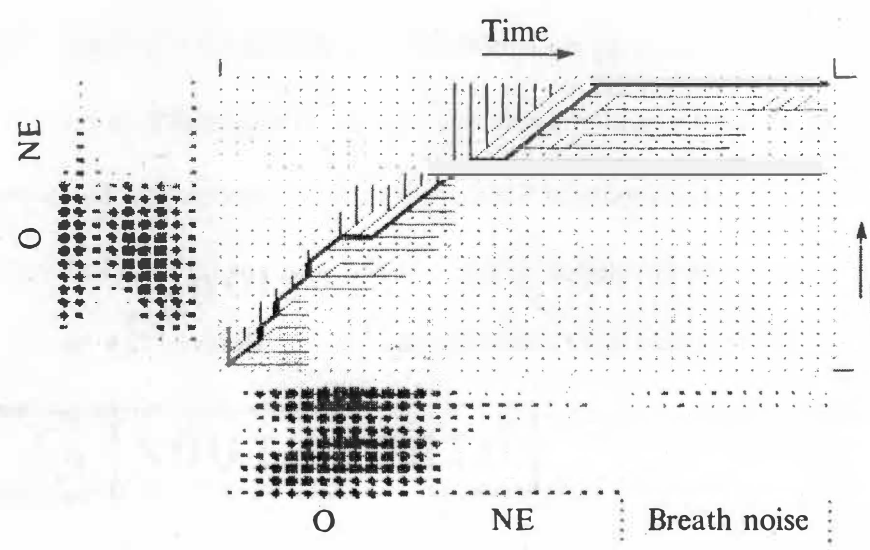



**Figure 11.** Dynamic time warping of the word *one*, being aligned with the *one* template.

Source: Holmes, J. N. (1988). *Speech Synthesis and Recognition*, Van Nostrand Reinhold (UK) Co: Wokingham, Berkshire, England. p.118.

Therefore, each state contains a model of probability distributions of possible output symbols. These models are "hidden" because the exact sequence of transitions is not directly observable. The HMM exhibits the Markov property since the probability of each transition is not based on any previous selection, but only on the current state of the system (Klevens & Rodman, 1997). An example of a two-state HMM is presented in Figure 12.

## Artificial Intelligence

In recent years, researchers have been developing Artificial Neural Network (ANN) algorithms for pattern recognition. An artificial neural network is an information-processing system that uses several assumptions in an attempt to generalize the mathematical model of human cognition or neural biology (Fausett, 1994). ANNs use Time Delay Artificial Neural Networks (TDANN), whose function parallels that of a DTW, to account for time delay constraints of the input speech waveform. Recent work with ANNs has shown tremendous potential for speech recognition in noisy environments. At the University of Southern California, researchers Theodore Berger and Jim-Shih Liaw have developed an ANN–based, speaker-independent voice recognition system that may practically eradicate errors. Berger-Liaw has shown that recognition rates using its system are as high as 88% while noise levels are 300 times the strength of the target word. A human listener subjected to the same relative noise level has a recognition rate of 58% (Berger-Liaw, 1999).

Research has shown that HMM and ANN can be linked together. Past research using this linking technique was limited to non-noisy speech recognition systems

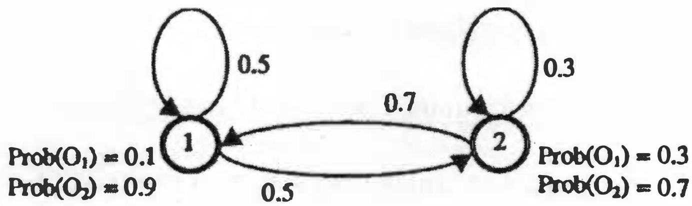



**Figure 12.** Two-state Hidden Markov Model.

Source: Klevans R. L., & Rodman, R. D. (1997). *Voice Recognition.* Norwood, MA: Artech House. p.40.

(Anderson, 1998). As more knowledge is gained about using ANNs, their application in speech recognition is sure to increase in frequency. The noise-tolerant algorithms developed by Berger-Liaw could prove useful in loud helicopter cockpits. Because of the promising results, the amount of neural network speech recognition research performed is expected to grow.

## Speaker Dependent versus Speaker Independent

Speech recognition technologies can be classified as either speaker dependent or speaker independent. Speaker dependent systems match the user's utterance with a predetermined template created during enrollment training. Speaker dependent systems lack flexibility since they cannot be shared, but they are more dependable tools (Weinschenk & Barker, 2000). Recent cockpit uses of speech recognition systems have employed speaker dependent systems.

A more universal form of speech recognition is a speaker independent system. These systems normally have small vocabularies to accommodate a large number of users whose vocal outputs vary. Speaker independent systems tend to be used for specialized, single-task systems, such as automated customer service queries.

## Continuous, Connected, and Discrete

Automatic speech recognition devices can be further classified as either continuous, connected, or discrete. Continuous speech recognition allows a user to speak to a system in a natural manner without using specific, learned commands (Weinschenk & Barker, 2000). This technology implies the capability to input a continuous string of words much like conversational speech. These systems require much computational power and are quite prone to error. The pattern matching process is additionally dependent on an extensive understanding of grammar and syntax.

A more pragmatic approach to speech recognition is a connected word recognition system. Connected recognition allows the user to input a short string of words in a connected manner. This approach is gaining momentum for use in aviation cockpits because it permits the co-articulation of a small number of words. These systems' computing algorithms are more tolerant of little or no spacing between words. Normally, connected speech recognition systems have high recognition rates and a moderately sized vocabulary, which, combined, provide enough capability for use in aviation.

The simplest of these is the fundamental, discrete speech recognition system. Discrete systems are based on isolated words separated with distinct pauses. Any time that phonemes are co-articulated between words, the recognition rate is drastically decreased. Discrete recognizers rely strictly on the acoustic signal and not on grammatical or syntactical structure, which causes the disadvantage that statistical data based on word usage is useless in recognition. Although the percent of recognition in these systems are in the high 90s, the systems are not likely to find use in the cockpit due to the lack of naturalness and speed inherent with the required method of giving commands.

## Speech Recognition In The Flight Environment

The flight environment presents several challenges for the use of DVI in helicopter cockpits. Among these challenges are unusual environmental, physical, and emotional factors that make reliable speech recognition difficult to achieve. Environmental factors, such as noise and vibration, have an effect not only on the pilot, but also on the speech recognition system. However, the latest speech recognition systems can be compressed to a circuit card that can easily be made flight-worthy. When the pilot is subjected to noise, vibration, fatigue, or stress, the result is a variation in speech patterns that decreases speech recognition accuracy. Stress and noise affect the voice in various ways, but of particular interest is the Lombard effect, the tendency for high noise levels in speakers' ears to result in shouted utterances, which distort the spectrum of the speech signal (Swail & Kobierski, 1997). The effect of vibration on the pilot's speech pattern is more complicated because it can only be resolved through the development of stress tolerant recognition algorithms. A proper rotor system track and balance can minimize in-flight vibration on the pilot, but the aerodynamic vibrations of the airframe associated with effective translational lift can not be eliminated. Human factors such as fatigue and stress on the pilot have inspired researchers to create stress tolerant algorithms. Womak and Hansen (1996) proposed an algorithm for estimating the probability of perceptually induced stress by assigning a stress score. The suggestion has been made that the resulting stress score could be integrated into the speech algorithm to improve recognition rates in adverse conditions. The proposed stress classification algorithm was incorporated into a speech recognition system and improvements ranging from 10.1% to 15.4% were achieved over conventional speech recognizers (Womak & Hansen, 1996).

## Ambient Noise

Overcoming the difficulties of using speech recognition in noisy environments is a primary concern. The main difficulty with noisy environments is not the noise itself, but the variations in the noise (Klevans & Rodman, 1997). The main sources of noise in helicopter cockpits are from rotational machinery and airflow. Several approaches exist to minimize the effect of this noise. Three widely accepted general areas of consideration are template development, IMELDA, and signal acquisition.

An accurate voice template for speaker dependent voice recognition systems requires either training with recorded background noise or training during flight. Because voice template formation is a long, ongoing process, the development of such by the pilot during flight is both burdensome and unrealistic. Kersteen and Damos (1984) identified three possible solutions to this problem. First, an algorithm that continually samples background noise and incorporates this noise into the template may alleviate the problem. However, no algorithm has yet been developed that can update quickly enough to keep pace with the rapidly changing noise. Second, template development could be conducted on the ground using recorded cockpit noise. This second technique can involve either recording the template while the pilot can hear the noise or recording the template separately and then incorporating the noise. The disadvantage of merging the noise to the template is that the in-flight recognition accuracy can decrease due to the Lombard effect, which was not a present factor during template development. The final technique is to use better sound proofing materials in the cockpit with the objective of reducing noise to acceptable levels for accurate speech recognition (Kersteen & Damos, 1984).

As opposed to the template approach of incorporating background noise into the pattern matching process, using IMELDA to refine the waveform in the signal processing of voice commands creates a highly noise tolerant speech recognition system. Research done by Zwierzynski (1993) using an IMELDA-based recognizer demonstrated laboratory accuracy rates of 100% and 99.6% for hover and cruise flight conditions, respectively. During actual flight trials using a Bell 205 helicopter, recognition rates were 100% for both the hover and cruise configurations. The promising results of this and other research using IMELDA will provide the enthusiasm for further research in this area.

Modifications to the signal acquisition process can also assist in reducing the noise effect on speech recognition. The correct positioning of the pilot's microphone has significant effects on recognition accuracy. Due to cockpit noise, a pilot puts the microphone as close as possible to his mouth. In this case, the acquired signal involves electronic saturation (Anderson, 1998). The microphone itself should include noise cancellation provisions and have a frequency response up to 8,000 Hz, the normal speech range. Ideally, during template development, the microphone type should be the same as that used in the cockpit to eliminate any differences in the speech signal due to hardware changes.

Flight research using speech recognition systems in noisy environments has shown promising results. For example, flight tests in a JOH-58 scout helicopter were conducted by the U.S. Army Avionics Research and Development Activity (AVRADA). The technology used in this study was reported to have a recognition accuracy of 90% in a 120+ db noise level environment (Holden, 1988). The Naval Air Systems Command (NAVAIR) conducted a speech recognition flight test with a Marine Corps' AV-8B Harrier jet, reporting a recognition accuracy of 95.7% in an environment with noise levels varying from 105 db to 110 db (O'Donoghue, 1991).

In summary, the flight environment will undoubtedly need to be addressed with respect to noise, vibration, stress, and fatigue when integrating DVI to the cockpit. The effect of noise levels in helicopter cockpits can be minimized through noise adaptive templates. Significant success in research using stress classification and IMELDA signal processing will further increase speech recognition accuracy. Regardless of the type of speech recognition system chosen, however, the initial signal acquisition requires particular attention to ensure a useable speech waveform is acquired for processing.

**Direct Voice Input Cockpit Research**

A large amount of work has been done in the development of DVI technology over the last 25 years; this work includes ground-based laboratory simulation, flight simulation, and actual flight test. Much of the research has been with speaker-dependent, discrete speech recognition systems with limited vocabularies in fixed wing aircraft, focused on the control of avionics and navigation and the display of MPD pages. The performances of voice recognition in these experiments have averaged about 90% during the first tests, with values climbing to the high 90s for subsequent iterations. DVI cockpit research in helicopters is somewhat incomplete, but recent flight tests have yielded promising results. One of the first in-flight uses of DVI in helicopters was in 1981. The results of this test confirmed the predicted obstacles caused by high noise levels. In 1987 the U.S. Army successfully tested voice-controlled avionics in a JOH-58C scout helicopter using a continuous, speaker-dependent, isolated word recognizer. In acknowledgement of previous noise problems, the recognizer was trained in an acoustic chamber with realistic background noise conditions (Henderson, 1989). The evaluation required pilots to fly a timed run through a slalom course while performing routine communication tasks. Flight times through the course using voice control averaged 12.5% faster than those of flights without it (Henderson, 1989). In 1997, the United Kingdom conducted research using a Lynx helicopter equipped with a commercial speech recognizer during the Day/Night All Weather (D/NAW) program. Both pilot and copilot used DVI to control display modes, radios, map displays, and the radar altimeter. Simulator test results indicated operational pilots were in favor of it and considered DVI's implementation would offer a considerable enhancement to mission effectiveness. In late 1997, flight tests were conducted under the same mission profiles, and the overall word recognition accuracy was 98% (Anderson, 1998).

Another simulator experiment was conducted by Vidulich and Bortolussi (1988) using a single-pilot advanced scout/attack helicopter at NASA's Ames Research Center. The simulation required pilots to data-burst target engagement information at a hover flight profile either using a manual means of pushing four buttons or using voice input to command data-burst transmission. During task execution, flight control positions and vehicle stability data were collected. In addition, the operational pilots flying the simulation rated each input mode using three subjective workload techniques. The results showed an increase in response time when performing a task using voice input and a reduction in workload from the subjective workload ratings. An analysis of vehicle stability showed that the helicopter was more stationary in its hover when pilots were using the voice input mode of task execution.

A more recent flight test was conducted by the Canadian National Research Council (NRC) in a Bell 412 helicopter using DVI to control avionics. A speaker-dependent, connected speech recognition system employing IMELDA type recognition algorithms was used. The system was evaluated during actual flight conditions by NRC and Canadian pilots. Test scenarios included a simulated operational mission and standard traffic patterns flown while changing radio frequencies. Individual recognition accuracy ranged from 88.4% to 99%. The average recognition accuracy for the system was 94.9%. In summary, the system was determined to be valuable in improving safety and reducing workload in an eyes-out, high workload mission (Swail & Kobierski, 1997).

## Voice Input Task Identification Studies

### Introduction

A pilot has many cockpit tasks to perform during the course of a flight. When speech technology began to mature during the 1980's, its application to the cockpit was recognized as worthy of investigation. As a result, several studies were conducted to identify which cockpit tasks would benefit from DVI to provide the pilot with the greatest workload reduction and optimal situational awareness. These investigations largely ignored task identification in helicopter cockpits; however, numerous reports on fixed-wing DVI application exist.

## Honeywell Study

This study, conducted by the Honeywell Corporation for the U.S. Air Force, was designed to evaluate the potential use of speech technology in a manned penetration bomber aircraft. The study detailed the application of a methodology for choosing the most useful tasks for conversion to be controlled by speech technology. The objectives were to analyze pilot and copilot crewstation tasks during a bomber's mission and determine the tasks that would benefit from the implementation of speech recognition/generation. The list of potential candidates was then evaluated against the technical feasibility of each task's conversion. Finally, the researchers made a prioritized list that could be used by design engineers to implement speech recognition/generation (North & Lea, 1982).

The disadvantage of this study is the specificity of its application. The methodology focuses on bomber aircraft and their missions, making its application to helicopters and their attack role difficult. The approach relies heavily on time-based activity logs of input/output modes (visual, aural, and manual) coupled with anthropometric zones in the cockpit. Additionally, a broader approach of voice application is assumed because the benefits of MPDs and placing additional controls on the stick's grips were yet to be realized. For these reasons, this approach does not lend itself to DVI task identification in the AH-64D Apache.

## Canyon Research Group

In this study, Canyon Research Group, Inc. provided the U.S. Air Force with a method of identifying speech recognition/generation tasks for current and future fighter aircraft. Since the fighter aircraft mission can vary considerably depending on threat and location, rigid mission profiles are not realistic for analyzing cockpit activities; as a result of the varying demands of the fighter aircraft, the Canyon group's approach deviated from that used by Honeywell. Canyon's study was conducted in five phases: analysis of cockpit activities, selection of speech input/output, assessment of technical feasibility, development of simulation specification, and creation of future aircraft design criteria. The Canyon approach assessed anthropometry difficulty by using a weighting factor that was subjectively applied during the analysis of cockpit activities. While the methodology remained similar to that of the Honeywell study in structure, its approach in the task analysis phase was more subjective. The objective approach used by Honeywell focused on a rigid, detailed mission profile and timeline data in conjunction with a set of other objective criteria. The Canyon study, having recognized the limitations created by using such a specific mission profile, instead shifted its emphasis on structured interviews with subject matter experts (Cotton, McCauley, North, and Strieb, 1983)

The Canyon study methodology provides the technique, which is most applicable to the AH-64D Apache. Since the mission profile of the AH-64D is less rigid, a subjective approach to task selection is necessary. In addition, the Canyon study used a more thorough aircraft system analysis than Honeywell's to develop the initial list of candidate voice input tasks. Since the AH-64D is system intensive, this approach lends itself well to identifying voice input tasks.

### Total Systems Approach (Lee, 1988)

The total system approach developed by Lee builds on the framework provided in the Honeywell study. In this study, a model with four modules is used to refine the process of selecting potential tasks for conversion to speech recognition/generation.

Although the first three modules draw extensively from the Honeywell study, the fourth module is unique; it uses a linear programming technique to maximize the candidate task list according to the associated input/output modes of the pilot. The net result is a first draft of the most desirable tasks to provide the largest reduction in pilot workload without overloading the voice channel.

This approach to DVI task identification has the same drawbacks as the Honeywell study. However, the optimization process developed in module four is an improvement. This optimization is only useful for an aircraft that has both numerous anthropometry zones and varying input modalities; in this case, the two require simultaneous comparison to identify potential voice input tasks for the aircraft. The AH-64D cockpits have essentially one anthropometric zone (MPDs) from which the majority of the systems are accessed; because there is only one zone and one input modality (manual), using linear programming to maximize advantage would be unnecessary.

### Aptec Study (Toney, 1988)

This study was conducted by Frank Toney for the U.S. Army during the period when voice recognition was being considered for application in helicopters. The objective of this research was to determine the feasibility of using voice commands to activate gun turret control in attack helicopters. The report outlined general flight profiles and scenarios that would benefit from voice commands, but it revealed no formal process of choosing potential tasks. Much of the research on selecting tasks for voice commands focused on the requirement for a crewmember to control weapon systems, which were not accessible in his own cockpit because of design or tandem seating arrangements. The virtually identical cockpits of the AH-64D effectively eradicated the difficulties this study focused on overcoming. Lastly, the generality of voice input task selection in this study was not precise enough to provide reliably accurate results.

### Eye/Voice Mission Planning Interface

The goal of Eye/Voice Mission Planning Interface (EVMPI) research was to provide a concept for integrating eye-tracking and voice recognition technology in aircraft cockpits. The report published by the research group describes general principles for identifying voice input tasks by using an analytical technique called Goals, Operations, Methods, and Selections (GOMS). GOMS defines a *Goal* as a state to be achieved, reflecting the user's intention. *Operators* are perceptual, cognitive, or motor acts performed in service of a goal (Hatfield, Jenkins & Jennings, 1995). *Methods* are sequences of operators that accomplish a goal (John & Kieras, 1994). Finally, *Selections* are rules for condition-action pairs that determine when to use particular methods to accomplish specific goals (Hatfield et al. 1995). Using these principles, a graphical model is developed to represent all the operators used to accomplish a task. Models developed for the same task using voice execution and hands busy are then compared to identify the number of critical path operators.

The GOMS approach used in this research was applied to a prototypical "generic cockpit" consisting of three MPDs and one Up Front Controller (UFC – a keypad) (Hatfield et al. 1995). An activity level model was developed listing the goals and sub-goals (cockpit tasks) based on a mission scenario. From this list, a GOMS model was generated for the hands-busy (manual) and eye/voice method of performing the selected tasks. Ultimately, the designer's goal was to compare each version of the model and determine which had fewer cognitive operators hence less workload.

Although this report is one of the most extensive voice integration studies published to date, the GOMS approach is still in the preliminary stages of development. The disadvantage of this approach for identifying DVI tasks is the time consuming method of developing the GOMS model for every possible task. Moreover, trying to compare models (voice and hands busy) for all the tasks would be difficult and time consuming without a mathematical approach. In addition, a model with fewer cognitive operators may, in fact, be more difficult and take longer than one with more operators. This situation can be found in tasks that require more difficult and time consuming cognitive operators. Furthermore, there exists no acceptable way of estimating the execution times along the critical path to determine actual task completion time. However, the model does provide design engineers with a valuable tool for planning voice interface in future aircraft since an existing cockpit is not required for analysis.

# CHAPTER 5

# METHODOLOGY

## Introduction

The overall goal of this thesis was to identify potential voice input tasks for integration of ASR technology in the AH-64D Apache. The methodology for accomplishing this objective involved four modules. The first module was to observe and then analyze a mission scenario flown in a simulator by operational pilots. The second module was to conduct a detailed analysis of all the potential cockpit tasks aircrews could perform during the course of a mission. Using the list of cockpit tasks developed in module two, an initial list of candidate tasks was developed by referencing the mission scenario flown in module one. Module three assessed pilot input on the potential voice input tasks and collected opinions on ASR integration to the cockpit. The final module was a simulation exercise flown in the AH-64D simulator to assess any potential benefit of using DVI to perform tasks. The entire process is listed below.

1) Module One: Mission analysis to identify cockpit tasks and general areas of implementation
2) Module Two: Identify preliminary cockpit tasks through systems analysis.
3) Module Three: Pilot questionnaire to evaluate opinion on potential tasks.
4) Module Four: Simulator evaluations of selected candidate tasks to evaluate workload and technical error.

Because extensive human factors engineering contributed to the crewstation design of the AH-64D, the scope of this thesis identifies only those tasks performed through the MPD. Since tasks performed HOCAC already allow the pilot to remain "eyes out" and "hands on", those tasks performed HOCAC were not evaluated using this methodology. The following sections describe the test simulator and the four modules used to identify voice input tasks.

### Description of the Test Simulator

The Apache Longbow Crew Trainer (LCT), illustrated in Figure 13, is a full mission, deployable flight simulator that provides high-fidelity training capabilities to AH-64D flight crews (Boeing, n.d.). The LCT consists of two mobile trailers; one is a service trailer providing electrical power, and the other contains the aircrew stations and an instructor/operator station. The pilot and CPG cockpits are replicas of those in the actual aircraft. The flight controls provide realistic force feel responses to the aircrews under most flight conditions. The WCA system provides voice warning messages and caution tones to the aircrews through their headset in a manner similar to that in the aircraft. In addition, environmental sounds are routed to the aircrew station to provide a realistic sound environment. The cockpit aircrew seats are dynamic, motion-cueing seats that provide onset cueing for the flight environment. The visual system is a high-resolution display of five screens that provide a 180° horizontal and 60° vertical field of view. The instructor/operator station contains all the controls to run the mission scenarios and score gunnery engagements. A high-definition video cassette recorder provides the capability to record the crewstations' displays, visual scenes, and the crewmembers themselves. After a mission, the video can be replayed for analysis, and computer generated reports of crew flight parameters can be analyzed. Among these


**Figure 13.** Apache Longbow Crew Trainer (LCT).

Source: Boeing Co. (n.d.). *Apache Longbow Crew Trainer.* [Brochure] St. Louis, MO: author.

reports is a switch action history with a time stamp that shows the sequence of MPD and HOCAC switch selections.

## Module One: Mission Analysis

As with any potential application of technology to a military aircraft, a careful analysis is required to assess the impact on the mission. The wave of political change across the world has spawned non-conventional threats that required U.S. Army Apache pilots to change their tactics, techniques, and procedures. The traditional anti-armor role of the AH-64D still remains; however, non-traditional roles such as urban close-air-support and over-water anti-ship warfare have emerged. Since the AH-64D mission can vary widely, a general mission scenario was chosen to represent a typical mission flown by Apache crews. A brief description of this mission is provided in the following section.

### Mission Overview

A flight of eight AH-64Ds are tasked with a deep attack mission to destroy enemy artillery forces in order to set conditions for seizure of an airfield by friendly ground forces. The flight will depart for the mission from a tactical field site at low-level altitudes, transitioning through friendly territory to the forward line of troops. Prior to crossing into enemy territory, coordination is made with friendly ground forces for passage, and artillery is fired to suppress enemy air defense systems. Once in enemy territory, the flight will navigate approximately 50 miles to an Attack By Fire (ABF) position to engage pre-planned targets. The flight will assume a hover flight profile in the ABF, and digital FCR target data will be exchanged between LBA aircraft and non-FCR equipped Apaches. The time on station in the ABF will not exceed 15 minutes, and then the flight will egress using a different route to a tactical Forward Aerial Arming and Refueling Point site (FAARP) in friendly territory. Once the flight is reconstituted at the FAARP location, preparations are made for future combat operations.

## Mission Analysis

This stage of module one consisted of operational pilots flying the aforementioned mission scenario in the Longbow Crew Trainer (LCT). During the course of the mission, a collection of the most frequently used MPD displays and tasks performed was identified by reviewing the mission as recorded by the LCT's video cassette recorder. To assist in identifying the MPD page selections, a switch action history report from the LCT was output. An example of that report is provided here, Table 2, Switch Action History.

Using the data collected from the mission playback and the action history report, the mission was reconstructed in an outline format as presented in Appendix A. The mission was further analyzed by identifying potential voice input tasks and organizing them into their general categories. Once categorized, the sub-tasks were decomposed into three separate columns in Table A1. First, the sub-task was represented by the MPD

**Table 2.** Example Switch Action History.

| Mission Elapsed Time | Description |
|---|---|
| 01:41:21 | PLT Cyclic Assembly Panel Communication Switch RTS |
| 01:41:21 | PLT Cyclic Assembly Panel Communication Switch None |
| 01:41:24 | PLT Left MPD Bezel Button "L6" from the Zone Page |
| 01:41:29 | PLT Right MPD Bezel Button "B6" from the COM Page |
| 01:41:31 | PLT Right MPD Bezel Button "B4" from the Net Page |
| 01:41:35 | PLT Right MPD Bezel Button "B5" from the Net Page |
| 01:41:38 | PLT Right MPD Bezel Button "L2" from the Net Page |

selections required to perform it. This gave a quick reference for comparison with other tasks performed during the mission, and the task grouping allowed high manual workload areas to be identified. The second column shows where the manual operations took place (MPD, KU, HOCAC). This was important because some tasks that require cursor control or HOCAC action in conjunction with MPD selections may not lend themselves well to voice input control. The final classification column is the sub-task type column, which identifies the type of operation taking place (selection, mental comparison, etc). Cockpit tasks that require mental comparison ultimately require the pilot to direct his gaze into the cockpit to interpret or perceive information; therefore, these tasks may not be wholly suited for voice control. Instead, a voice command in this situation could configure the display to the point where the pilot can direct visual attention inside to make a mental comparison.

At this point, the mission tasks identified in this module served only to provide a reference for the following modules. During module two, when tasks were selected, the mission scenario and the mission analysis in Table A1 enabled subjective decision to be applied against the mission to keep the decision making process sensible.

In summary, module one consisted of a mission scenario development followed by the simulator flight of the mission. A post-mission data collection of MPD displays and tasks were documented. The detailed breakdown of the mission tasks and the mission scenario provided a reference for decisions to be made in subsequent modules.

## Module Two: Task Identification

### Aircraft Systems Analysis

In this module, an aircraft systems analysis was performed to compile an initial list of voice input tasks. This was accomplished by using the LCT and a computer based MPD emulator to execute cockpit tasks. Each top level MPD page was examined, and all discrete cockpit tasks were executed on the emulator or in the simulator. Both the number of bezel button actions required to perform each task and whether that task required the use of the KU were recorded.

Because some tasks are executed with varying numbers of required button pushes, two counts were done for each task to record the minimum and maximum number of buttons needed. For example, to change a manual VHF frequency the number of keystrokes can vary depending on the frequency. The frequency could be either 118.0 or 125.725. In the latter case, two additional keystrokes are required.

### Choosing DVI tasks

Not all the tasks identified in the systems analysis are suitable for DVI. Therefore, a series of filters were applied to reduce the list to the most beneficial tasks. The first filter, inherent in the scope of this thesis, was the restriction of candidates to tasks performed through the MPD. This filter meets an additional requirement of technical feasibility. Any task performed through the MPD is managed by the DMS and can be accessed through the multiplex data bus, hence making it technically possible for DVI to perform. The human factors optimization of the AH-64D cockpit has eliminated many of the hard switches characteristic of its predecessors; therefore, the previous problems of how to incorporate DVI to a hard switch, which were addressed in the Honeywell and Canyon studies, are not applicable the AH-64D.

The remaining filters are summarized in a decision chart presented in Figure 14. A brief explanation of each filter is provided in the following paragraphs.

1) Does the task involve arming or releasing weapons? If yes, reject task. If no, continue to evaluate. This filter was applied for obvious safety reasons. Additionally, selecting weapons and firing them are performed strictly from the cyclic and ORT handgrips. This filter did not, however, preclude changes to the weapons system configuration.

2) Is the task involved in an emergency procedure? If yes, reject task. If no, continue to evaluate. During an emergency, a pilot's attention should be focused on assessing the problem and taking corrective action. Using DVI tasks during an emergency would likely be very difficult considering the highly variable speech signal induced by the high-stress situation.

3) Is task a manual discrete? If no, reject task. If yes, continue to evaluate. According to North and Lea (1982), human control of the speech channel favors discrete utterances and does not lend itself to continuously controlled tasks, such as piloting an aircraft.

4) Can task be accomplished with HOCAC at all times? If yes, proceed to pilot input rating. If no, continue to evaluate. Obviously, if the task can be performed "hands on" and "eyes out" using HOCAC, the benefit from using DVI is reduced. Nevertheless, if there is an overwhelming pilot request for a HOCAC task to be performed using DVI, then it can be accepted for implementation.

5) Is task very time critical? If yes, accept task. If no, continue to evaluate. Time critical functions were given priority for acceptance through this filter. The intent is to capture those tasks that need to be accomplished immediately, but cannot be accomplished because of continuous manual operation of the flight controls.

6) Does task occur frequently? If yes, continue to evaluate for KU operation. If no, continue to evaluate for number of KU entries. Manual tasks that occur several times during the course of a mission are particularly important for DVI implementation. Conversely, a task that requires several buttons to complete may occur so infrequently that DVI has negligible benefit.

7) Does task require any KU entry? If yes, accept task. If no, continue to evaluate. This filter captures tasks that are not time critical, but occur frequently and require

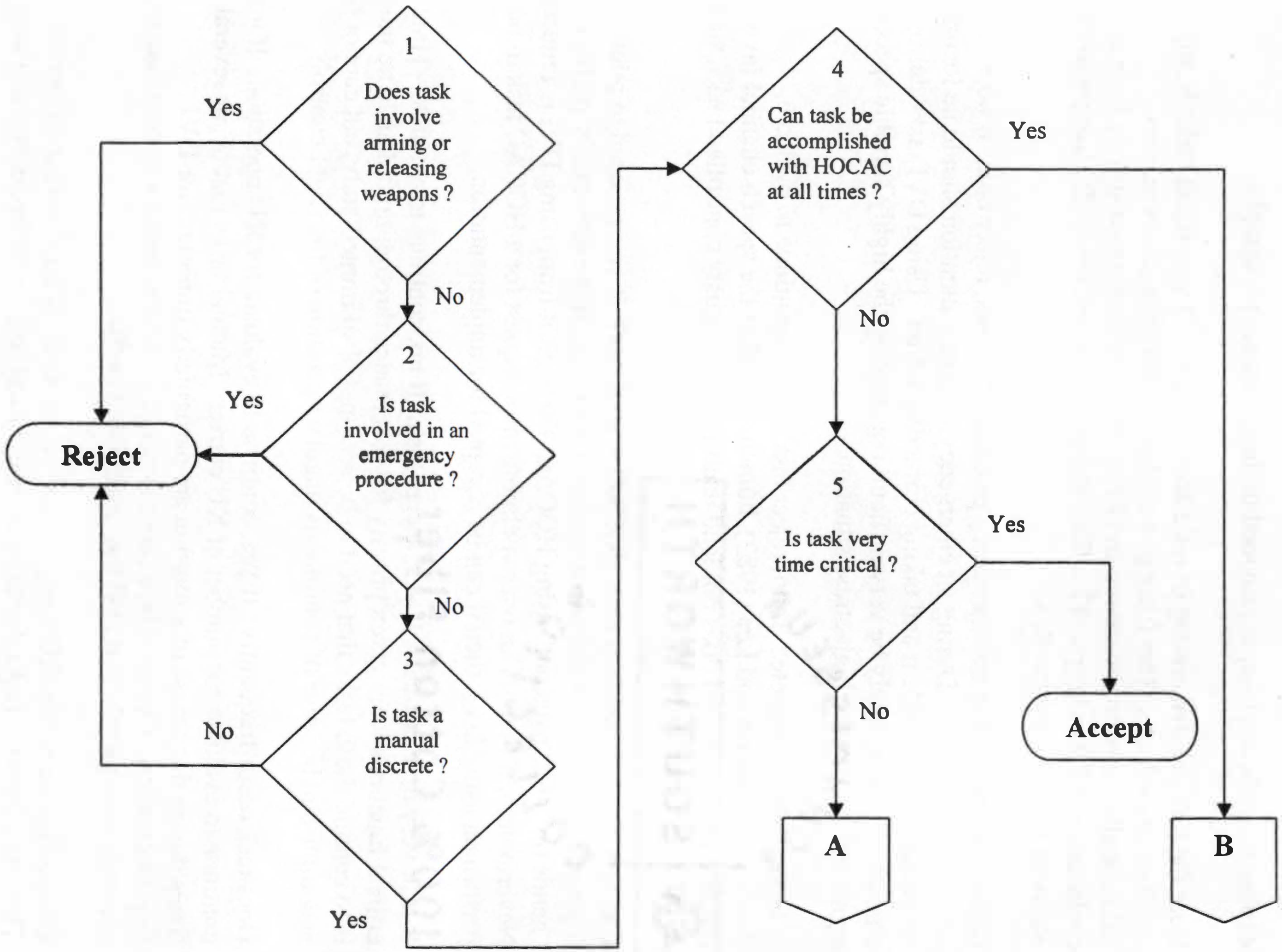



**Figure 14.** Direct Voice Input Criteria.

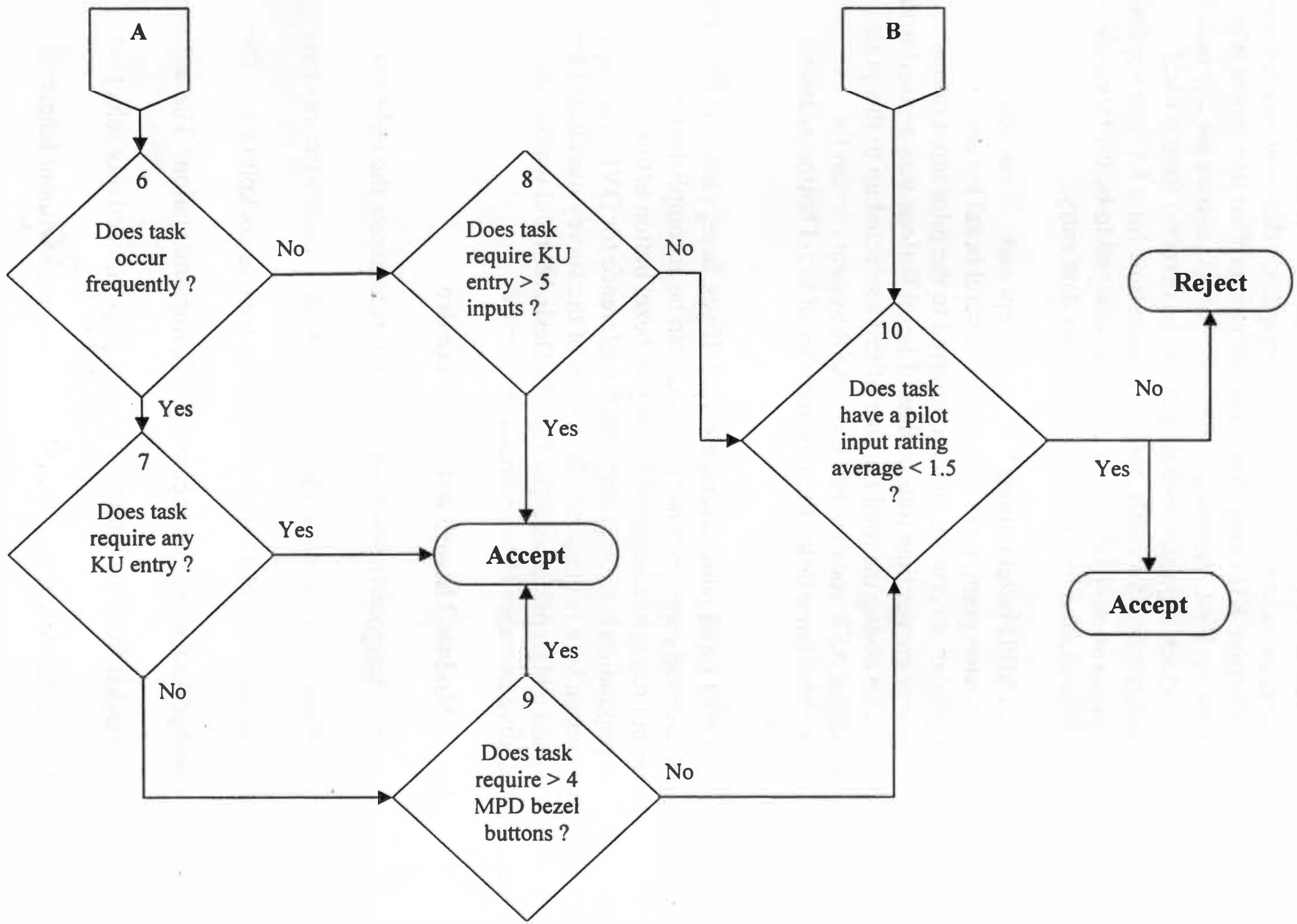



**Figure 14.** Continued.

a KU entry. Supported by research done by Malkin and Christ (1985), a task using voice input has a combined data entry and response time less than keyboard entry.

8) Does task require a KU entry >5 inputs? If yes, accept task. If no, continue to evaluate. This filter is an extension from the task frequency decision and accepts tasks that require extensive KU entry. The value of greater than five inputs was selected for two reasons: First, the minimum number of KU entries for any task in the AH-64D is two, which requires minimum attention diverted from critical visual and manual demands. Secondly, task execution time for a KU entry greater than five inputs (approximately 10 seconds) was determined to be the threshold of time a pilot should be allotted for "inside" the cockpit data entry.

9) Does task require >4 MPD bezel buttons? If yes, accept task. If no, continue to evaluate. At this decision point, tasks that require several bezel buttons to accomplish are accepted; otherwise, they are referred to the pilot input rating. The decision to accept greater than four pushes of bezel buttons was derived from an iterative process involving the total number of tasks selected up to this point and the capacity of the ASR vocabulary. If the ASR system chosen for implementation permits more tasks, then the number of bezel button actions should be reduced.

10) Does task have a pilot input rating average < 1.5? If yes, accept task. If no, reject task. This final decision captures those tasks that can be accomplished using HOCAC and do not require extensive KU entry or bezel button action, but for which the pilot population has expressed a high preference for DVI. The input rating average chosen here is unique to the results of the survey mentioned herein. The value reflected a high preference (Extremely Desirable) and was selected based on the relative averages obtained from the survey.

**Module Three: Pilot Questionnaire**

A questionnaire was designed to allow AH-64D pilots to assess the utility of using DVI to perform selected cockpit tasks. The questionnaire was divided into two sections. The first section consisted of 43 questions about discrete cockpit tasks. The second section contained general questions regarding DVI implementation. The tasks in the first section were compiled from the output of module two, subjectively selected to provide enough variety to accurately reflect the pilot's preferences without lengthening the questionnaire unreasonably. The tasks were grouped into their respective systems and labeled with the corresponding top-level page. Each question asked the pilot to rate the desirability of using DVI to perform the task on a five point scale. The tasks were presented with examples of potential implementations to facilitate understanding. An example of this format is presented here. The complete questionnaire is presented in Appendix C.

FLIGHT

1) Change the Altimeter setting. Ex. Pilot: *"Altimeter 29.98"*

____________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

In the second section, the remaining six questions asked the pilot to provide input on display priority and voice technology implementation. Respondents answered a series of questions about MPD page display priority and preference. To assist the pilot in remembering the MPD page hierarchy, an outline of the MPD paging tree was provided. Two questions provided the pilot the opportunity to write/type in opinions about DVI tasks or general concerns about the technology. Finally, question 48 was designed to assess pilot preference about how to activate the voice recognition system.

**Module Four: Simulator**

The final module was developed to collect data on task execution times of using the "hands busy" and voice input methods. The LCT simulator was used with operational pilots performing selected tasks. The reason for this module is supported by Cotton et al., (1983) who stated, "Ultimately, task selection must progress to carefully controlled simulation tests to check the validity of choices" (p. 28). Furthermore, the study recommended that a highly demanding manual/visual control task be used to obtain the high workload level representing flight control. The approach used here was developed from that insight.

## Simulator Test Methodology

The LCT test methodology included subjective and objective measures of workload. The subjective metric used was the Bedford Scale, Figure D1, Appendix D. The Bedford scale is a widely accepted method of subjectively measuring the amount of workload an aircrewmember experiences. The objective metric used was the secondary-task paradigm (Kantowitz & Casper, 1988). Both evaluation metrics attempted to measure the amount of "spare" capacity available to the pilot. Two pilots with operational experience flying the AH-64D were selected to participate in the test. Each pilot flew one evaluation session under identical conditions. The objectives of the evaluation program were to determine task execution time, to subjectively evaluate the workload level of performing tasks, and to collect data on flight parameters to evaluate the effect of task execution on helicopter control.

The two pilots chosen to participate in data collection were from different experience levels. The first pilot was 43 years old, with 19 years of military experience, 750 flight hours in the AH-64D, and a total flight time of over 3000 hours. The second pilot was 32 years old, with 6 years of military experience, 120 flight hours in the AH-64D, and a total flight time of 370 hours.

Six tasks were evaluated in the LCT. The tasks were chosen from module two and had varying levels of difficulty. During the first session, the three tasks chosen were (a) changing an altimeter setting, (b) changing a manual frequency, and (c) selecting a route from the TSD route menu. For the second simulator session the tasks performed were (d) adding a target to the threat file, (e) transmitting a Radar Frequency Handover (RFHO) target, and (f) editing and tuning a Frequency Hop (FH) net.

The tasks were performed using three methods of input: (a) hands busy, (b) cursor control, and (c) direct voice input (DVI). Each method of input was evaluated on-the-ground, "non-flying", where the pilot's primary task was to perform the cockpit task. Following the ground evaluations, the pilots flew a slalom course, Figure E1, Appendix E, at predetermined airspeed and altitude while performing each task using one of the three different input methods. After each input method and test condition, the pilot evaluated the workload by assigning a workload level (WL) from the Bedford Scale. Objective data were collected for each task by timing the task execution and recording airspeed and altitude deviations. Test conditions are presented in Table 3, Test and Test Condition Matrix.

## Direct Voice Input Method

The technique developed to emulate the DVI method of task execution was based on the GOMS model of task execution (Hatfield et al. 1995). In GOMS, a task has a discrete number and order of cognitive operators required to complete a task. Similarly, a task that shares the same order and number of cognitive operators and uses the same input/output modalities should have the same level of difficulty and workload. In this experiment, the pilot was required to emulate DVI by replicating the process of interacting with a voice recognition system. First, the pilot was required to press the intercommunications button on the cyclic. This coincided with pressing the Push To Recognize (PTR) button on a real system. Second, the pilot spoke the command using a

**Table 3.** Test and Test Condition Matrix.

| Test Condition | Input Method | Airspeed[1] (KTAS) | Altitude[2] (ft AGL) | Data Collected |
|---|---|---|---|---|
| Ground Test | Hands Busy | 0 | 0 | Task execution time |
| | Cursor Control | | | |
| Slalom Course | Hands Busy | 20 | 20 | Task execution time. Airspeed and altitude plot. |
| | Cursor Control | | | |
| | Direct Voice Input | | | |

[1] Airspeed in Knots True Airspeed (KTAS).
[2] Altitude in feet Above Ground Level (AGL).

limited vocabulary. Third, the pilot was required to focus into the cockpit and read the fuel status from the UFD. This was necessary because a visual feedback of the voiced command was chosen as the method of feedback to be simulated. Finally, the pilot was required to key the intercommunications button again and voice the fuel numbers. This last step accounted for the need to provide an affirmation and execution command to the voice recognition system.

# CHAPTER 6

# FINDINGS AND DISCUSSION

As was expected, the mission analysis (module 1) and aircraft system analysis (module 2) revealed several tasks that were suitable for DVI. The pilot questionnaire (module 3) and simulator sessions (module 4) led to some interesting conclusions. The results of each of these modules are presented separately in the following sections.

## Module One Findings: Mission Analysis

The analysis of three separate missions identified the following key points. More "hands busy" cockpit tasks were performed through the MPDs than through HOCAC and console mounted hard switches. The pilot and copilot/gunner MPD page preferences were similar and predictable.

During all of the missions, the pilot and copilot viewed the Flight page, Weapons page, and TSD page the majority of the time. However, during the en-route phase, the pilot and copilot tended to switch between the Flight page and FCR page. A post-mission debriefing revealed two reasons for the pilot's preference to toggle between the Flight page and the FCR page: (a) pertinent flight data was available on the Helmet Display Unit (HDU), which made the Flight page less important, and (b) the Flight page could be easily accessed by the FCR page instantly through switch paging from the cyclic. Conversely, the copilot/gunner favored the FCR page more than the Flight page for obvious reasons--the copilot was not flying. The Flight page, therefore, was less important. In addition, the copilot/gunner was actively searching with the radar and

TADS, which made the FCR page more useful. Unlike the pilot, the copilot was more active in switching pages and performing "heads down" tasks through the MPDs.

The display preference changed during the Attack By Fire (ABF) phase of the mission. The pilot and copilot predominately viewed the FCR page, Weapons page, and TSD page. For the majority of this phase, the pilot favored placing the FCR page on the left side and the TSD page on the right side with the TADS video underlay. However, during the onset of this phase, the high gross weight of the aircraft created a situation where an engine limitation needed frequent monitoring, causing the pilot to frequently alternate between the FCR page and the Engine page. The copilot also used the FCR page on the left side, but alternated between that and the Weapons page for weapons employment. The copilot's right side MPD was used similarly to the pilot's, with the exception that the copilot displayed the TADS video display more frequently. The Flight page was never accessed by either crewmember during battle position operations.

**Switch Action History**

The switch action history enabled the observation of an important parameter that was difficult to capture during mission observation. The report showed the cockpit tasks that were performed on the pages that were displayed for only short periods of time. For example, the pilot favored the Flight page but would occasionally select the Fuel page momentarily to monitor fuel transfer or start/stop the fuel check. From the history log, the majority of cockpit tasks were performed on the TSD page, Weapons page, and Communications page. Because of this finding, a preference for those tasks were applied for DVI task selection in module two.

## Summary of Module One Findings

Module one results provided the general framework needed to proceed to the detailed task selection. The mission outline presented in Appendix A represents the basic structure of the three missions observed. In general, the pilots most frequently exhibited and reported a preference for the Flight, Weapons, TSD, FCR, and Communications pages. The switch action history supported this preference by revealing that these pages contain the majority of tasks performed during the mission.

## Module Two Findings: Task Identification

The aircraft systems analysis identified 214 cockpit tasks that Apache crews could perform through the MPDs. From this list, the DVI selection criteria reduced the number of potential DVI tasks to 56. The complete list compiled in module two is summarized in Table B1, with the 56 potential DVI tasks identified by shading.

## Module Three Findings: Pilot Questionnaire

The questionnaire was administered to 24 active, operational pilots. The results are summarized in Tables 4 - 9. The pilots surveyed, whose mean age is 38 years old, have an average of 16 years of military experience. The pilots averaged 396 hours of experience in the AH-64D and an additional 1,200 hours in the AH-64A. The majority of the respondents were instructor pilots (11) and maintenance test pilots (9). A total of 16 pilots had experience with a voice recognition device, but none of the pilots had ever flown an aircraft using DVI. Although the total number of pilots queried was limited due to ongoing combat operations, the fact that standard deviation of all the responses was less than 1.3 indicates that most pilots would be in a state of relative agreement regarding the desirability of the tasks in question.

Questions 1-43 pertained to the desirability of performing a task using DVI. The results are presented in Table 4. There are two ways to consider the rating data: relative ratings among the questions or absolute ratings based on the five-point scale. The questions that received the highest relative ratings tended to be functions that:

1) occurred frequently during a mission,
2) required several pushes of bezel buttons, or
3) required the use of the keyboard unit (KU).

When task ratings are viewed with respect to the endpoints of the rating scale, one can see that five tasks received a mean rating above 1.5 ("extremely desirable") for DVI. Furthermore, two tasks received a mean rating below 2.5 ("not sure"), and the remaining tasks were ranked as "somewhat desirable". Unexpectedly, the pilots tended to rate almost all of the tasks as desirable for DVI. Although this was helpful in reinforcing the methodology used in module two for preliminary task selection, the results did not help reduce the total number of ultimately accepted tasks.

Questions 44 - 47 assessed the pilots' preferences for display pages and general areas for DVI implementation. These questions revealed the pilots' desire for DVI in the areas of and pages pertaining to Tactical Situation Display, Weapons, Flight, Engine, and Fire Control Radar. On other pages, such as Communications, pilots preferred to have DVI commands that provided them with the ability to accomplish a task in that area without having to display the corresponding page. A summary of results for questions 44 - 46, are presented in Tables 5 - 8, respectively. Question 47 comments on are presented in text.

**Table 4.** Pilot Questionnaire Results, Questions 1-43.

| Question | Rating 1 | 2 | 3 | 4 | 5 | Mean n=24 | Standard Deviation |
|---|---|---|---|---|---|---|---|
| 1) Change the Altimeter setting. | 12 | 10 | 2 | 0 | 0 | 1.54 | .66 |
| 2) Change the LO/HI Bug setting. | 3 | 10 | 4 | 6 | 1 | 2.67 | 1.12 |
| 3) Change the cockpit temperature | 1 | 16 | 3 | 2 | 2 | 2.50 | 1.13 |
| 4) Acknowledge Warning after an ENGINE auto-page | 12 | 5 | 2 | 3 | 2 | 2.08 | .97 |
| 5) Acknowledge Caution after a UFD message. | 7 | 9 | 2 | 5 | 1 | 2.33 | 1.08 |
| 6) Acknowledge Advisory after a UFD message. | 4 | 13 | 1 | 4 | 2 | 2.46 | 1.25 |
| 7) Engage FMC channels. | 6 | 11 | 2 | 4 | 1 | 2.29 | 1.19 |
| 8) Display Engine Systems ENG SYS page | 13 | 10 | 1 | 0 | 0 | 1.50 | .51 |
| 9) Start/Stop Fuel Check. | 11 | 10 | 1 | 1 | 1 | 1.79 | .87 |
| 10) Select manual fuel transfer. | 0 | 14 | 6 | 2 | 2 | 2.67 | .66 |
| 11) Tune a manual frequency (VHF/UHF/FM). | 16 | 7 | 0 | 1 | 0 | 1.42 | .38 |
| 12) Select Transponder status (NORM/STBY). | 12 | 9 | 2 | 1 | 0 | 1.67 | .66 |
| 13) Change the transponder code. | 15 | 9 | 0 | 0 | 0 | 1.38 | .44 |
| 14) View Free Text message. | 9 | 14 | 1 | 0 | 0 | 1.67 | .52 |
| 15) Listen to Free Text message. | 10 | 10 | 4 | 0 | 0 | 1.75 | .75 |
| 16) Compose Free Text message. | 16 | 5 | 1 | 2 | 0 | 1.54 | .63 |
| 17) Select Radio Mode (SC, FH, and FH/M). | 12 | 10 | 2 | 0 | 0 | 1.58 | .66 |
| 18) Select Radio Mode (Cipher/Plain). | 12 | 10 | 2 | 0 | 0 | 1.58 | .66 |
| 19) Select FM Hopsets that are preset | 9 | 10 | 5 | 0 | 0 | 1.83 | .80 |

**Table 4.** Continued.

| Question | Rating 1 | 2 | 3 | 4 | 5 | Mean n=24 | Standard Deviation |
|---|---|---|---|---|---|---|---|
| 20) Edit FM Hopsets that are not preset. | 7 | 9 | 6 | 2 | 0 | 2.13 | .93 |
| 21) Transmit a Call For Fire. | 5 | 13 | 4 | 2 | 0 | 2.13 | 1.12 |
| 22) Perform authentication. | 8 | 11 | 3 | 2 | 0 | 1.96 | .93 |
| 23) Select a video underlay. | 9 | 12 | 1 | 2 | 0 | 1.83 | .95 |
| 24) Select Zoom/Norm/Wide of video underlay | 4 | 8 | 8 | 4 | 0 | 2.50 | 1.04 |
| 25) Change the scale of the TSD Page. | 9 | 12 | 1 | 2 | 0 | 1.83 | .95 |
| 26) Center/De-center the TSD Page. | 6 | 15 | 2 | 0 | 1 | 1.96 | 1.04 |
| 27) Change the current route. | 12 | 10 | 1 | 1 | 0 | 1.63 | .88 |
| 28) Select Reverse Route from the Route Menu. | 9 | 11 | 3 | 1 | 0 | 1.83 | .83 |
| 29) Select a waypoint to fly direct to. | 18 | 4 | 2 | 0 | 0 | 1.33 | .63 |
| 30) Perform a waypoint store on the fly. | 15 | 8 | 1 | 0 | 0 | 1.42 | .66 |
| 31) Store a target in the threat file. | 11 | 9 | 3 | 1 | 0 | 1.75 | .99 |
| 32) Change the Show page options. | 3 | 12 | 6 | 3 | 0 | 2.38 | .97 |
| 33) Select Route Review for a waypoint. | 9 | 11 | 2 | 2 | 0 | 1.88 | 1.04 |
| 34) Select PAN options. | 6 | 12 | 4 | 1 | 1 | 2.13 | .86 |
| 35) Send Reports (PP/FARM/BDA/TGT). | 14 | 7 | 1 | 2 | 0 | 1.63 | 1.11 |
| 36) Store FCR targets. | 7 | 11 | 3 | 3 | 0 | 2.08 | 1.00 |
| 37) Transmit RFHO to a zone member. | 12 | 7 | 3 | 2 | 0 | 1.79 | 1.12 |
| 38) Select Burst Limit on the 30mm. | 1 | 16 | 4 | 3 | 0 | 2.38 | .87 |

**Table 4.** Continued.

| Question | Rating 1 | 2 | 3 | 4 | 5 | Mean n=24 | Standard Deviation |
|---|---|---|---|---|---|---|---|
| 39) Input manual range value on the Weapon page. | 19 | 4 | 0 | 1 | 0 | 1.29 | .88 |
| 40) Select Missile trajectory (DIR/LO/HIGH). | 4 | 14 | 5 | 1 | 0 | 2.13 | .64 |
| 41) Select Rocket type (Multi-Purpose/ Point Detonating). | 10 | 11 | 3 | 0 | 0 | 1.71 | .65 |
| 42) Select Rocket Quantity. | 10 | 12 | 2 | 0 | 0 | 1.67 | .65 |
| 43) Change MPD displays. | 15 | 9 | 0 | 0 | 0 | 1.38 | .38 |

**Table 5.** Pilot Questionnaire Results, Question 44.

| **Question 44** **If you used voice to change MPD displays, list which pages you would find most useful for a voice command.** | **Number of occurrences** |
|---|---|
| 1) Engine Systems Page. | 4 |
| 2) TSD Page. | 4 |
| 3) Weapons Page. | 4 |
| 4) FCR. | 3 |
| 5) Engine Page. | 2 |
| 6) Communications Page. | 2 |
| 7) Weapons Missile Pages. | 2 |
| 8) Flight Page. | 2 |
| 9) Flight Set Page. | 1 |
| 10) Performance Page. | 1 |
| 11) WCA Page. | 1 |
| 12) Fuel Page. | 1 |
| 13) TSD Scale Page. | 1 |
| 14) Communications Utility Page. | 1 |
| 15) Video Page | 1 |
| 16) Transponder Page | 1 |
| 17) To gain access to any page that isn't top level | 1 |

**Table 6.** Pilot Questionnaire Results, Question 45.

| Question 45 | Rating | | | Mean n=24 | Standard Deviation |
|---|---|---|---|---|---|
| Rate each MPD page on order of importance | High-1 | Medium-2 | Low-3 | | |
| 1) Flight Page. | 18 | 5 | 1 | 1.29 | .55 |
| 2) Engine Page. | 18 | 5 | 1 | 1.29 | .55 |
| 3) Fuel Page. | 4 | 14 | 6 | 2.08 | .65 |
| 4) Performance Page. | 8 | 6 | 10 | 2.08 | .88 |
| 5) DMS Page. | 4 | 11 | 9 | 2.21 | .72 |
| 6) ASE Page. | 6 | 12 | 6 | 2.00 | .72 |
| 7) Weapons Page. | 22 | 2 | 0 | 1.08 | .28 |
| 8) TSD Page. | 23 | 1 | 0 | 1.04 | .20 |
| 9) FCR Page. | 16 | 6 | 2 | 1.42 | .65 |
| 10) SOI Page. | 2 | 7 | 15 | 2.54 | .66 |
| 11) SINC Page. | 3 | 15 | 6 | 2.13 | .61 |
| 12) HQ2 Page. | 4 | 13 | 7 | 2.13 | .68 |
| 13) Transponder Page. | 3 | 12 | 9 | 2.25 | .68 |
| 14) ADF Page. | 2 | 1 | 21 | 2.79 | .59 |
| 15) Video Page. | 3 | 11 | 10 | 2.29 | .69 |
| 16) Video Recorder Page. | 1 | 6 | 17 | 2.67 | .56 |
| 17) Message Send. | 7 | 8 | 9 | 2.08 | .88 |

**Table 7.** Pilot Questionnaire Results, Question 46.

| **Question 46** **Rank the desirability of performing these general areas of tasks using DVI with (1) being the most desirable** | **Mean n=24** | **Standard Deviation** |
|---|---|---|
| 1) Tactical Situation Display | 1.92 | 1.10 |
| 2) Weapons | 2.67 | 2.01 |
| 3) Engine | 3.63 | 2.32 |
| 4) Communications | 3.71 | 1.83 |
| 5) Flight | 3.83 | 2.24 |
| 6) Fire Control Radar | 4.38 | 2.10 |
| 7) Fuel | 6.42 | 1.38 |
| 8) Video | 7.00 | 1.74 |

**Table 8.** Additional Pilot Responses to Question 46.

| **Area** | **Number of Responses** | **Rank Assigned** |
|---|---|---|
| 1) Performance | 1 | 1 |
| 2) Chaff | 1 | 6 |
| 3) ASE | 1 | 8 |

**Question 47:** Write in any additional tasks that you feel a voice command would be useful for.

**Responses:**

Pilot 8: "Hold Modes On/Off e.g. 'Hover Hold On' 'Altitude Hold On'"

Pilot 9: "Stabilator, flight mode(hover, bobup, cruise, transition),boresight, IAT [Image Auto Tracker], IAT Offset,change polarity,altitude hold,heading hold, RTS. [remote transmit select],last-some items should never be voice recognition-engine shutdown,weapon firing"

Pilot 12: "Possibly have some sort of voice command to remind the crew of the fuel check either complete or to end it."

Pilot 13: "'Engage altitude hold'"

Pilot 15: "In general any tasks that require more than ONE button push. For example, I don't want voice to "acknowledge caution". I DO want voice to minimize the 7+ button pushes it takes to change altimeter setting, or manually tune a radio, or change a manual range."

Pilot 16: "Change the range on the weapon page"

Pilot 17: "windshield wipers!!!"

Pilot 18: "aquisition [sic] source selection"

Pilot 20: "AQC [acquistion] SOURCE CHANGE would be very very nice"

Pilot 22: "aircraft lighting on/off"

Pilot 23: "Most useful would be 'acquisition source select' and 'manual range'!"

Question 48 identified the use of a Push To Recognize (PTR) switch as the preferred method of activating a voice recognition system for DVI. This conclusion is supported by research done by NAVAIR in an AV-8B Harrier jet, which experienced a 51% activation rate using a keyword (O'Donoghue, 1991). Moreover, a PTR button would eliminate the mandatory unnatural "keyword" in the utterance that would preface each command. Ideally, the PTR switch should be located on the cyclic, and when activated would route the pilots voice directly to the ASR engine and prevent it from being heard by the other crewmember. Results of Question 48 are provided in Table 9.

## Pilots' Written Comments

Lastly, Question 49 allowed the pilots to comment on the use and integration of DVI in the Apache Longbow. Comments from the pilots reflected a desire that any DVI system be simple and intuitive. Furthermore, any task that required more than a few bezel button pushes to accomplish and that occurred frequently during flight, was generally favored as a DVI task. Many pilots, however, expressed concern regarding the implementation of DVI technology. Pilots were generally uncomfortable with the possibility that a DVI system's misrecognition of a voice command could make inadvertent changes to the aircraft. This concern reinforces the identification of the requirements to have a reliable method of activating and deactivating the system, some form of feedback, and a necessary pilot's confirmation before the system acts upon a voice command. A copy of each pilot's comments is presented below.

**Table 9.** Pilot Questionnaire Results, Question 48.

| Question 48<br>Please rank the following methods of activating a DVI system. | Rating | | | Mean | Standard Deviation |
|---|---|---|---|---|---|
| | High-1 | Medium-2 | Low-3 | | |
| 1) Push To Recognize. | 14 | 5 | 5 | 1.63 | .82 |
| 2) Keyword | 7 | 9 | 8 | 2.04 | .81 |
| 3) Actively listening | 3 | 9 | 12 | 2.38 | .71 |

**Question 49:** Comments: Please comment on the use and integration of DVI technology in the Apache Longbow

**Responses:**

Pilot 4: "In referance [sic] to question 44, I would like to see a way to access all pages directly (i.e. ENG system page, FLT SET page). Also setting freqs, altimeter, and xponder codes would sure simplify life."

Pilot 6: "Sounds good but how much weight does it add to the aircraft? We are flying in High DA [Density Altitude]/ PA [Pressure Altitude] / Temp environments (Afganistan [sic] / Iraq) now and are pretty heavy with ordnance."

Pilot 7: "This would be a great leap forward for the crew and the weapons systems employment."

Pilot 9: "I believe this technology could be very useful especially during night high workload situations. I think initially using a pushbutton to activate the system would be prudent until there was great certainty that activation was not possible from the other seat or external radio sources."

Pilot 11: "I believe the most imortant MPD displays are TSD, FCR, WPNS, and a video selection. Although the communications display is not one that I need shown for any duration of time, I think it would be most beneficial to access/change communications settings through the use of DVI. I believe that DVI would be most useful with the four MPD displays selections mentioned above and communications interface. I think the biggest obstacle would be the crew coordination between crew members as if to tell your crew member to do something and the computer recognizes it as a command or vice versa."

Pilot 13: "Great concept, good luck on instituion."

Pilot 14: "Keep it simple so you can perform the task while people are shooting at you."

Pilot 15: "I like the idea of anything that makes task execution faster and more intuitive!"

Pilot 16: "The way to go!"

Pilot 17: "Be carefull [sic] of DVI with important features. Example: Reseting the master warning light is something you fisically [sic] have to do. It shouldn't be too easy to reset the warning light in a 'stressfull' [sic] situation without thinking/looking what the emergency is. Re-engaging the fmc-axes [flight management computer] might be dangerous to do with DVI because then you wouldn't see the affected axis. It would be great to be able to use DVI instead of the KU. DVI has to work when both crewmembers are speaking at the same time. (Other crewmember talking on the radio(s). Setting of the manual range would be a great feature also."

Pilot 18: "Voice commands will be usefull [sic] for controls that take more then 2 button pushes and are used in almost every flight."

Pilot 19: "I doubt it will be a great improvement since this means even more talking in the cockpit. In general i [sic] find top level switches or hard switches much faster and less subjectable to error."

Pilot 20: "Push to recognize button on the floor and on the cyclic (at least for the front seat)"

Pilot 21: "Especially the way the system is activated is something to pay close attention to. Because of the two pilot concept I think it is quite hard to come up with a system which continously is listening for voice commands"

Pilot 22: "If all these functions are possible, isn't it going to be a 1 pilot aircraft???"

Pilot 23: "Especially the activation/acknowledgement of the DVI is very important in my opinion. Futhermore, it would be non-sense if the activation of DVI would take more effort than simply pushing one or two buttons that can already be set upon start-up. E.g. the example of the 'show page' and the 'low bug'."

Pilot 24: "Do not want a system that inadvertently makes changes to aircraft configuration (errors in recognition). Idealy it would be on continuously and recognize comands without confusing radio traffic or cockpit discussions with desired commands. I think a switch activated system would be required until confidence was built. Also, recognition of voice commands associated with high workload enviornments would be the most desireable (ie. during running fire, or while being engaged by the enemy). Voice recognition system must be highly reliable. Memorizing a slew of voice recognition sequences could be combersome on the flight crew. Voice sequences must be easy or natural."

## Summary of Module Three Findings

The output of this module is the list of potential DVI tasks for implementation in the AH-64D. The DVI tasks ultimately recommended for implementation by this study was created after evaluting the feedback provided by the questionnaire and comparing it with the 56 tasks identified in module three; these tasks are presented below, grouped by category.

1) Display MPD pages: Engine, Engine System, Fuel, Performance, TSD, FCR, Weapons Missile, and Video.
2) Digital Communications: transmit digital information whenever a MPD page displays a "send" option.
3) Flight: change altimeter setting.
4) Fuel: initiate and stop a fuel check.
5) Communications: change a manual frequency, edit a preset hopset, select the radio mode (SC, FH, Cipher, and Plain), and view/compose free text message.
6) Tactical Situation Display: change scale of TSD, select acquisition source, add a waypoint or threat, perform target/waypoint store, select a waypoint to fly direct to, and transmit present position report.
7) Fire Control Radar: transmit RFHO.
8) Weapons: input a manual range for ballistic solution, and select rocket quantity for engagement.

This list is intentionally short because the tasks it contains should be viewed as the highest priority for integration with DVI; if an implemented DVI system is able to incorporate few tasks, these are the tasks which should be included. If additional tasks can be added, they should be chosen from others of the 56 tasks output from module 3. Selection of these tasks should occur in the order of TSD, communications, weapons, FCR, and engine. Ultimately, the capacity of the ASR system chosen for the AH-64D will decide how many of the tasks mentioned above can be used. Another constraint for implementation is the pilot's ability to remember the vocabulary associated with all these tasks. The list mentioned here is small enough that even a cumbersome vocabulary would not exceed the limits of the pilot's memory.

### Module Four Findings: Simulator

The simulator sessions measured aircrew response times and workload levels for six potential DVI tasks. The objective measures were response time and aircraft flight path. Workload levels were measured subjectively using the Bedford scale.

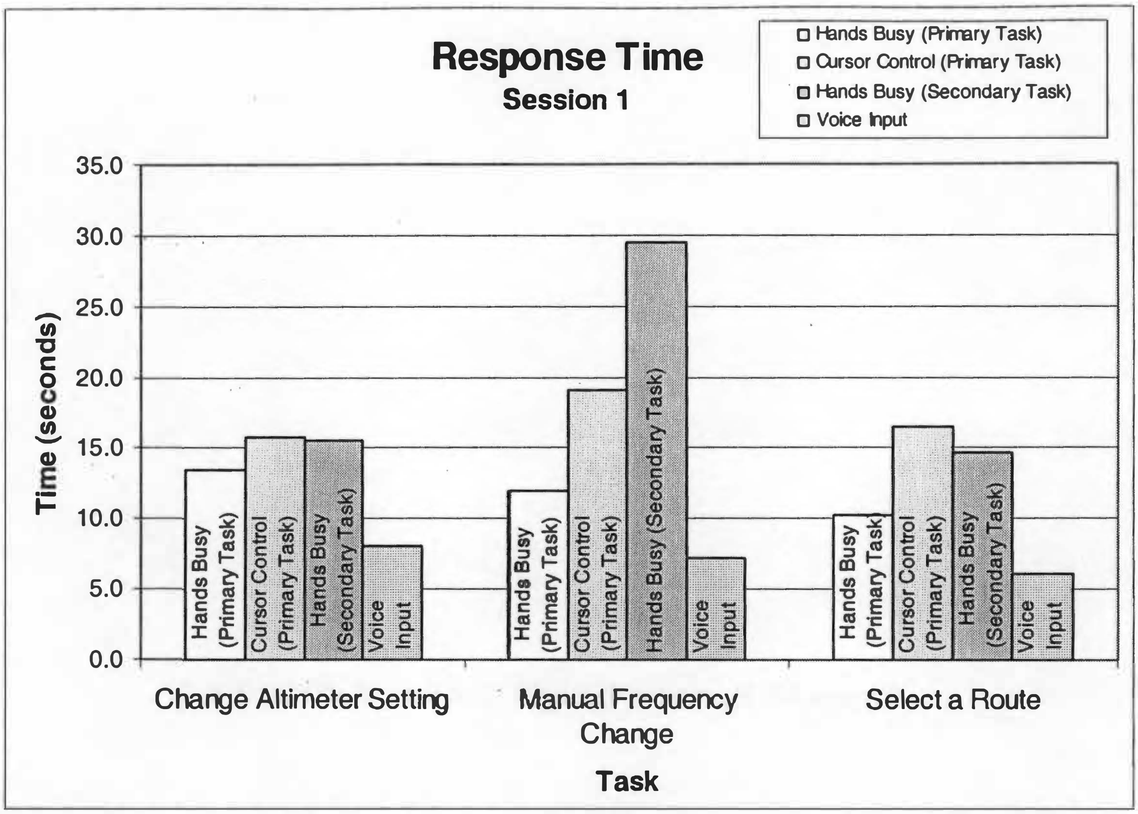
#### Response Time

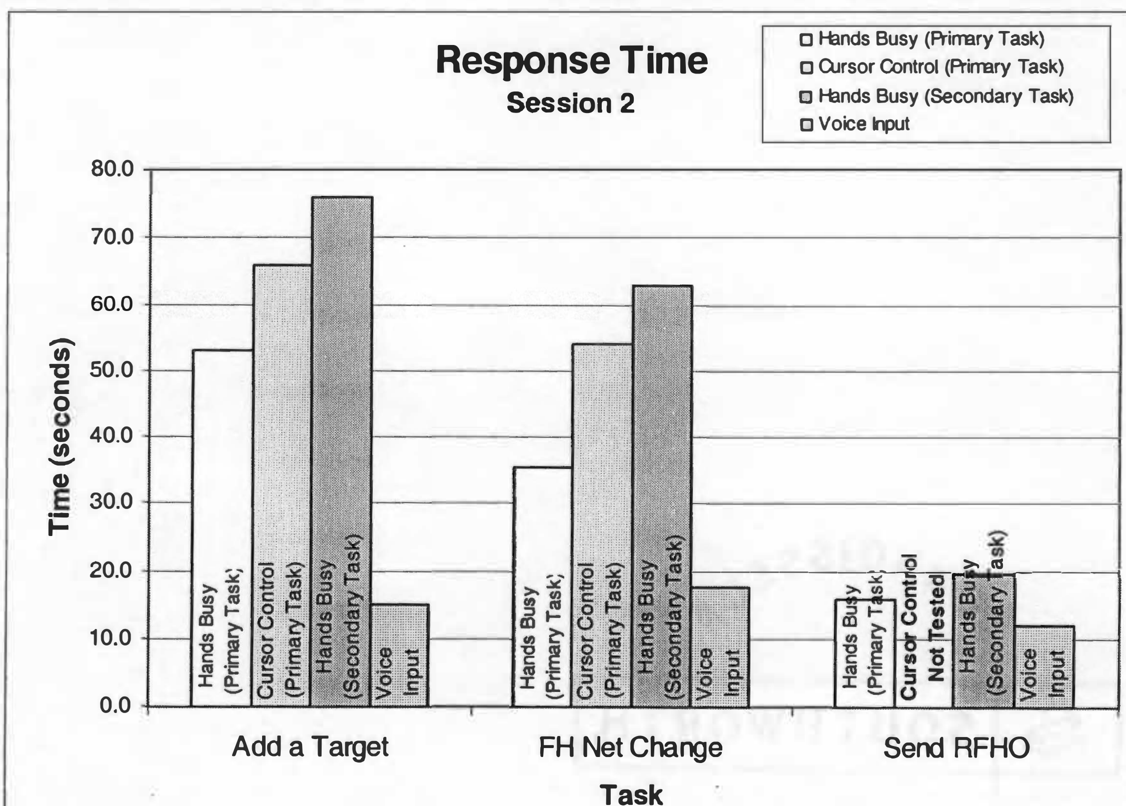
Aircrew response time was measured from when the LCT operator's command to execute a task until the aircrew completed the task. The response times for the six evaluted tasks are presented in Figure 15. An analysis of the response time shows that for the two manual methods of input, the "hands busy" method required less time than cursor control method. During flight, the DVI method required less time than the "hands busy" input method. The analysis assumed that DVI has a 100% recognition rate and can only be valid for trials in which the "hands busy" method was performed to the desired result. Although the subject pilots made errors while executing their assignments, both pilots ultimately completed each task.

#### Workload

After each test condition and input method, a Bedford scale workload rating was assigned to the condition. For example, immediately after performing a task while flying the slalom course, the pilot was asked to rate the workload by estimating the amount of spare capacity available. In general, the subjective workload assessments supported the conclusions drawn from the objective response times, indicating an increase in workload

**Figure 15.** Response Time for Simulator Sessions 1 & 2.


Response Time
Session 1
Hands Busy (Primary Task)
Cursor Control (Primary Task)
Hands Busy (Secondary Task)
Voice Input
Time (seconds)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Hands Busy (Primary Task)
Cursor Control (Primary Task)
Hands Busy (Secondary Task)
Voice Input
Change Altimeter Setting
Manual Frequency Change
Select a Route
Task


Response Time
Session 2
Hands Busy (Primary Task)
Cursor Control (Primary Task)
Hands Busy (Secondary Task)
Voice Input
Time (seconds)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Hands Busy (Primary Task)
Cursor Control (Primary Task)
Hands Busy (Secondary Task)
Voice Input
Cursor Control Not Tested
Add a Target
FH Net Change
Send RFHO
Task

for an increase in response time. A summary of the results are presented in Table 10.

## Technical Error

To evaluate the effect of aircraft control between the different input methods, aircraft airspeed and altitude of task execution were analyzed. This information was helpful in two ways: (a) it permitted the observer to monitor degradation in the primary task of flying, and (b) it showed the effect of a secondary task on aircraft control. When analyzing the six potential DVI tasks, the response time and flight data were viewed collectively to ensure any decrease in response time was not at the cost of aircraft control. First, the subject pilots flew a baseline slalom course to which subsequent iterations can be compared for deviation. Then, the pilots performed the candidate tasks using a "hands busy" method and by the voice input method. A sample of the airspeed and altitude data extracted from each subject pilot is presented in Appendix F, Figures F1 – F6.

**Table 10.** Bedford Workload Ratings for Simulator Sessions.

| Situation Rated | | | Bedford Rating (WL) | |
|---|---|---|---|---|
| Status | Primary Task | Secondary Task | Pilot 1 | Pilot 2 |
| Non-Flying | Hands Busy Input | None | 2 | 2 |
| Non-Flying | Cursor Control Input | None | 3 | 3 |
| Flying | Negotiate Slalom Course | None | 5 | 5 |
| Flying | Negotiate Slalom Course | Hands Busy Input | 7 | 6 |
| Flying | Negotiate Slalom Course | Cursor Control Input | 9 | - |
| Flying | Negotiate Slalom Course | Voice Input | 6 | 5 |

The results were not surprising. While performing all six candidate tasks, the airspeed and altitude deviated from the assigned values, but remained within acceptable safety margins during all but two iterations. Subject Pilot One inadvertently allowed airspeed and altitude to reduce to almost zero during task execution during one iteration. Similarly, Subject Pilot Two once allowed such a reduction in altitude that he impacted the ground. See Figure F5. Both pilots demonstrated less control over altitude than airspeed during task execution.

**Summary of Module Four Findings**

The simulator sessions give further evidence of the efficiency of time-sharing between input modalities, supporting the hypothesis of Wickens's (1990) multiple resource model. In general, using voice as an input method resulted in a decreased response time and reductions in workload coupled with negligible impact on aircraft control. Even if response times using voice were longer, the benefit of having one's "hands-on" the controls and "eyes-out" of the cockpit exceeds the penalty of the longer response time. An additional benefit of the simulator sessions was that it validated the methodology used to select DVI tasks. All of the candidate tasks seleceted for simulator testing were performed quicker and with less technical error than the manual method.

The results, however, are somewhat incomplete for two reasons: a limited number of pilots participated in the test, and the method of emulating voice input did not account for misrecognition errors. Future research in this area should expand on the simulator trials by integrating an ASR platform into candidate task evaluations. Further, candidate tasks should be tested under a mission scenario outlined in module one of the methodology to ensure compatibility in a dynamic environment such as combat.

# CHAPTER 7

# CONCLUSION & RECOMMENDATIONS

## Conclusion

Future attack helicopters will inevitably have more complex sensors and avionics to manage the digital battelfield, creating a need to have an alternative method of interacting with these new technologies. Currently, attack helicopter pilots are constrained to only the manual form of interface with their aircraft. The rapid advances in computer technology during the last twenty years has made speech recognition the most viable alternative control available. The use of Direct Voice Input (DVI) in the cockpit of the AH-64D Apache should improve workload by providing relief for the already overloaded visual channel and excessive motor demands. The large number of hard switches, including, keyboards, bezel buttons, and HOCAC switches poses a high cognitive demand, and tends to overload critical attentional resources needed to fly and fight efficeintly. In particular, the number of HOCAC switches in the AH-64D has reached the limit of pilot memory, and the overabundace serves to create more workload than it alleviates.

Integration of DVI in the Apache should encompass the cockpit tasks that will maximize workload reduction while retaining DVI's intutitive approach. Repetitive tasks such as displaying MPD pages, changing communication settings, manipulating navigation options, reconfigurating weapons systems, and transmitting digital information are subject areas for implementation. In particular, tasks that occur frequently, are time critical, or require the use of either a keyboard or several bezel buttons are generally potential tasks for conversion to DVI. Once these tasks are converted to DVI, continually performing the tasks by DVI reinforces the pilot's natural instinct to use voice input. Regardless of the degree of implementation, a DVI-integrated aircraft should always have a redundant, silent method of performing the same task, which can override any voice input.

When a DVI system is developed, the pilots' preferences and concerns should take a high priority. When asked for input on the role of DVI, pilots have expressed concern about inadvertent activation due to misrecognition. Therefore, both visual or aural feedback and command confirmation must be included in any DVI design. Further, DVI should be simple and easy to use, have a limited vocabulary, and perform non-critical tasks. A push-to-recognize switch located on the cyclic is the favored means of activating a DVI system, which increases aircrew confidence and the speech recognition rate.

The results of the simulator evaluation validated the methodology used to select candidate tasks, and confirmed the hypothesis of workload reduction using DVI. Additionally, the simulator proved to be a good tool for evaluating potential DVI tasks. Simulator trials demonstrated preliminary time savings in task completion and reductions in workload when voice was used as an input mode. Multiple resource theory predicts this demonstrated efficiency due to the balanced, multi-modal use of voice and manual inputs.

The use of DVI in helicopter cockpits has excellent potential to increase safety, reduce workload, and enhance mission effectiveness. Obviously, several issues remain unresolved, such as noise, pilot stress, recognition accuracy, and systems integration with existing voice displays. Direct Voice Input may not be "the answer" to reduce pilot workload in the AH-64D, but it clearly exhibits the potential for alternative control in the AH-64D.

**Recommedations**

The following recommendations concerning voice recognition in the AH-64D Apache are listed below.

1) Further testing and screening of potential DVI tasks in the simulator using operational pilots should be accomplished before in-flight testing in the actual aircraft. The LCT has proved to be an excellent means of controlling key variables, which assesses candidate tasks easier.
2) A speaker-dependent, limited-vocabulary, IMELDA type voice recognition system should be chosen and flight tested in the AH-64D Apache.
3) The system should be lightweight, simple, relatively inexpensive, and preferably use existing aviation speech recognition platforms that have at least 98% recognition accuracy.
4) Cockpit tasks performed by DVI should be primarily in the areas of and pages pertaining to Tactical Situation Display, Weapons, Communications, Flight, Engine, and Fire Control Radar.
5) DVI should always be an alternative method of input. The silent, manual method of performing tasks should always be retained to safeguard against misrecognition and to be used during times of aural overload.
6) Voice output should be integrated with DVI implementation to provide aural feedback during high visual workload situations.

7) The effect of pilot stress on DVI should be evaluated in a simulated combat environment during actual flight test.

# LIST OF REFERENCES

# LIST OF REFERENCES


Anderson, T. R. (1998). Applications of Speech-Based Control. In *Research and Technology Organization Lectures Series 215 Alternative Control Technologies: Human Factors Issues.* Neuilly-Sur-Seine Cedex, France: Research and Technology Organization. (AD-A355 911)

Berger-Liaw Neural Network. (1999). *Machine Demonstrates Superhuman Speech Recogniton Abilities* [On-line]. Available: www.usc.edu/extrelations/news_service/release/stories/36013.html

Boeing Co. (1998a). *AH-64D Aircraft and System Description* (PFN 4933). [Student Handout.] Unpublished text.

Boeing Co. (1998b). *AH-64D Control and Display Methodology* (PFN 4934). [Student Handout.] Unpublished text.

Boeing Co. (n.d.). *Apache Longbow Crew Trainer.* [Brochure] St. Louis, MO: author.

Burcher, N.M., Karly, R., Voorhees, J. & Werner, E. (1984). Alerting Prefixes for Speech Warning Messages. In *Proceedings: National Aerospace and Electronics Conference (NAECON).* (pp. 924-931). New York: IEEE.

Christ, K. A. (1984). *Literature Review of Voice Recognition and Generation Technology for Army Helicopter Applications* (Tech. Note 11-84). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory. (DTIC No. AD-A146 878)

Cotton, J. C., McCauley, M. E., North, R. A., & Strieb, M. I. (1983). *Development of Speech Input/Output Interfaces for Tactical Aircraft* (AFWAL-TR-83-3073). Wright-Patterson AFB, OH: Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory. (DTIC No. AD-A136485)

Department of the Army. (2002). *Operator's Manual for Helicopter, Attack, AH-64D Longbow Apache* (TM 1-1520-251-10). Washington, D.C.: Author.

Downey, D.A. (1995). *Analysis of the MH-47E Integrated Avionics System.* Master's thesis, University of Tennessee, Knoxville

Durbin, D. B. (2002, May). Human Factors Characteristics of the AH-64D Apache Longbow Crewstations. *MANPRINT Quarterly*, 4-6.

Durbin, D. B. (2001). *Assessment of Crew Workload for the RAH-66 Comanche Force Development Experiment 1* (ARL-TN-183). Aberdeen Proving Ground, MD: Army Research Laboratory, p. 25.

DVI-Making the Difference. (2001, October). *Team Eurofighter, 1-2001,* 1-4.

Fausett, L. V. (1994). *Fundamentals of Neural Networks: Architectures, Algorithms, and Applications.* Upper Saddle River, NJ: Prentice-Hall.

Goldberg, R., & Riek, L. (2000). *A Practical Handbook of Speech Coders.* Boca Raton, FL: CRC Press.

Hatfield, F., Jenkins, E. A., & Jennings, M. W. (1995). *Eye/Voice Mission Planning Interface (EVMPI)* (AL/CF-TR-1995-0204). Wright-Patterson AFB, OH: Armstrong Laboratory, Crew Systems Directorate. (DTIC No. AD-A308 044)

Henderson, B. W. (1989, May 22). Army Pursues Voice-Controlled Avionics to Improve Helicopter Pilot Performance. *Aviation Week & Space Technology.* 43.

Holden, James M. (1988). *Field Testing Voice I/O in Army Helicopters*, Proceedings of the American Voice I/O Systems Application Conference, 1988.

Holmes, J. N. (1988). *Speech Synthesis and Recognition: Aspects of Information Technology.* Wokingham, Berkshire, England: Van Nostrand Reinhold (UK) Co. Ltd.

Janes Information Group. (2000). *Boeing AH-64D Apache: An Article from the Boeing Company* [On-line]. Available: http://www.janes.com/defence/air_forces/news/jawa/jawa001013_1_n.shtml

John, B. E., & Kieras, D. E. (1994). *The GOMS Family of Analysis Techniques: Tools for Design and Evaluation.* (Rep. No. CMU-CS-94-181). Pittsburgh, PA: Carnegie Mellon University, School of Computer Science.

Kanotowitz B. H., & Casper P. A. (1988). Human Workload in Aviation. In E. L. Weiner & D. C. Nagel (Eds.), *Human Factors in Aviation* (pp. 157-187). San Diego: Academic Press.

Kersteen, Z. A., & Damos, D. (1984). *Human Factors Issues Associated with the Use of Speech Technology in the Cockpit* (NASA CR-166548). Moffett Field, CA: Ames Research Center. (DTIC AD-A213 127)

Klevans, R. L., & Rodman, R. D. (1997). *Voice Recognition.* Norwood, MA: Artech House.

Lea, W. A. (1980). *Trends in Speech Recognition.* Englewood Cliffs, NJ: Prentice-Hall.

Lea, W. A. (1986). The Elements of Speech Recognition. In G. Bristow (Ed.), *Electronic Speech Recognition: Techniques, Technology, & Applications* (pp. 49-129). New York: McGraw-Hill.

Lee, M. A. (1988). *Development of a Model which Provides a Total System Approach to Integrating Voice Recognition and Speech Synthesis into the Cockpit of U.S. Navy Aircraft* (Master's Thesis). Monterey, CA: Naval Postgraduate School. (DTIC No. AD-A202 122)

Leger, A. (1998). Synthesis-and [sic] expected benefits Analysis. In *Research and Technology Organization Lectures Series 215 Alternative Control Technologies: Human Factors Issues.* Neuilly-Sur-Seine Cedex, France: Research and Technology Organization. (AD-A355 911)

Malkin, F. J. (1983). *The Effects on Computer Recognition of Speech When Speaking through Protective Masks* (AMCMS 612716.H700011 Technical Memorandum 7-83). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory. (DTIC No. AD-A129371)

Malkin, F. J., & Christ, K. A. (1985). *A Comparison of Voice and Keyboard Data Entry for a Helicopter Navigation Task* (AMCMS 612716.H700011; HEL-TM-17-85). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory. (DTIC No. AD-A163 245)

Military Standard. (2001). *Aeronautical Design Standard Performance Specification Handling Qualities Requirements for Military Rotorcraft* (ADS-33-E-PRF). Redstone Arsenal, AL: U.S. Army Aviation and Missile Command, Aviation Engineering Directorate.

Nolan, F. (1986). The Nature of Speech. In G. Bristow (Ed.), *Electronic Speech Recognition: Techniques, Technology, & Applications* (pp. 18-48). New York: McGraw-Hill.

North, R., & Lea, W. (1982). *Application of Advanced Speech Technology in Manned Penetration Bombers* (AFWAL-TR-82-3004). Wright-Patterson AFB, OH: Air Force Wright Aeronautical Laboratory, Flight Dynamics Laboratory. (DTIC No. AD- A119 274)

Noyes, J., & Starr, A. (1996). Use of Automatic Speech Recognition: Current and Potential Applications. *Computing & Control Engineering Journal,* 7(5), 203-208.

O'Donoghue, D. P. (1991). *The Development of a Voice-Interactive Avionics System for the AV-8B Harrier II Tactical Jet Aircraft* Master's thesis, University of Tennessee, Knoxville.

Orlady, H. W., & Orlady, L. M. (1999). *Human Factors in Multi-Crew Flight Operations.* Brookfield, VT: Ashgate.

Pallett, D. (1986). Assessing the Performance of Recognisers. In G. Bristow (Ed.), *Electronic Speech Recognition: Techniques, Technology, & Applications* (pp. 277-306). New York: McGraw-Hill.

Poock, G. K., Roland, E. F., & Schwalm, N. D. (1983). *Wearing Army Gas Masks While Talking to a Voice Recognition System* (Report No. NPS55-83-005). Monterey, CA: Naval Postgraduate School.

Prochnow, D. (1987). *Chip Talk: Projects in Speech Synthesis.* Blue Ridge Summit, PA: Tab.

Rood, G. M. (1998). Operational Rationale and Related Issues for Alternative Control Technologies. In *Research and Technology Organization Lectures Series 215 Alternative Control Technologies: Human Factors Issues.* Neuilly-Sur-Seine Cedex, France: Research and Technology Organization. (AD-A355 911)

Stokes, A., Wickens, C., & Kite, K. (1990). *Display Technology: Human Factors Concepts.* Warrendale, PA: Society of Automotive Engineers, Inc.

Swail, C., & Kobierski, R. (1997). Direct Voice Input for Control of an Avionics Management System. In *53rd Annual Forum Proceedings: American Helicopter Society: Vol. 1.* (pp. 109-115). Alexandria, VA: American Helicopter Society.

Taylor, M. (1986). Voice Input Applications in Aerospace. In G. Bristow (Ed.), *Electronic Speech Recognition: Techniques, Technology, & Applications* (pp. 322-337). New York: McGraw-Hill.

Technical Insights. (2000). *Voice Recognition: Innovation Brings Speech to the Market.* New York: John Wiley & Sons.

Toney, F. (1988). *Scientific and Technical Report Voice Activated Gun Turrent* [sic] *Control* (DAAA 21-82-C-0184). Picatinny Arsenal, NJ: U. S. Army AMMCCOM. (DTIC No. AD-A210 350)

United States Army Aviation Center USAAVNC. (2000, September). *AH-64D Data Management System* (10-6135-3.4). [Student Handout]. Unpublished text.

United States Army Aviation Logistics School USAALS. (1994, April). *Design Considerations/Airframe* (071-620-04). [Student Handout]. Unpublished text.

Vidulich, M. A., & Bortolussi, M. R. (1988, April). *Speech Recognition in Advanced Rotorcraft: Using Speech Controls to Reduce Manual Control Overload.* Paper presented at the National Specialists' Meeting, Automation Applications for Rotorcraft, Atlanta, GA.

Weinschenk, S., & Barker, D. T. (2000). *Designing Effective Speech Interfaces.* New York: Wiley.

Wickens, C. D. (1984a). *Engineering psychology and human performance.* Columbus, OH:Merrill

Wickens, C. D. (1984b). Processing resources in attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention* (pp. 63-101). New York: Academic Press.

Wickens, C. D., & Flach J. M. (1988). Information Processing. In E. L. Weiner & D. C. Nagel (Eds.), *Human Factors in Aviation* (pp. 111-155). San Diego: Academic Press.

Womack, B. D., & Hansen, J. H. L. (1996). Classification of Speech under Stress Using Target Driven Features. *Speech Communication, 20*, 131-150.

Zwierzynski, D. A. (1993). Speech Recognition in a Helicopter Cockpit: A Step toward Operational Use. In *International Symposium on Automotive Technology and Automation.* Symposium conducted at Aachen, Germany.

## APPENDICES

# APPENDIX A: MISSION OUTLINE

## MISSION OUTLINE

### Pre-Takeoff Phase

1. Pre-Mission Planning (AMPS)
2. Pre-Flight (CL)
3. Before Starting APU (CL)
4. Starting APU (CL)
5. After Starting APU (CL / MPD)
6. Before Starting Engines (CL / MPD)
7. BUCS Test (CL / MPD / HOCAC)
8. Navigation Operational Check (CL / MPD)
9. Starting Engines (CL / MPD)
10. Before Taxi Check (CL / MPD / HOCAC)
    10.1. HIT/Anti-Ice Check (CL / MPD / HOCAC)
11. Radio
    11.1. Change Frequency (MPD)
    11.2. Communicate (HOCAC)
12. Taxi Check (CL/MPD)
    12.1. Engine Page (MPD)
    12.2. Flight Page (MPD)
13. Before Takeoff Check (CL/MPD)
    13.1. Systems
        13.1.1. Fuel Page - Monitor (MPD)
        13.1.2. Engine Page - Monitor (MPD)
        13.1.3. Flight Instrumentation - Check (MPD)
        13.1.4. ASE – As desired(MPD)
        13.1.5. Transponder - Set (MPD)
    13.2. Power Check (CL / HDU / MPD)
        13.2.1. Performance Page (MPD)
14. Navigation System (MPD)
    14.1. Select Route (MPD)
    14.2. Initiate direct steer to route (MPD)
15. Weapon Systems (MPD / HOCAC / HDU)
16. Radio
    16.1. Change Frequency (MPD)
    16.2. Communicate (HOCAC)
17. Transponder
    17.1. Mode - On (MPD)
18. Takeoff (HDU)

### Enroute To Attack By Fire Position (ABF) Phase

19. Navigate (HDU)
    19.1. Route Review (MPD)

20. FCR scan (MPD / HOCAC)
    20.1. Perform Target Handover
        20.1.1. FCR Target Report
21. Weapon Systems – Armed (Armament Panel)
    21.1. Chaff – Armed (MPD)
22. Mission Update
    22.1. Digital Message – Receive (MPD / UFD)
    22.2. Free Text Message – Receive (MPD / UFD)
    22.3. Free Text Message – Transmit (MPD / KU)
23. Coordinate SEAD
    23.1. Change Frequency (MPD / UFD)
    23.2. Communicate (HOCAC)
24. Digital Communication with Artillery
        24.1.1. Radio
            24.1.1.1. Change Frequency (MPD)
            24.1.1.2. Send Digital Message (MPD / HOCAC)
25. Initiate Fuel Check (MPD)
26. Coordinate Passage Point, PP
    26.1. Change Frequency (MPD / UFD)
    26.2. Communicate (HOCAC)
27. Lights – Off (Left Console)
28. ASE
    28.1. IR Jammer – On (MPD)
29. Transponder
    29.1. IFF - On (MPD)
    29.2. Verify Interrogation (UFD)
30. FLIR – Scan (LHG / RHG / MPD / HOCAC)
31. Video Recorder – On (MPD / LHG)
32. Weapon Systems – Actioned (HOCAC / RHG)
33. Report Present Position PP (MPD)
    33.1. Radio
        33.1.1. Change Frequency (MPD / UFD)
        33.1.2. Communicate (HOCAC)
34. FCR – scan (HOCAC / LHG / MPD)
    34.1. Transmit targets to team members (MPD)
35. Complete Fuel Check (MPD)
36. Digital Communications:
    36.1. Radio
        36.1.1. Report Fuel Status (MPD / UFD)
        36.1.2. Request PP Query from Team Members (MPD / UFD)
        36.1.3. Communicate (MPD)

**Attack By Fire (ABF) Phase**

37. Report ABF arrival

37.1. Radio
37.1.1. Communicate (MPD / HOCAC)
38. TSD Operations
38.1. No Fire Zone – Draw (MPD / HOCAC)
38.1.1. Transmit to Team Members (MPD / HOCAC / UFD)
39. Radar Jammer – On (MPD)
40. FCR – scan (HOCAC / LHG / MPD)
41. TSD Operations
41.1. Priority Fire Zones – Draw (MPD / HOCAC)
41.1.1. Transmit PFZs to Team Members (MPD)
41.2. Targets
41.2.1. Store Targets (MPD)
41.2.2. Transmit to Team Members (MPD / HOCAC / UFD)
42. Send SALUTE report to higher headquarters (MPD)
42.1.1. Radio
42.1.1.1. Communicate (HOCAC)
43. Weapon Systems
43.1. Select Video Underlay (MPD)
43.2. Select Weapon Sub-Page (MPD)
43.3. Target – Designate with TADS (LHG / MPD)
43.4. Aircraft – Pre-Launch constraints (HDU)
43.5. Fire – Missile / Rocket / Gun (HOCAC / RHG)
43.6. Target – Assess damage (MPD / FLIR / LHG)

## Egress Phase

44. Navigation System (MPD)
44.1. Select Egress Route (MPD)
44.2. Initiate direct steer to route (MPD)
45. Report BDA
45.1. Shot At Files – Transmit to Commander
45.2. FARM Report – Transmit to Commander
46. Radar Jammer – Standby (MPD)
47. Establish Contact with FAARP
47.1. Radio
47.1.1. Communicate (MPD / HOCAC)

## Landing At FAARP Phase

48. Before Landing Check (CL)
48.1. Weapon Systems
48.1.1. Safe (Armament Panel)
48.1.2. Gun / Rocket / Missile - Off (MPD)
48.2. ASE
48.2.1. IR Jammer – Off (MPD)

49. Landing (HDU / FLIR)
50. After Landing Check (CL)
51. Rapid Refueling (CL)
    51.1. Engine Page (MPD)
    51.2. Fuel Page (MPD)
52. Rapid Rearming (CL)
    52.1. Weapon Page (MPD)
    52.2. Aircraft System Page (MPD)

**Table A1.** Mission Task Categorization.

| Task Brief | Sub-Task | MPD Selections | Manual Operation | Sub-Task Type |
|---|---|---|---|---|
| Before Take-Off Check | Power Check | PERF CUR | MPD | Mental Comparison |
| Navigation System | Select Route | TSD RTE RTM Select Route, deselect RTE | MPD | Selection |
| | Select Direct | TSD RTE DIR Select Waypoint, deselect RTE | MPD | Selection |
| | Route Review | TSD RTE | MPD | Selection / Mental Comparison |
| Radio | Change Frequency<br>Coordinate SEAD<br>Report Passage Point<br>Report ABF arrival<br>Establish Contact with FARP<br>Send SALUTE Report | COM SINC RADIO FM1 SINC 1 MODE FH/M ERF SEND FUNCTION EDIT Select Hopset, Enter Net number via KU, deselect ERF SEND, SINC 1 MODE FH, Select HOPSET | MPD, KU | Selection |
| Mission Update | Digital Message | COM MSG REC STORE, Select location CUR MSN 1 MSN 2, or DEL | MPD | Mental Comprehension |
| | Free Text Message | COM MSG REC RVW DEL | MPD, KU | Mental Comprehension |

**Table A1.** Continued.

| Task Brief | Sub-Task | MPD Selections | Manual Operation | Sub-Task Type |
|---|---|---|---|---|
| Digital Communication With Artillery | Free Text Message | COM ATHS INDEX MSGS/FTXT DEST enter in KU, FREE TEXT enter using KU, SEND | MPD, KU | Mental Comprehension |
| Fuel Management | Initiate / Stop Fuel Check | FUEL CHECK, Select time interval, START/ STOP | MPD | Selection |
| | Monitor Fuel Status | FUEL | MPD | Mental Comparison |
| Transponder | Mode change | COM XPNDR MASTER NORM, or, XPNDR XPNDR MASTER NORM | MPD, KU | Selection |
| | IFF | XPNDR REPLY UFD/AUDIO, Deselect MODE 1, 2, 3, & C | MPD | Selection |
| Video Recorder | Select Video Source | VCR, Select Record Source: 6 options, RECORD | MPD | Selection |
| Digital Communications | Send/Receive Present Position (PP) | TSD RPT PP Select, Subscriber, MODE SEND/RQST, Select SEND | MPD | Situational Awareness |

**Table A1.** Continued.

| Task Brief | Sub-Task | MPD Selections | Manual Operation | Sub-Task Type |
|---|---|---|---|---|
| | Send/Receive Fuel Status | TSD RPT FARM, Select Subscriber, MODE SEND, SEND | MPD | Situational Awareness |
| | Send/Receive BDA (Shot At Files) | TSD RPT BDA ALL/OWN, Select Subscriber, SEND | MPD | Selection |
| Aircraft Survivability Equipment (ASE) | IR Jammer | ASE IR JAM OPER | MPD | Selection |
| | Arm/Safe Chaff | ASE CHAFF SAFE/ARM | MPD | Selection |
| | Radar Jammer Mode | TSD JAM or ASE RJAM OPER/STBY | MPD | Selection |
| TSD Operations | Create / Transmit No Fire Zone (NFZ) | TSD ZN, TYPE NF, Select NF#, Select Box/Line, Select corners of NFZ, Select desired Subscriber, XMIT | MPD, HOCAS | Mental Comparison |
| | Create / Transmit Priority Fire Zone | TSD ZN, TYPE PF, Select # of Zones, Select Box/Line, Select corners of PFZ, ASN, Select desired Subscriber, XMIT | MPD, HOCAS | Mental Comparison |

**Table A1.** Continued.

| Task Brief | Sub-Task | MPD Selections | Manual Operation | Sub-Task Type |
|---|---|---|---|---|
| Target Handover | FCR Target Report | TSD RPT TGT ALL/PRI or using Cursor select targets, SEND, deselect RPT | MPD, HOCAS | Mental Comparison |

# APPENDIX B: MODULE TWO DATA

**Table B1.** Task Analysis From Module Two Of Methodology.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 1 | Flight | Display Flight Page | 2 | 2 | No | |
| 2 | | Change Altimeter | 11 | 11 | Yes | |
| 3 | | Change Lobug | 10 | 8 | Yes | 1/2/3/4 Digit Entry |
| 4 | | Change Hibug | 11 | 9 | Yes | 1/2/3/4 Digit Entry |
| 5 | | Select Flight Page Units | 5 | 5 | No | |
| 6 | | G-Reset | 5 | 5 | No | |
| 7 | Engine | Display Engine Page | 3 | 2 | No | Flight/Ground |
| 8 | | Display Systems Status | 4 | 4 | No | |
| 9 | | Acknowledge Warning/Caution | 1 | 1 | No | Autopage has occurred |
| 10 | | Reset WCA | 5 | 5 | No | |
| 11 | | Verify ETF | 4 | 4 | No | |
| 12 | | Change ETF | 9 | 7 | Yes | 1/2/3 Digit Entry |
| 13 | Fuel | Display Fuel Page | 2 | 2 | No | |
| 14 | | Initiate Fuel Check | 6 | 4 | No | 15/20/30 Min. Fuel Check |
| 15 | | Stop Fuel Check | 4 | 4 | No | |
| 16 | | Cross Feed Fuel | 3 | 3 | No | |
| 17 | | Boost | 3 | 3 | No | |
| 18 | | Select Manual Fuel Transfer | 4 | 4 | No | |
| 19 | Engine Utility | Display Utility Page | 2 | 2 | No | |
| 20 | | Change Cockpit Temperature | 6 | 6 | Yes | |
| 21 | | Re-engage ASE Channels | 6 | 3 | No | Pitch/Roll/Yaw/Collective |
| 22 | | Select NOE/Approach | 3 | 3 | No | |

## Table B1. Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 23 | | Turn On/Off Pitot Heat | 3 | 3 | No | |
| 24 | | Turn On/Off Inlet Anti-Ice | 3 | 3 | No | |
| 25 | | Select Anti-Ice Mode | 3 | 3 | No | |
| 26 | | View Cockpit Temperature | 2 | 2 | No | |
| 27 | Performance | Display Perf Page | 3 | 2 | No | Current/Max/Plan |
| 28 | | View Aircraft Weight | 4 | 3 | No | Select Perf Mode to Current |
| 29 | Communications | Display Comm | 2 | 2 | No | |
| 30 | | Change Manual Frequency | 13 | 12 | Yes | 6/7 Digit Entry |
| 31 | | Select Transponder Status | 3 | 3 | No | |
| 32 | | View Team/Zone Members in Net | 4 | 4 | No | |
| 33 | | SelectTeam/Zone Members | 6 | 5 | No | Select Team/Zone Member |
| 34 | | Add Digital Net | 14 | 14 | Yes | Enter Only Unit ID |
| 35 | | Add Entire Digital Net Info | 49 | 22 | Yes | Enter Max Allowable Entry for Each Field |
| 36 | | Tune VHF/UHF to Guard | 4 | 4 | No | |
| 37 | | Add Team/Zone Member | 15 | 15 | Yes | |
| 38 | Message Rec'd | View Free Text Message | 5 | 5 | No | |
| 39 | | View and Store IDM Message | 6 | 5 | No | Select Location |
| 40 | Free Text | Compose Free Text Message | 5+ | 5+ | Yes | Min. number of steps w/o entry |
| 41 | Comm Utility | Select Radio Mode (Cipher,Plain,Rcv) | 5 | 5 | No | |
| 42 | | Select Radio Mode (SC,FH,FH/M) | 5 | 5 | No | |
| 43 | | Select FM1 IFM Status | 5 | 5 | No | |
| 44 | | Select CNV for Radio (UHF,FM1,FM2) | 6 | 6 | Yes | |

**Table B1.** Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 45 | | Change SOI Day | 4 | 4 | No | |
| 46 | | Select Fallback Mode | 5 | 5 | No | |
| 47 | | Enable UHF Guard Receiver | 4 | 4 | No | |
| 48 | | Change VHF/UHF Bandwidth | 4 | 4 | No | |
| 49 | | Select VHF/UHF Tone | 4 | 4 | No | |
| 50 | Transponder | Change Mode 3/A Code | 8 | 8 | Yes | |
| 51 | | Change Mode 1 Code | 6 | 6 | Yes | |
| 52 | | Select Reply Mode | 4 | 4 | No | |
| 53 | | Select Mode 1,2,3/A,C | 3 | 3 | No | |
| 54 | | Select Antenna Position | 4 | 4 | No | |
| 55 | | Squawk Ident | 3 | 3 | No | |
| 56 | | Transponder Mode (STBY,NORM) | 3 | 3 | No | |
| 57 | Have Quick 2 | Change HQ2 Net | 10 | 6 | Yes | 2/3/4/5/6 Digit Entry |
| 58 | | Select HQ2 Receive Mode | 5 | 3 | No | Return Radio to Single Channel |
| 59 | | Time HQ2 Radio | 7 | 3 | No | Return Radio to Single Channel |
| 60 | | Send TOD | 7 | 3 | No | Return Radio to Single Channel |
| 61 | | Emergency Time HQ2 | 7 | 3 | No | Return Radio to Single Channel |
| 62 | | Change Calendar Day | 6 | 5 | Yes | 1/2 Digit Entry |
| 63 | | Select WOD | 7 | 6 | Yes | 1/2 Digit Entry |
| 64 | | Display WOD | 9 | 3 | No | Page for Previous/Next WOD |
| 65 | | Manually Enter WOD | 62 | 58 | Yes | Rename WOD |
| 66 | | Display TSET | 4 | 4 | No | |

## Table B1. Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 67 | | Manually Enter TSET | 148 | 148 | Yes | |
| 68 | | Change Training Net | 10 | 6 | Yes | 2/3/4/5/6 Digit Entry |
| 69 | SINC | Change Manual/Cue Freq | 10 | 7 | Yes | 3/4/5/6 Digit Entry |
| 70 | | Tune Manual/Cue Freq | 3 | 3 | No | |
| 71 | | GPS Time Radio | 6 | 3 | No | Select Radio/Change Mode |
| 72 | | View FM Time | 3 | 3 | No | |
| 73 | | Manually Enter FM Date/Time | 10 | 10 | Yes | |
| 74 | | Select FM1/FM2 | 3 | 3 | No | |
| 75 | | Select Sinc Mode | 5 | 4 | No | Select Radio (FM1/FM2) |
| 76 | | Select Hopset | 5 | 4 | No | Select Radio (FM1/FM2) |
| 77 | | Change Hopset Preset | 18 | 17 | Yes | Select Radio (FM1/FM2) |
| 78 | | Select Late Net Entry | 4 | 3 | No | Select Radio (FM1/FM2) |
| 79 | | Copy Hopset | 13 | 12 | No | Select Radio (FM1/FM2) |
| 80 | | ERF Send | 10 | 9 | No | Select Radio (FM1/FM2) |
| 81 | | ERF Receive | 12 | 11 | No | Select Radio (FM1/FM2) |
| 82 | SOI | Authenticate | 3 | 3 | No | |
| 83 | | Reply to Authentication | 6 | 6 | Yes | |
| 84 | | Initiate Transmission Authentication | 3 | 3 | No | |
| 85 | | Validate Transmission Authentication | 6 | 6 | Yes | |
| 86 | | Search UHF Freq | 11 | 8 | Yes | 4/5/6/7 Digit Entry |
| 87 | | Display Expander | 3 | 3 | No | |
| 88 | Message Send | Send Current Mission | 8 | 5 | No | Select All Routes. Team Members Previously Selected |

## Table B1. Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 89 | | Send Mission 1,2,IDM/SOI | 4 | 4 | No | Team Members Previously Selected & Up Digital Net |
| 90 | VCR | Display VCR Page | 2 | 2 | No | |
| 91 | | Start Recording | 4 | 3 | No | Select Record Source |
| 92 | | Select Tape Length | 3 | 3 | No | |
| 93 | | Select Record Mode | 3 | 3 | No | |
| 94 | Video | Display Video Page | 2 | 2 | No | |
| 95 | | Select Video Underlay | 4 | 4 | No | |
| 96 | | Zoom Video Underlay | 5 | 5 | No | |
| 97 | | Select Wide/Norm View Underlay | 5 | 5 | No | |
| 98 | ADF | Display ADF | 2 | 2 | No | |
| 99 | | Manually Tune Preset ADF | 5 | 5 | No | |
| 100 | | ID NDB | 4 | 4 | No | |
| 101 | | Test NDB | 3 | 3 | No | |
| 102 | | Manually Tune ADF | 7 | 7 | Yes | |
| 103 | | Set Heading Bug | 7 | 7 | Yes | |
| 104 | | Select Last Freq ADF | 3 | 3 | No | |
| 105 | | Center ADF Page | 3 | 3 | No | |
| 106 | | Change Scale of ADF Page | 4 | 4 | No | |
| 107 | | Select Zoom | 3 | 3 | No | |
| 108 | | Start/Stop Timer | 3 | 3 | No | |
| 109 | | Enter ADF Preset | 16 | 16 | Yes | |
| 110 | ASE | Display ASE Page | 2 | 2 | No | |

## Table B1. Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 111 | | Select ASE Auto Page | 3 | 3 | No | |
| 112 | | Select Radar Jam Mode | 3 | 3 | No | |
| 113 | | Arm Chaff Dispenser | 3 | 3 | No | |
| 114 | | Select Chaff Mode | 3 | 3 | No | |
| 115 | | Select RLWR Voice Mode | 4 | 4 | No | |
| 116 | | Select RFI Mode | 4 | 4 | No | |
| 117 | | Select RFI Train Mode | 4 | 4 | No | |
| 118 | TSD | Display TSD Page | 2 | 2 | No | |
| 119 | | Display TSD Utility Page | 3 | 3 | No | |
| 120 | | Select ASE Auto Page | 5 | 5 | No | |
| 121 | | Select Local/Zulu Time | 4 | 4 | No | |
| 122 | | Display Show Page | 3 | 3 | No | |
| 123 | | Select Show Page Options | 17 | 10 | No | Select All Options Including Default |
| 124 | | Change Scale of TSD Page | 4 | 4 | No | |
| 125 | | Center TSD Page | 3 | 3 | No | |
| 126 | | Select Zoom | 3 | 3 | No | |
| 127 | | Select Acquisition Source | 4 | 4 | No | |
| 128 | | Active Cursor Acquisition (CAQ) | 4 | 4 | Yes | Cursor Control Required |
| 129 | | Add/Edit Waypoint | 32 | 9 | Yes | Enter Ident, Free Text, Altitude |
| 130 | | Delete Waypoint | 8 | 4 | Yes | Select Waypoint |
| 131 | | Store Waypoint | 5 | 5 | No | |
| 132 | | Transmit Waypoint | 10 | 5 | Yes | Select Waypoint |

**Table B1.** Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 133 | | View Waypoint/Threat Abbreviations | 12 | 4 | No | View All Abbreviations Pages |
| 134 | | Add/Edit Threat | 31 | 9 | Yes | Enter Ident, Free Text, Altitude |
| 135 | | Delete Threat | 8 | 4 | Yes | Select Threat |
| 136 | | Store Threat | 5 | 5 | No | |
| 137 | | Transmit Threat | 10 | 5 | Yes | Select Threat |
| 138 | | Add Point to Route | 10 | 10 | Yes | |
| 139 | | Delete Point from Route | 5 | 5 | No | |
| 140 | | Select Route Review | 7 | 5 | No | Select Waypoint from Grouped Option |
| 141 | | Select Waypoint to Fly Direct | 8 | 4 | Yes | Select Waypoint from Grouped Option |
| 142 | | Select Current Route | 6 | 5 | No | Select Page for Route |
| 143 | | Reverse Current Route | 5 | 5 | No | |
| 144 | | Draw Priority Fire Zone | 13 | 5 | No | Cursor Control Required, Varies with Defaults |
| 145 | | Draw No Fire Zone | 8 | 3 | No | Cursor Control Required, Varies with Defaults |
| 146 | | Send BDA Report | 7 | 6 | No | Send Ownship or All BDA |
| 147 | | Send Target Report | 7 | 6 | No | Send All or Priority Targets |
| 148 | | Send Present Position Report | 13 | 4 | No | Number of Zone Members |
| 149 | | Send FARM Report | 13 | 4 | No | Number of Zone Members |
| 150 | | Select Reply Mode | 4 | 4 | No | |
| 151 | | Select PAN Mode | 8 | 4 | Yes | Use Cursor or KU Entry |
| 152 | | PAN Up Route | 27 | 4 | No | Number of Waypoints |
| 153 | | Select Last PAN | 4 | 4 | No | |
| 154 | | Select Present Position Display | 3 | 3 | No | |

**Table B1.** Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 155 | | View Threat File | 13 | 3 | No | Number of Targets in Threat File |
| 156 | | View Waypoint File | 14 | 4 | No | Number of Waypoints in Waypoint File |
| 157 | | View Line File | 8 | 4 | No | Number of Line Pages |
| 158 | | View Area File | 7 | 4 | No | Number of Area Pages |
| 159 | | View Shot-At File | 19 | 4 | No | Number of Shot-At Pages |
| 160 | | View FARM Report | 5 | 4 | No | Select FARM Type |
| 161 | Weapon | Display Weapons Page | 2 | 2 | No | |
| 162 | | View Gun/Missile/Rocket Page | 3 | 3 | No | |
| 163 | | Select Boresight Mode | 5 | 5 | No | |
| 164 | | Select Grayscale | 4 | 4 | No | |
| 165 | | Select Train Mode | 3 | 3 | No | |
| 166 | | Select Missile Channel/Code | 5 | 4 | No | Select Appropriate Channel |
| 167 | | Select LRFD/LST Code | 4 | 4 | No | |
| 168 | | Change LRFD Frequency | 10 | 10 | Yes | |
| 169 | | Input Manual Range | 8 | 7 | Yes | 3/4 Digit Entry |
| 170 | | Select Acquisition Source | 4 | 4 | No | |
| 171 | | Select Gun Burst Limit | 4 | 4 | No | |
| 172 | | Select Gun Mode | 4 | 4 | No | |
| 173 | | Select Missile Type | 4 | 4 | No | |
| 174 | | Select Missile Mode | 5 | 5 | No | |
| 175 | | Select Missile Trajectory | 5 | 5 | No | |
| 176 | | Select Priority/Alternate Missile Channel | 5 | 5 | No | |

**Table B1.** Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 177 | | Select RF Missile LOBL Inhibit | 4 | 4 | No | |
| 178 | | Select 2nd Target Inhibit | 4 | 4 | No | |
| 179 | | Launch Remote Hellfire Missile | 24 | 14 | No | Number of Threat Pages |
| 180 | | Select Rocket Inventory | 4 | 4 | No | |
| 181 | | Select Penetration Level | 5 | 5 | No | |
| 182 | | Select Rocket Quantity | 5 | 5 | No | |
| 183 | | Select Rocket Zone Type | 6 | 6 | No | |
| 184 | | Input Gun Rounds Count | 10 | 7 | Yes | 1/2/3/4 Digit Entry |
| 185 | | Select Pylon Ground Stow | 4 | 4 | No | |
| 186 | | Select TADS Stow | 4 | 4 | No | |
| 187 | | Select/Deselect Cueing | 4 | 4 | No | |
| 188 | FCR | Display FCR Page | 2 | 2 | No | |
| 189 | | Select C Scope Mode | 3 | 3 | No | |
| 190 | | Select Manual Antenna Elevation | 4 | 4 | No | |
| 191 | | Select Auto Antenna Elevation | 4 | 4 | No | |
| 192 | | Store FCR Targets | 4 | 4 | No | Cursor Control Required for Selected FCR Targets |
| 193 | | Select Next-to-Shoot | 18 | 3 | No | 1-16 FCR Targets |
| 194 | | Send RFHO | 5 | 5 | No | |
| 195 | | Select FCR Zoom | 5 | 5 | No | |
| 196 | | Select FCR TPM Profile Mode | 4 | 4 | No | |
| 197 | | Select TPM Number of Lines | 4 | 4 | No | |
| 198 | | Select TPM Clearance Plane | 4 | 4 | No | |

**Table B1.** Continued.

| | Page | Task | Max. # of Steps | Min. # of Steps | KU | Comments |
|---|---|---|---|---|---|---|
| 199 | | Select FCR TPM Elevation | 3 | 3 | No | |
| 200 | | Select FCR Terrain Sensitivity | 5 | 5 | No | |
| 201 | | Select RFI Mode | 4 | 4 | No | |
| 202 | | Select Priority Scheme | 5 | 5 | No | |
| 203 | | Slew FCR in Azimuth | 3 | 3 | No | |
| 204 | DMS | Display DMS Page | 2 | 2 | No | |
| 205 | | View Active Faults | 3 | 3 | No | |
| 206 | | View Exceedence File | 4 | 4 | No | |
| 207 | | View Warnings/Cautions/Advisories | 6 | 3 | No | 1-5 Pages of WCA |
| 208 | | Select Master Load | 5 | 5 | No | |
| 209 | | Upload Mission 1 Data | 10 | 6 | Yes | Load All or Part of Mission 1 Data |
| 210 | | Upload Communications Data | 6 | 6 | No | |
| 211 | | Select IBIT | 6 | 6 | No | |
| 212 | | View Software Versions | 3 | 3 | No | |
| 213 | | View ECS Temperatures | 5 | 5 | No | |
| 214 | | View Boresight Data | 11 | 7 | No | Number of Boresight Pages |

# APPENDIX C: PILOT QUESTIONNAIRE

## PILOT QUESTIONNAIRE[2]

THE ROLE OF DIRECT VOICE INPUT (DVI) IN THE AH-64D LONGBOW

This questionnaire is designed to provide you with an opportunity to contribute your ideas and opinions about how voice recognition technology might be implemented in the AH-64D. As you know, flying nap-of-earth requires the pilot to remain "eyes-out" and "hands-on" the controls. Consequently, many cockpit tasks are deferred or delegated to the non-flying pilot to perform, decreasing crew effectiveness.

Voice recognition technology has undergone extensive research and development over the past twenty years. Recent work has involved using Artificial Neural Network (ANN) algorithms to pattern match voice inputs in a noisy environment. Studies using ANN have shown that recognition rates in noisy environments can be better than that of the human ear.

Direct Voice Input (DVI) would use the latest voice recognition technology to permit the pilot to speak to the aircraft to perform tasks, request information, and display MPD pages. The system would recognize your voice and feedback would be given, either visually or aurally, for the pilot to confirm the command. An example of this exchange is provided below. Although the system would perform certain tasks, the silent method of pushing MPD bezel buttons would always have priority.

<u>For example:</u>

| | |
|---|---|
| Pilot: | *"Put the TSD page on the right display."* or *"TSD on right"* |
| Computer: | temporary UFD text display "TSD Right" and an audio icon "*Clink-Clink*" |
| Computer: | Changes right display to the TSD page. |

Flight tests in a Bell 412 helicopter using DVI to control avionics have shown the potential effectiveness of DVI in reducing workload and improving situational awareness. Recognition rates using six different pilots averaged 95%. Currently, the Eurofighter Typhoon multi-role fighter is being produced using DVI technology to perform over 26 cockpit functions. It remains to be seen if this technology could be useful in the noisy environment of the Apache Longbow. DVI technology, among many others, is being considered for potential upgrades to the Apache Longbow Block III. Your inputs from this questionnaire will be made available for that process.

This questionnaire asks you to evaluate certain tasks with respect to their potential desirability of having speech recognition perform these tasks. Your input is important. The goal is to determine what types of tasks would be best suited for DVI. When you evaluate each task keep in mind not only the amount of time required to perform the task, but also the phase of flight (Nighttime, NOE, IGE Hover) and the urgency to complete the task.

---

[2] Questionnaire format adapted from Kersteen, Z. A., & Damos, D. (1984). *Human Factors Issues Associated with the Use of Speech Technology in the Cockpit* (NASA CR-166548). Moffett Field, CA: Ames Research Center. (DTIC AD-A213 127)

The personal data on this sheet is for data analysis only. No comments or answers will be associated with your name or traced back to you.

**Name** (optional)

**Organization** (optional)

**Date** **Age**

**Number of years of military experience:** _____

**Position(s):** Pilot ☐ PIC ☐ UT☐ IP ☐ IFE ☐ SIP ☐ MTP ☐ ME ☐ XP ☐

**Aircraft Flown**: AH-64D ☐ AH-64A ☐ AH-1☐ OH-58D☐ AH-6/MH-6 ☐

OH-58A/C (TH-67) ☐ CH-47/MH-47 ☐ UH-60/MH-60 ☐ Fixed Wing ☐ Other ☐

**Flight Hours in the AH-64D**

**Flight Hours in the AH-64A**

Have you ever used a Voice Recognition device on a (cell phone, home PC, etc.)? _____

Have you ever flown an aircraft that used Voice Recognition? _____

A voice command could be used to perform the following tasks. Please rate how desirable it would be to have DVI to perform each task.

Computer users select your choice from the drop down menu.

**FLIGHT**

1) Change the Altimeter setting. Ex. Pilot: "*Altimeter 29.98*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

2) Change the LO/HI Bug setting. Ex. Pilot: "*Low Bug 50 feet*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

**ENGINE**

3) Change the cockpit temperature. Ex. Pilot: "C*ockpit temperature 65*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

4) Acknowledge Warning after an ENGINE auto-page. Ex. Pilot: "*Acknowledge warning*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

5) Acknowledge Caution after a UFD message. Ex. Pilot: "*Acknowledge caution*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

6) Acknowledge Advisory after a UFD message. Ex. Pilot: "*Acknowledge advisory*"

______________________

1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable

7) Engage FMC channels. Ex. Pilot: *"Engage FMC channels"*

______________________

1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable

8) Display Engine Systems ENG SYS page. Ex. Pilot: *"Engine systems page on right"*

______________________

1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable

**FUEL**

9) Start/Stop Fuel Check. Ex. Pilot: *"Start Fuel Check"*

______________________

1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable

10) Select manual fuel transfer. Ex. Pilot: *"Transfer forward"*

______________________

1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable

**COMMUNICATIONS**

11) Change a manual frequency (VHF/UHF/FM). Ex. Pilot: *"Tune VHF radio 118.8"*

______________________

1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable

12) Select Transponder status (NORM/STBY). Ex. Pilot: *"Transponder normal"*

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

13) Change the transponder code. Ex. Pilot: *"Squawk Code 1200"*

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

14) View Free Text message. Pilot: *"View Free Text"*, Computer displays on MPD: *"Move to ABF 21"*

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

15) Listen to Free Text message. Ex. Pilot: *"Listen Free Text"*, Computer: *"Move to ABF 21"*

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

16) Compose Free Text message. Pilot: *"Compose Free Text <u>rally at Waypoint 10"</u>*, (Voice recognition software may have a limited vocabulary)

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

17) Select Radio Mode (SC, FH, and FH/M). Ex. Pilot: *"FM1 Single Channel"*

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

18) Select Radio Mode (Cipher/Plain). Ex. Pilot: "*FM1 Cipher mode*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

19) Select FM Hopsets that are preset Ex. Pilot: "*FM1 Freq. Hop Net 742*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

20) Edit FM Hopsets that are not preset. Ex. Pilot: " *Tune FM1 Freq. Hop Net 330 Secure*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

21) Transmit a Call For Fire. Ex. Pilot: "*Transmit Fire Mission Target 5*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

22) Perform authentication. Ex. Pilot: "*Authenticate Whiskey Bravo*" Computer: "*Reply Delta for Whiskey Bravo*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

**VIDEO CONTROL**

23) Select a video underlay. Ex. Pilot: "*Underlay TADS*"

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

24) Select Zoom/Norm/Wide of video underlay. Ex. Pilot: "*Zoom Underlay*"

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

**TACTICAL SITUATION DISPLAY**

25) Change the scale of the TSD Page. Ex. Pilot: "*Zoom In/Out TSD Page*"

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

26) Center/De-center the TSD Page. Ex. Pilot: "*Center ownship*"

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

27) Change the current route. Ex. Pilot: "*Select route Bravo*"

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

28) Select Reverse Route from the Route Menu. Ex. Pilot: "*Reverse current route*"

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

29) Select a waypoint to fly direct to. Ex. Pilot: "*Fly direct Waypoint 12*"

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

30) Perform a waypoint store on the fly. Ex. Pilot: *"Waypoint store now"*

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

31) Store a target in the threat file. Ex. Pilot: *"Target store SA13 grid NV 2350 5450"*

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

32) Change the Show page options. Ex. Pilot: *"Show/Remove all enemy/friendly"*

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

33) Select Route Review for a waypoint. Ex. Pilot: *"Route Review Passage Point 12"*

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

34) Select PAN options. Ex. Pilot: *"PAN up (or down) route"*

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

35) Send Reports (PP/FARM/BDA/TGT). Ex. Pilot: *"Send PP report"*

______________________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

**FIRE CONTROL RADAR**

36) Store FCR targets. Ex. Pilot: *"Store Priority FCR Targets"*

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

37) Transmit RFHO to a zone member. Ex. Pilot: *"Transmit RFHO to L52"*

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

**WEAPONS**

38) Select Burst Limit on the 30mm. Ex. Pilot: *"Set Gun Burst Limit to ALL"*

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

39) Input manual range value on the Weapon page. Ex. Pilot: *"Manual Range 900"*

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

40) Select Missile trajectory (DIR/LO/HIGH). Ex. Pilot: *"Select Low Trajectory"*

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

41) Select Rocket type (Multi-Purpose/ Point Detonating). Ex. Pilot: *"Select PD's"*

____________________

| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |
|---|---|---|---|---|

42) Select Rocket Quantity. Ex. Pilot: *"Select Pairs for Rockets"*

______________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

**GENERAL**

43) Change MPD displays. Ex. Pilot: *"Engine page on right"*

______________

| | | | | |
|---|---|---|---|---|
| 1 Extremely Desirable | 2 Somewhat Desirable | 3 Not Sure | 4 Somewhat Undesirable | 5 Extremely Undesirable |

44) If you used voice to change MPD displays, list which pages you would find most useful for a voice command (see MPD hierarchy on the last page for reference). Example: ACFT SYS, WPN MSL, COM SINC, etc.

45) Rate each MPD page on order of importance (High, Medium, or Low)

FLT _____ ENG _____ Fuel _____ Perf _____ DMS _____

ASE _____ WPN _____ TSD _____ FCR _____

SOI _____ SINC _____ HQ2 _____ XPNDR _____

ADF _____ VIDEO _____ VCR _____MSG SEND _____

46) The following items are general areas of tasks for which a voice command might be used to perform. Rank the desirability of performing these tasks using DVI with (1) being the most desirable. If you feel two general areas are of equal importance, you may assign them the same value. Ex. 1, 2, 2, 4, 4, 6, 7, 7, 9

Flight ____ Engine ___ Fuel ____ Communications ____ Video ____

TSD ____ FCR ____ Weapons ____ Other ____ (write in)

47) Write in any additional tasks that you feel a voice command would be useful for.

48) If voice commands were used in the Apache, there are a number of ways in which the system could be activated. Please rank the following methods from one (1) to three (3) with one meaning the most desirable.

___ Push-to-Recognize button on the cyclic

___ Have the voice system actively listening for your commands all the time.

___ Say a 'keyword' to active the system to begin recognition of a command.

☐ No Opinion (check box)

49) Comments: Please comment on the use and integration of DVI technology in the Apache Longbow.

## MPD PAGE HIERARCHY

Adapted from Boeing (1998a).

1. MISSION selections.
    1.1. ASE Page / UTIL
    1.2. TSD Page / UTIL / SHOW / WPT / THRT / RTE / ZN / RPT / RTM / ABR
    1.3. WPN Page / UTIL / MSL / RKT / GUN / LOAD / CODE / CHAN
    1.4. FCR Page / UTIL
2. AIRCRAFT selections.
    2.1. ENG Page / ENG SYS / WCA
    2.2. FLT Page / FLT SET
    2.3. FUEL Page
    2.4. PERF Page (CUR/MAX/PLAN)
    2.5. UTIL Page
3. Communication selections.
    3.1. SOI Page / EXPND
    3.2. Single Channel Ground & Airborne Radio (SINC) Page / ERF / ERF REC / ERF SEND
    3.3. HAVE QUICK (HQ2 or HQ1) Page / SEG / TSET
    3.4. XPNDR Page
    3.5. Utility (UTIL) Page / FALLBACK
    3.6. COM Page / ATHS / MAN / NET (SUFFIX, MODEM, EDIT)
4. ADF Page / ADF UTIL
5. VIDEO page (VSEL).
6. Videocassette Recorder (VCR) Page
7. Checklist (CL) Page
8. Maintenance Test Flight (MTF) Page
9. Message Send (MSG SEND) Page / CURRENT MISSION / MSG REC / FREE TEXT
10. DMS Page / UTIL / DTU / FAULT (ACT, HST, EXC, LRU) / IBIT / VERS / WCA

# APPENDIX D: BEDFORD SCALE

## BEDFORD SCALE

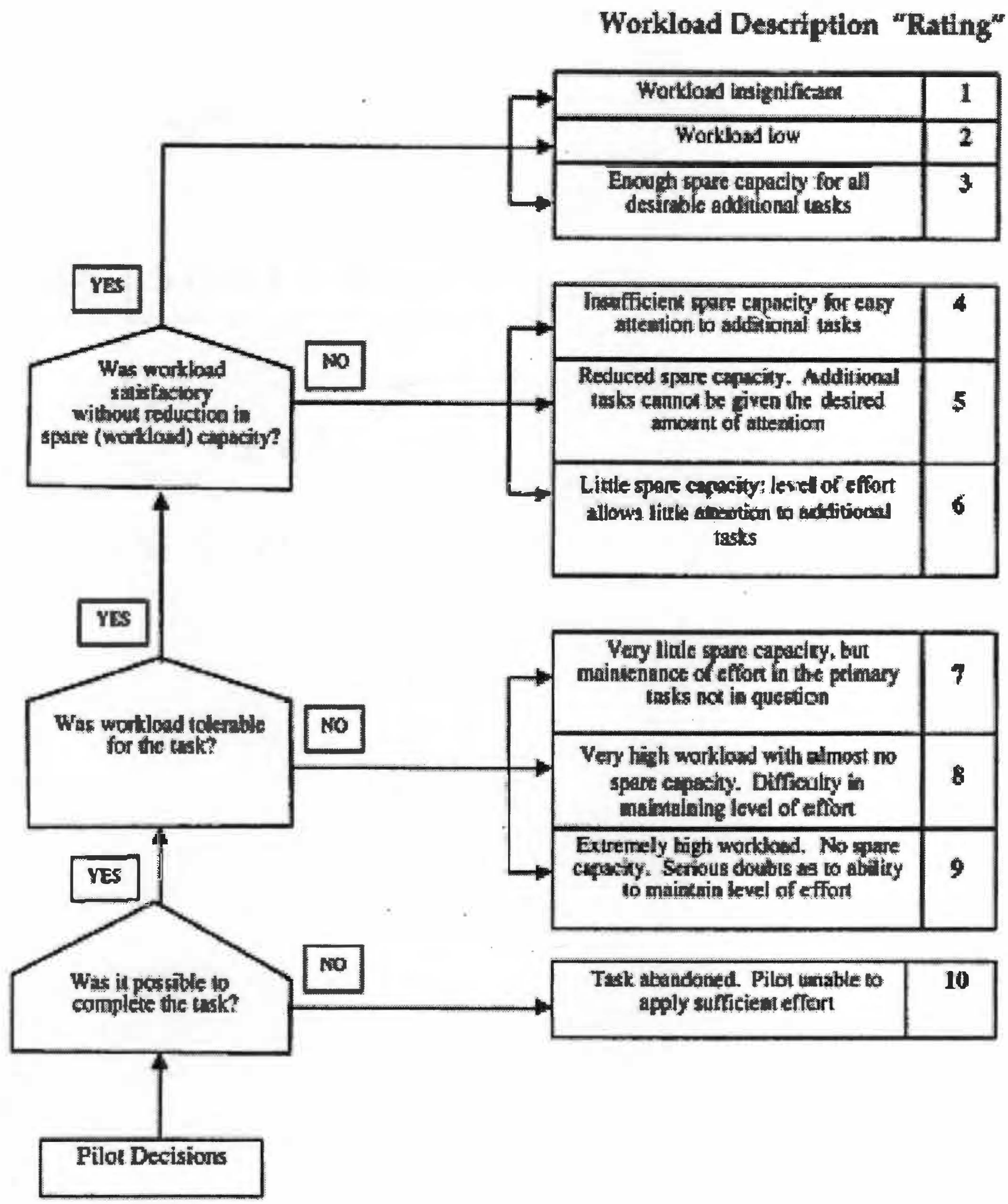



**Figure D1.** The Bedford Scale developed by Roscoe and Ellis at the Royal Aircraft Establishment in Bedford, England.

Source: Durbin, D. B. (2001). *Assessment of Crew Workload for the RAH-66 Comanche Force Development Experiment 1* (ARL-TN-183). Aberdeen Proving Ground, MD: Army Research Laboratory, p. 25.

# APPENDIX E. SLALOM COURSE

## SLALOM COURSE

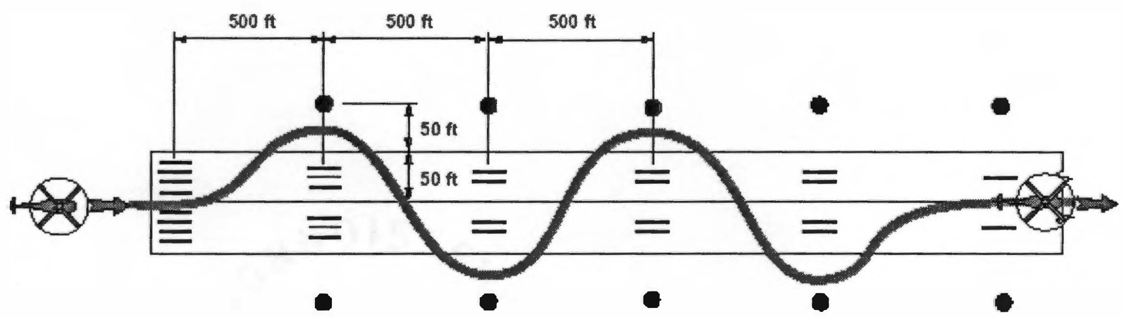



**Figure E1.** Slalom Course.

Source: Military Standard. (2001). *Aeronautical Design Standard Performance Specification Handling Qualities Requirements for Military Rotorcraft* (ADS-33-E-PRF). Redstone Arsenal, AL: U.S. Army Aviation and Missile Command, Aviation Engineering Directorate, (p. 90.).

# APPENDIX F: SIMULATOR DATA

# SIMULATOR DATA

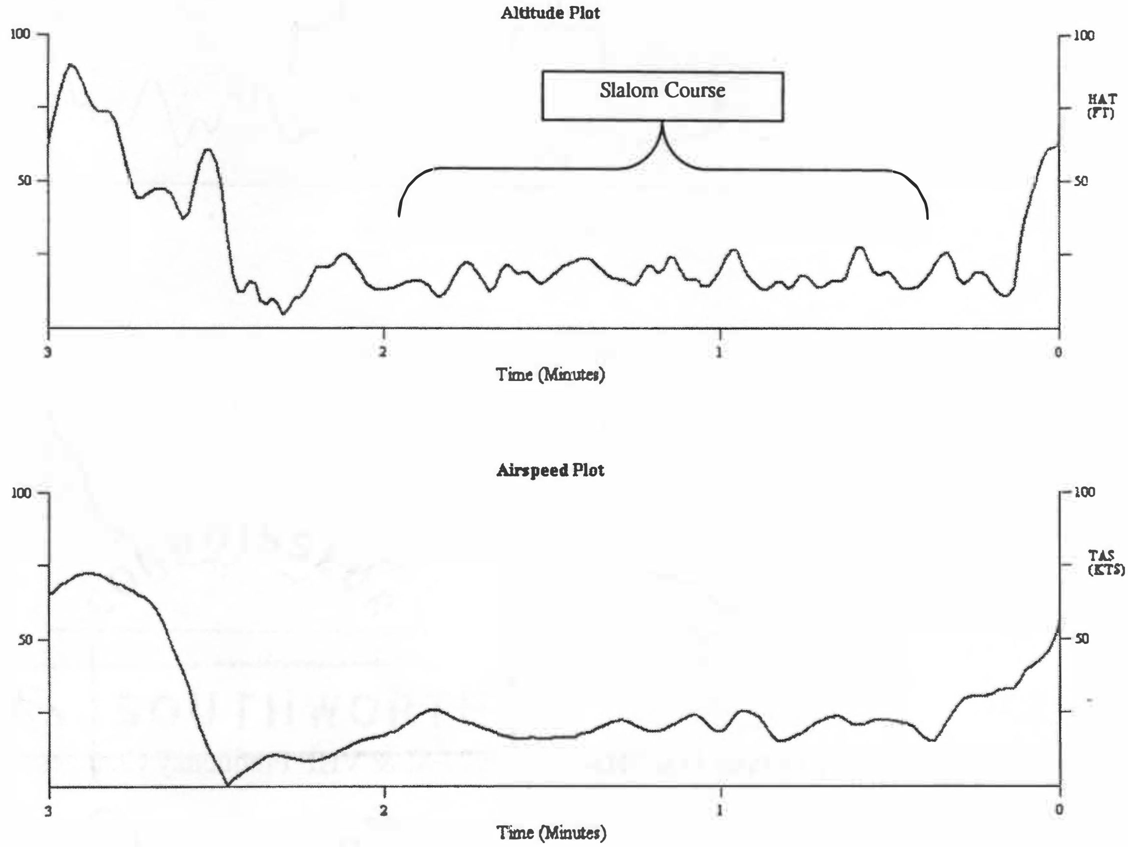



**Figure F1.** Subject Pilot One Slalom Course Baseline.

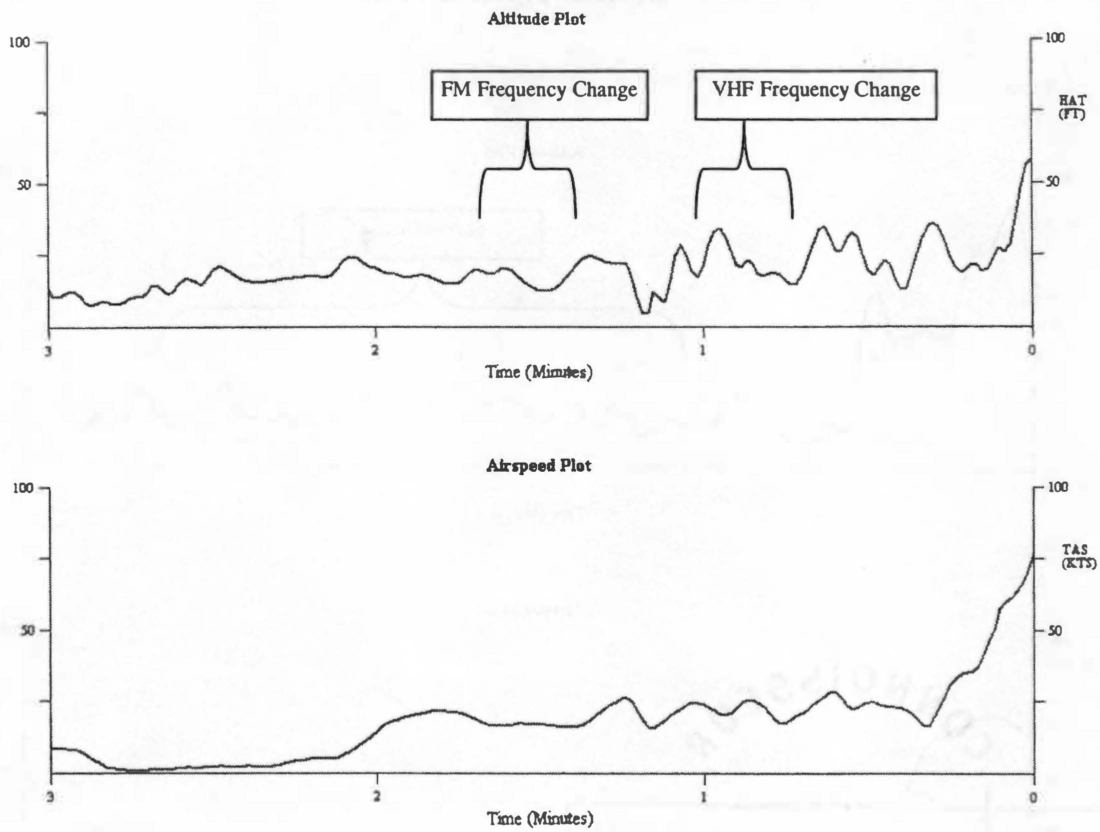



**Figure F2.** Subject Pilot One "Hands Busy" FM & VHF Frequency Changes.

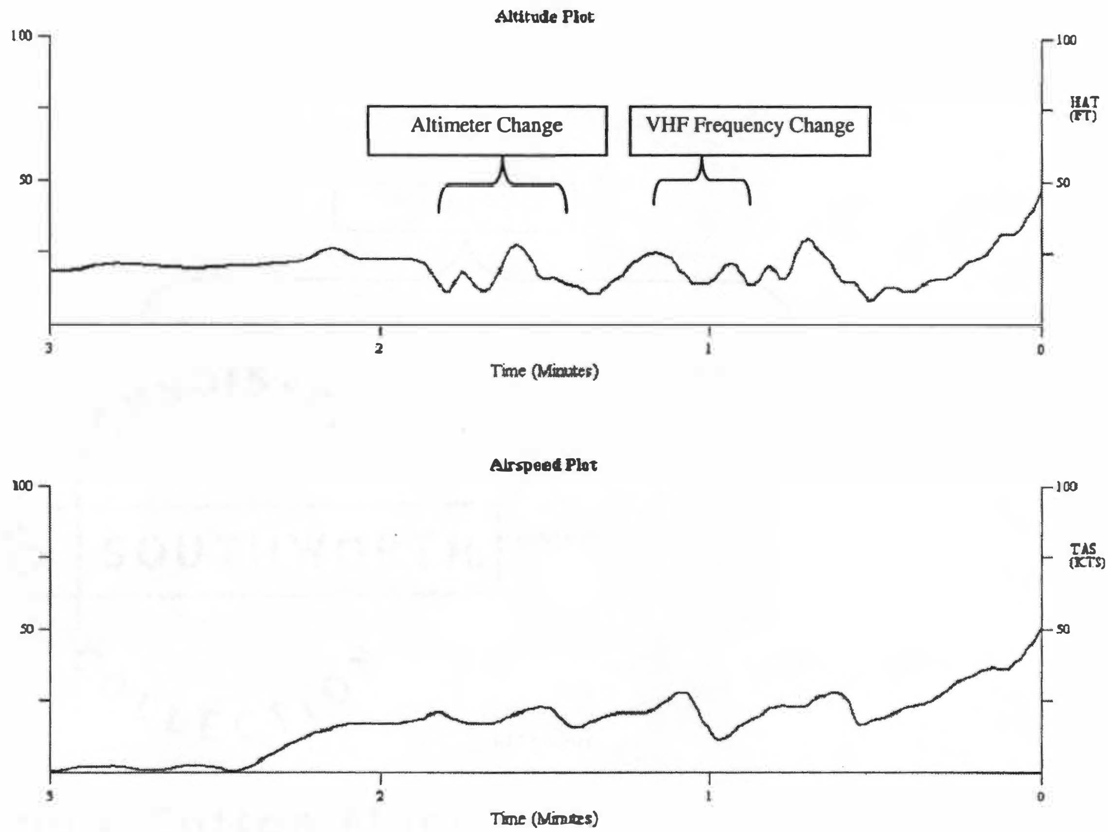



**Figure F3.** Subject Pilot One Using Voice Input.

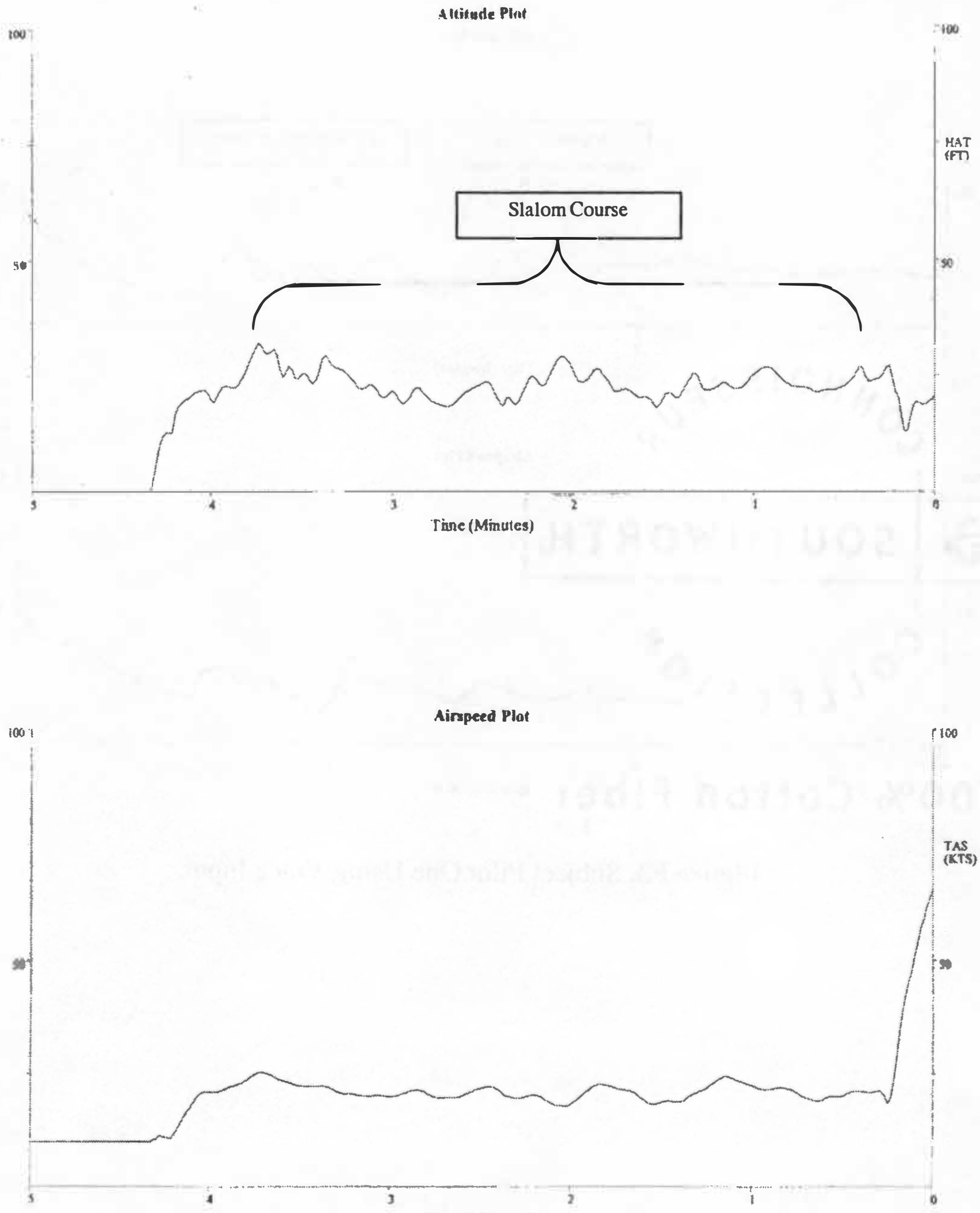
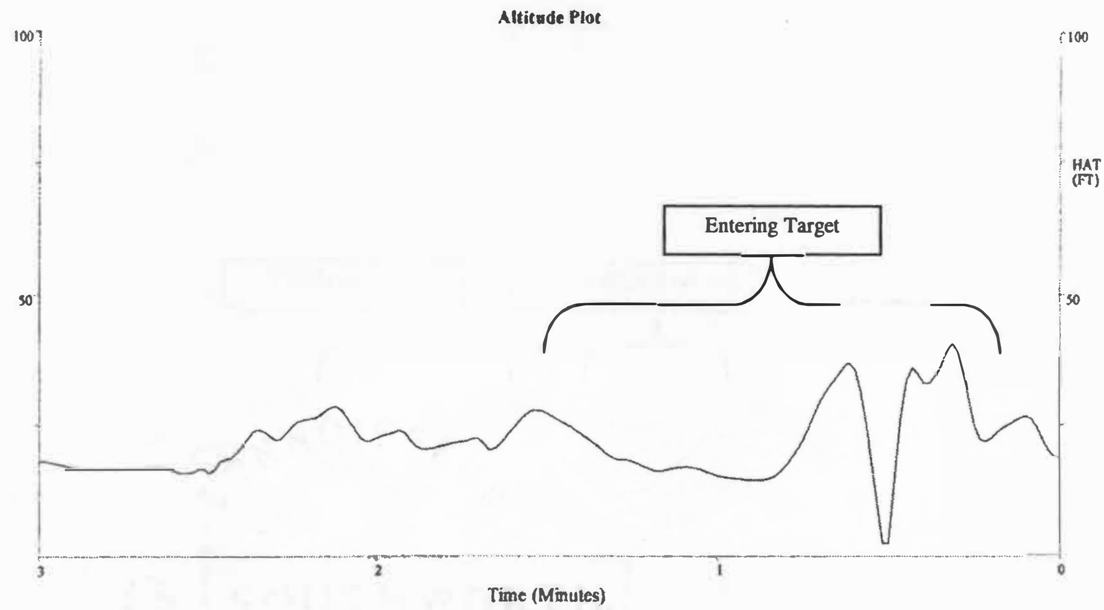



**Figure F4.** Subject Pilot Two Slalom Course Baseline.



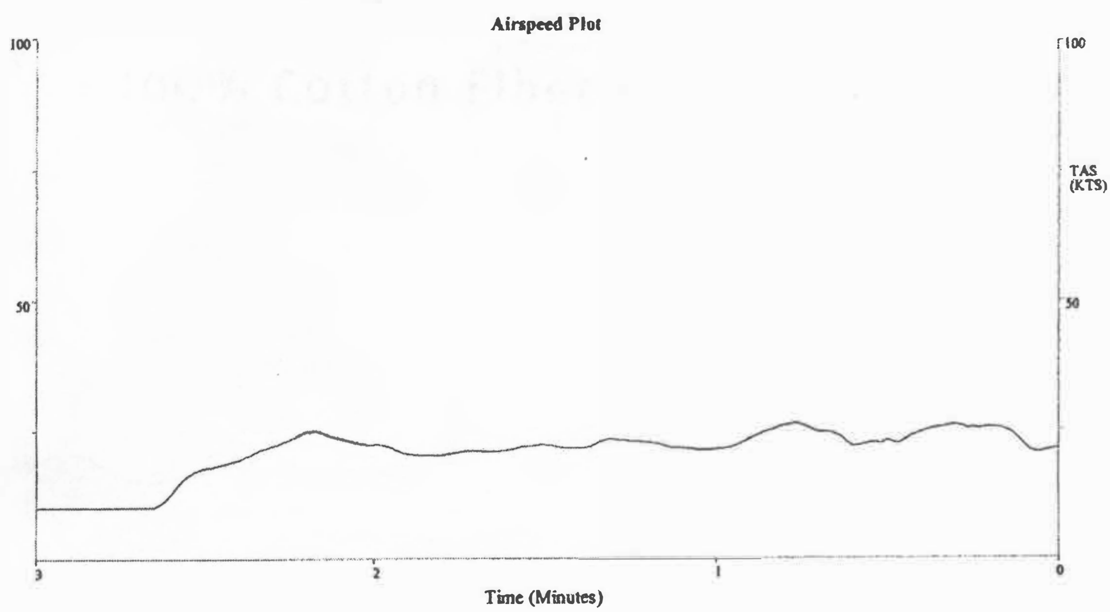
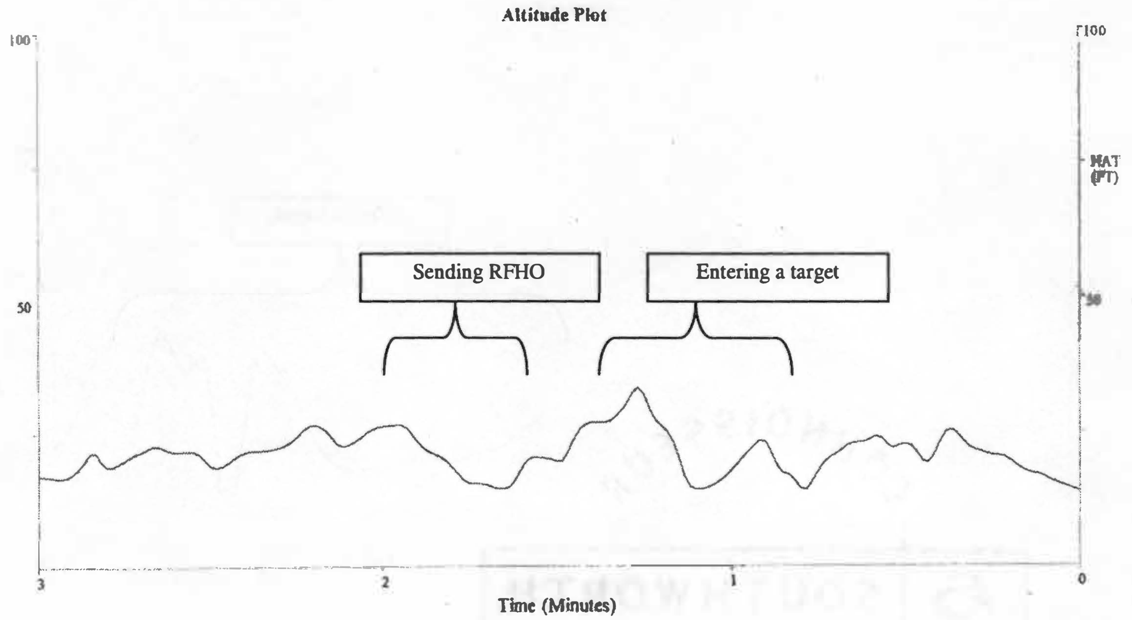




**Figure F5.** Subject Pilot Two "Hand Busy" Entering A Target.



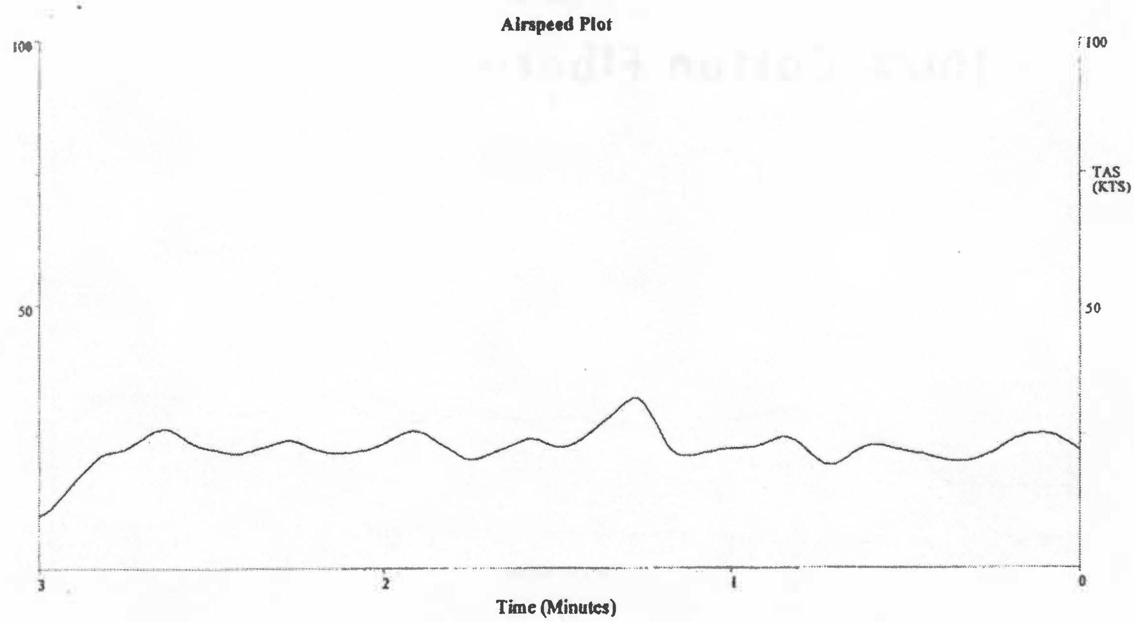




**Figure F6.** Subject Pilot Two Using Voice Input.

# VITA

Donald J. Hunter was born in Akron, Ohio, on June 20$^{th}$, 1970. He graduated from Newberry Jr. /Sr. High School in Newberry, Florida. In July of 1988, he entered the U.S. Army to attend Warrant Officer Flight Training, graduating as an AH-1 attack helicopter pilot in November of 1989. His first assignment was in Ansbach, Germany, and in December 1990, he was deployed to serve in Operation Desert Shield/Storm. Afterward, he trained in the AH-64A Apache with subsequent assignments in Colorado, Egypt, and Bosnia-Herzegovina. He received his Bachelor of Science degree in Professional Aeronautics from Embry-Riddle Aeronautical University in 1999. After transitioning to the AH-64D Apache Longbow in 2000, he was selected for the U.S. Army Engineering Test Pilot program. Upon graduation from the University of Tennessee Space Institute, he will attend the U.S. Navy Test Pilot School, Patuxent River, Maryland.