NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

CASE STUDY OF THE DEVELOPMENT OF THE APACHE ATTACK HELICOPTER (AH-64)

by

Edward W. "Bill" Ference

December 2002

Thesis Advisor:	Michael W. Boudreau
Associate Advisor:	Richard G. Rhoades
Second Reader:	Brad R. Naegle

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

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** December 2002	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Case Study of the Development of the Apache Attack Helicopter (AH-64)	**5. FUNDING NUMBERS**
6. AUTHOR(S) Ference, Edward, William	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

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

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

13. ABSTRACT *(maximum 200 words)*

This research examines advances in aviation technologies that allowed the Apache to become the world's premier attack helicopter. This thesis presents answers to a structured set of questions that address issues concerning outside influences, technology maturity and program management. It evaluates the role of development and test strategies, and whether these have helped to create a functional system. The research methodology is a Case Study. This thesis provides the reader with a thorough understanding of how the history of Army aviation has evolved leading to the requirement for an attack helicopter on the modern battlefield. The emphasis of this document is to follow a major weapon system through its lifecycle leading to successful deployment. Lessons learned are presented in a clear concise manner addressing issues of prime concern to any size program.

14. SUBJECT TERMS Aviation, Helicopter, Apache, Program Management, , TRADOC Funding, Requirements, Test and Evaluation, Technology Readiness Levels	**15. NUMBER OF PAGES** 95
	16. PRICE CODE

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

NSN 7540-01-280-5500

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

THIS PAGE INTENTIONALLY LEFT BLANK

CASE STUDY OF THE DEVELOPMENT OF THE APACHE ATTACK HELICOPTER (AH-64)

Edward W. “Bill” Ference Jr.
GS-861-14, United States Army
B.S., University of Pittsburgh, 1985

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN PROGRAM MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 2002

Author: Edward W. Ference Jr.

Approved by: Michael W. Boudreau
Thesis Advisor

Dr. Richard G. Rhoades
Associate Thesis Advisor

Douglas A. Brook
Dean, Graduate School of Business and Public Policy

ABSTRACT

This research examines advances in aviation technologies that allowed the Apache to become the world's premier attack helicopter. This is one of a series of research pieces, conducted under the auspices of an ongoing research effort sponsored by Headquarters U.S. Army Material Command. The U.S. Army Aviation and Missile Command (AMCOM) has contracted with the University of Alabama in Huntsville (UAH) to do this research. After all of the research is completed, the principal investigators at UAH and Massachusetts Institute of Technology (MIT) will do a crosscutting analysis across all the systems to identify key factors that can be used to guide future decision-making. This thesis presents answers to a structured set of questions that address issues concerning outside influences, technology maturity and program management. It evaluates the role of development and test strategies, and whether these have helped to create a functional system. The research methodology is a Case Study, a limited number of questionnaires were sent to key personnel intimately involved with the program development. This thesis provides the reader with a thorough understanding of how the history of Army aviation has evolved leading to the requirement for an attack helicopter on the modern battlefield. The emphasis of this document is to follow a major weapon system through its lifecycle leading to successful deployment. Lessons learned are presented in a clear concise manner addressing issues of prime concern to any size program.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE

This research examines advances in aviation technologies that allowed the Apache to become the world's premier attack helicopter. This thesis presents answers to a structured set of questions that address issues concerning outside influences, technology maturity and program management. It evaluates the role of development and test strategies, and whether these have helped to create a functional system. The research methodology is a Case Study. The research findings and conclusions are primarily based on answers to questionnaires that were filled out by key personnel in the Government and contractor Apache Program Managers' (PM) offices. When required, the questionnaire results are supplemented with my research and interviews with key personnel. I will complete a master questionnaire, address my research questions, and elicit relevant information to augment the answers to build the case study. The title is: Case Study of the Development of the Apache Attack Helicopter (AH-64).

B. BACKGROUND

A long history of trial and error has led to the development of an aircraft that dominates the battlefield like no other system. The highly integrated subsystems that makeup the AH-64 Apache allow it to evolve to fight in nearly any conditions. However, the transition to an attack helicopter presence in the Army arsenal was not trouble-free. Obstacles to development of the Apache included service rivalries, funding cuts and cultural misunderstandings. There are several key areas that led to the successful fielding and continued use of aviation firepower on the modern battlefield.

C. RESEARCH QUESTIONS

1. Primary Question:

What were the key aspects of the Apache development that resulted in its successful employment in Desert Storm?

2. Secondary Questions

a. To what extent was there user support and funding stability during system development?

b. To what extent did the maturity of critical technologies being integrated into the Apache influence the development? How were the organizations that had developed the critical technologies involved during system development?

c. Did the test strategy adequately evaluate the system for operational use?

d. How effectively were teams employed during development?

e. What was the key issue that the PM had to deal with during the project?

D. SCOPE

The scope of the thesis includes factors that influenced Apache development, and explores how well the system performed in Desert Storm. It considers the critical technologies and how they were effectively implemented in this system. The thesis explores the interrelationship of players such as users, government and contractor program managers, technology developers and testers and how they interacted in carrying out the development, production and fielding of the system. The research method is a case study, including questionnaires, interviews and supplemental research.

E. METHODOLOGY

The methodology used in this research consisted of the following steps:

i. Identified key Government and Contractor Program Management personnel instrumental to the development process.
ii. Sent questionnaires to key personnel.
iii. Conducted a literature search of books, magazine articles, CD-ROM systems, Government reports, internet-based materials, and other library information resources.
iv. Conducted interviews with key personnel.
v. Analyzed this data.

vi. Data combined to form a single integrated master survey.

Results from all survey questionnaires and research form the basis of the final written Case Study.

F. ORGANIZATION

Chapter II: BACKGROUND	History of Army Aviation as it relates to this thesis Overview of the Apache Attack Helicopter
Chapter III: DATA	Present survey data and research data
Chapter IV: ANALYSIS	Address research Questions Build a single overall survey
Chapter V: CONCLUSIONS	Present conclusions and recommendations

G. BENEFITS OF THE STUDY

This research studies the issues and relationships associated with the development of the Apache Attack Helicopter. This case study is one of a series being prepared under an ongoing research effort sponsored by Headquarters U.S. Army Material Command. The U.S. Army Aviation and Missile Command (AMCOM) has contracted with the University of Alabama in Huntsville (UAH) to do this research. After all of the Case Study research is completed, the Principal Investigators at UAH and Massachusetts Institute of Technology (MIT) will do a crosscutting analysis across all the systems to identify key factors that can be used to guide future decision-making. The case studies will be made available to the Defense Acquisition University (DAU) and the Naval Postgraduate School (NPS) to use in teaching and research.

THIS PAGE INTENTIONALLY LEFT BLANK

II. BACKGROUND

Dateline: January 17, 1991 -- The largest military assault since D-Day began rather unceremoniously as eight Apache Attack Helicopters are led out into the desert by four Air Force MH-53J Pave Low Helicopters. Dubbed Task Force Normandy, their mission, to open the door into Iraq, will signal the beginning of the Gulf War. This mission would mark yet another success in the long history of Army aviation.

Aviation has seen amazing evolutionary transformations, from the balloon outposts during the Civil War to the "flying tanks" of the Gulf War. In order to gain a full understanding of this warfighting system, one must first look at the broad environment in which it operates. This chapter will look at how the history of Army aviation has evolved and the nuances that have grown among the different services as well as those within the Department of the Army. I will briefly discuss the history of Army Aviation and the socioeconomic and political forces that it has evolved around. I will then lay out the Apache program time line, followed by a description of the aircraft system as it entered Desert Storm.

A. HISTORY OF AVIATION

1. Balloon Corps

The Union Army established the first "aviation unit" in the 1860's during the Civil War. Dubbed the "Balloon Corps of the Army of the Potomac"[1], they used balloons to place observers above the battlefield to track enemy movement. This gave the commander a distinct advantage in this war of positioning. The Balloon Corps was later placed under the Signal Corps for the remainder of the war. It appears that there was considerable distrust for this new technology and the men who risked their lives to make it work. The Balloon Corps was disbanded shortly after the end of the war. This marked the first of several shortsighted moves by the top brass to thwart Army Aviation in favor of ground troops.

Balloons were once again called into service in 1898 during the Spanish American War. During the fighting, the first U.S. airman was shot down in combat as his balloon was hit by enemy fire. Any hint of future Army aviation ended, as the balloons once again disappeared from the inventory at war's end.

Balloons have been used by the military since the turn of the century. They have evolved from one-man observation posts to highly sophisticated surveillance platforms. Balloons have also been used to drop ordnance in times of war. The use of balloons marked the unofficial beginning of Army aviation. Throughout the early years, aviation remained a fairly mundane communication asset in the Signal Corps. That was all to change with the onset of World War I.

2. Aircraft

On December 17, 1903, the first flight of a "heavier than air" craft took place at Kitty Hawk, North Carolina. The Wright brothers succeeded where many had failed and thus brought the world a little bit closer together. By August 1907, the Army Aeronautical Division was established to promote the use of aircraft in the military. In the fall of 1908, the Wright brothers build a "heavier than air flying machine" in response to Signal Corps request for proposal (RFP). During initial flight tests, Lt. Selfridge became the first aviation casualty, and the pilot, Orville Wright sustained severe injuries, as the plane they were riding in fell to the ground. This event brought those opposed to aviation out of the woodwork. Wilbur Wright quickly repaired the plane and resumed flight-testing. He successfully demonstrated that the craft exceeded all Army requirements and Wright Brothers aircraft soon entered military service.

As the fledgling aviation fleet began to evolve, a daring young Russian inventor, Igor Sikorsky, was trying to prove his helicopter design. In 1909 Sikorsky got his craft off the ground, marking the first flight of a counter rotating, twin-bladed helicopter.[2] As WWI approached, Sikorsky was forced to concentrate his efforts on large military aircraft. By 1914, he had created a four-engine aircraft capable of carrying one thousand pound bombs for the Russian Army.[3] Meanwhile, back in the U.S., Congress officially created the Aviation Section within Signal Corps on July 18, 1914. Aircraft were beginning to be used by the Allied forces in the war. By May 1918, Congress saw the importance of aviation; through the Overman Act they formed the "Air Service". This removed aviation assets from the Signal Corps, giving aviators more control over their own destiny. However, just as aviation needed most to increase the research and development of this new technology, the war ended and defense funding was once again severely cut.

As civil aviation boomed in the 1920's and 1930's, Army aviation tried to find itself. In 1926 Congress established the Army Air Corps. The Air Corps spent the next several years concentrating on large bombers; close air support was practically ignored. Military doctrine at the time was that the next war would be fought on the ground and from high in the air, and that air power was best used beyond the range of artillery.[4] Meanwhile, in May 1941, the first sustained flight of a Sikorsky V-300 helicopter took place. This aroused the Air Corps interest in helicopters and on 20 April 1942, Sikorsky delivered the first XR-4 helicopter to Army. The R-4 was the first mass produced military helicopter. They were used for observation, reconnaissance, and medical evacuation missions. An Army R-4B was the first perform a military rescue behind enemy lines on April 25, 1944 in Burma.[5] Between 1942 through 1946, the Army Air Force had purchased over 300 helicopters. However, combat usage of this unproven technology remained rather limited.

Considerable changes hit the military when on 9 March 1942, Congress established three separate and coequal commands: Army Ground Forces, Army Air Forces, and Army Service Forces. This division of power was in its infancy as WW II raged on. Then in the 1947 the National Defense Act, formally established the Air Force. The military chiefs met to carve up their missions. The Army was forced to limit their fixed wing assets to less than five thousand pounds, while the Air Force would provide the necessary close air support. This historic event forced the Army to develop helicopter fleets to compensate for the loss of its fixed wing support.

The United States entered Korea with nearly the same sad state of readiness that they took into WW II. The services had suffered from years of neglect at the hands of "downsizing" after the war. The Air Force was mainly equipped to fight a nuclear war with heavy bombers. Once the few significant targets were eliminated in Korea, the bombers had little impact. Helicopter use was delegated to search and rescue missions as the Army did their part from the air. As the war raged on, Army H-13 helicopters, first fielded in 1951, were retrofitted with stretchers on their landing skids to transport the growing number of wounded to Mobile Army Surgical Hospitals (MASH). By war's end, over eighteen thousand wounded had been transported by H-13s.[6] The civilian version of the H-19 Chickasaw was the world's first transport helicopter. Built by Sikorsky, the H-19 could carry six litters and one medical attendant during Medevac missions. With seating for twelve, the Chickasaw was also used as a troop transport, utility carrier, and rescue helicopter.[7] The success of the H-13 and H-19 in Korea helped the Army brass see the importance of the helicopter on the future battlefield.

B. ATTACK HELICOPTERS:

The use of force from the air dates back to the Balloon Corps and their limited attempts to arm aviators. With their growing fleet of large aircraft, the Air Force quickly perfected aerial bombing techniques. The Boeing B-17 "Flying Fortress" ushered in the use of an all around aerial attack with its various crew gun mounts and the ball-turret mounted beneath the huge slow aircraft. Fighter aircraft were developed to help protect the bombers. However, close air support was left largely to the different services and usually heroic individual efforts. Backyard trial and error continued throughout WW I and WW II as ingenious aviators and mechanics attempted to arm their aircraft for battle.

The Army Ground Forces Board at Ft. Bragg, North Carolina, documented the first formal test of an armed helicopter on December 14, 1945. The purpose of the test was to determine if a recoilless rifle could be mounted on a helicopter and fired in flight. Test results show that when fired, the backpressure of the 75mm rifle broke the Plexiglas windscreen and slightly buckled the tail cone of the test aircraft. Lacking an adequate means of sighting the gun, the testing was halted. Helicopter armament was brought to a standstill for the next several years as the fledgling helicopter industry grew. Meanwhile, the Air Force continued to concentrate on fixed wing assets and nuclear war.

The Army used lessons learned from the Korean conflict to boost their helicopter transport fleet. When the Army entered Vietnam, the need for close air support quickly became a priority. The entire helicopter fleet came under enemy fire; it wasn't long before the need for aerial defense was realized. The Army relied on it's aging fleet of

CH-21 Shawnee tandem rotor helicopters as flying trucks. Dubbed the "flying banana", this was the first true multi-mission helicopter, utilizing wheels, skis or floats for different terrains. Shawnee was the fourth of a line of tandem rotor helicopters designed by Piasecki. The slow, CH-21's were sitting ducks for enemy fire, one was even rumored to be brought down with a Viet Cong spear.[8] The CH-21's were soon outfitted with guns in the doorways and on the skids. Several different gun experiments took place in the early 1960's. Some Shawnees were equipped with movable nose guns. The Army even attempted to mount a B-29 Superfortress ball-turret beneath a CH-21, but this experiment was quickly discarded as the forces of the blast damaged the test aircraft. The Shawnee remained the workhorse of the Army through the early years of Vietnam. Use of the CH-21 ended with the arrival of the UH-1 Huey and the CH-47 Chinook to the battlefield.

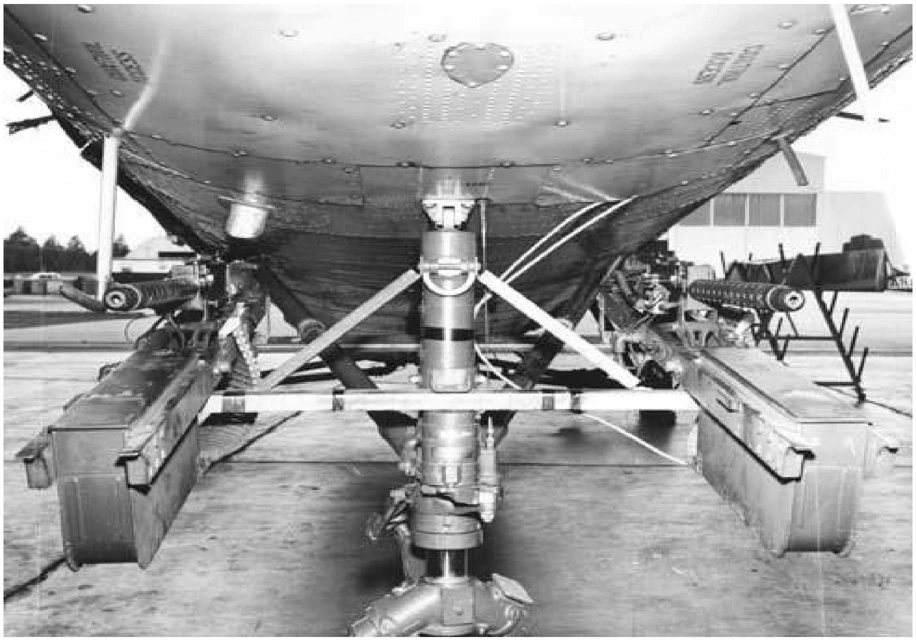

Figure 1. Test of .50 cal Guns on CH-21 Shawnee (1962)

Bell Helicopter's UH-1 Iroquois was a result of an Army request for a general utility helicopter. Bell began development of the prototype in 1955 to meet the Army specification. The Huey as it was called after it's original model designation, the HU-1, was essentially a stretched Bell model 47 Sioux with room for seven troops or three stretchers in it's cargo compartment behind the pilot. As Huey's entered service in Vietnam they were first armed with two door guns.

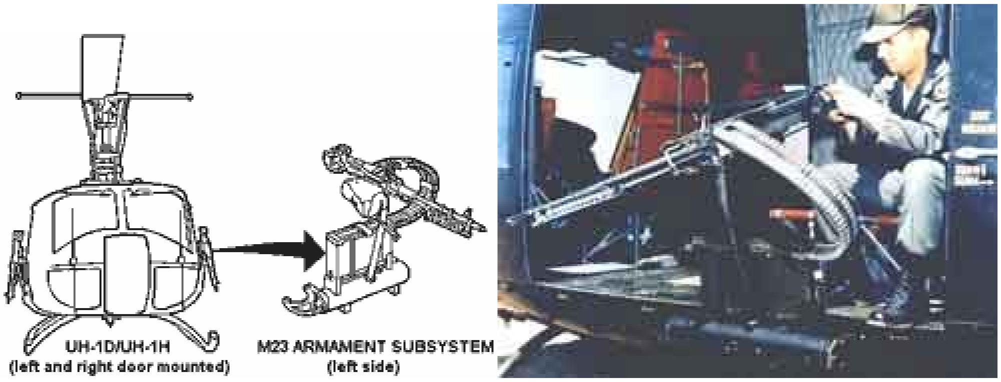

Figure 2. Huey Door Mounted Machine Gun

The CH-47 Chinook tandem rotor helicopter was developed in the late 1950's in order to meet increased demand for an all-weather heavy cargo carrier. The YCH-47A made its initial flight on 21 September 1961 and was fielded to Vietnam in the mid 1960's.[9] In an experimental project, Boeing Vertol equipped four Chinooks with five machine guns, two 20 mm cannons, two rocket launchers and a "chin-mounted" grenade launcher.[10] Designated "Guns-A-Go-Go" these heavily armored aircraft, each with a crew of eight, entered service in late 1965. The aircraft proved highly effective clearing landing zones and in assault missions. Each aircraft was capable of carrying a ton of expendable munitions. However, they were difficult to maintain and following a number of accidents, the effort was terminated in 1967 with the introduction of the AH-1 Cobra.

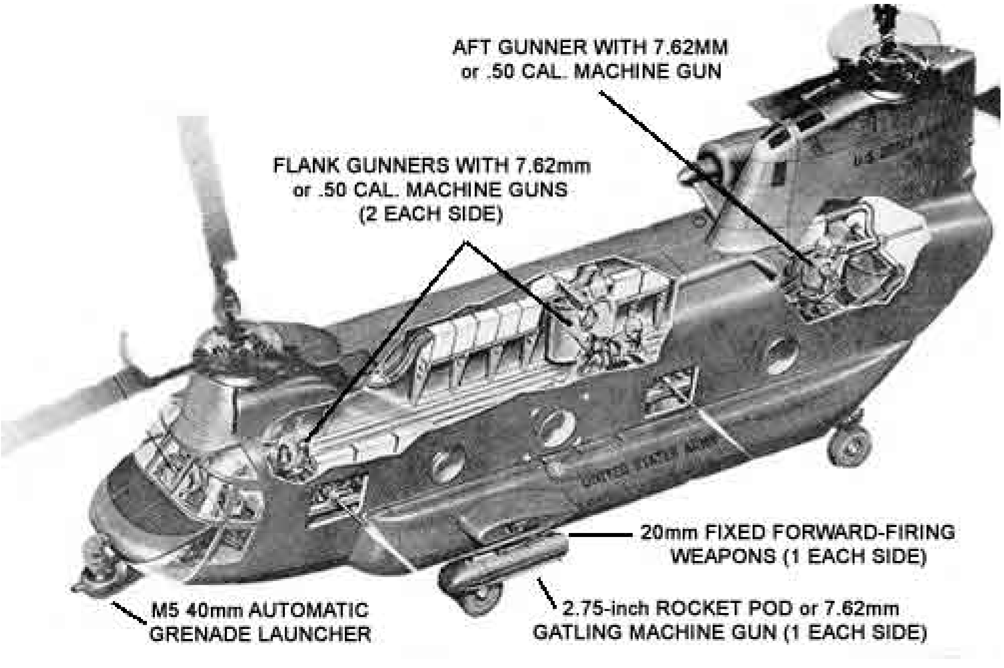

Figure 3. Heavily Armed "Guns-a-Go-Go" Chinook

As the war raged on in Vietnam, the Army realized the need to control it's own close air support. In June 1963, the Army issued a request for proposal (RFP) for the Advanced Aerial Fire Support System (AAFSS). A competition pitted the traditional helicopter builders Sikorsky and Bell versus Lockheed, a newcomer to the helicopter trade but with considerable fixed wing experience. Bell entered a scaled-down version of it's Iroquois Warrior. The other competitor was the Sikorsky S-66. The Sikorsky design had a rotorprop tail rotor which could rotate on it's axis 90° to act both as an anti-torque rotor or as a pusher, thereby transforming the S-66 into a compound aircraft in cruising flight. The Lockheed AH-56A Cheyenne won the competition.

On May 3, 1967, the first prototype YAH-56 Cheyenne rolled out of the Lockheed facility. The futuristic design had exceeded Army expectations. The Cheyenne had a single rigid four-bladed main rotor and anti-torque tail rotor, and a three-bladed pusher. The radical design of the Cheyenne helped it to reach an astonishing speed of 256 miles per hour, over twice the top speed of a UH-1. The rigid-rotor Cheyenne, with a crew of two, had a swiveling gunner's station linked to rotating belly and nose turrets, and a laser range-finder tied to a fire control computer. It was armed with a 30mm automatic gun in the belly turret and a 40mm grenade launcher or a 7.62mm Gatling machine gun in the chin-turret, TOWs, and 2.75 inch rocket launchers. The turret guns were slaved to the pilot’s or copilot’s helmet sight, this allowed them to aim and fire by simply turning their head. The age of the attack helicopter had arrived. However, as requirements creep set in, the Cheyenne became even more complex, expensive and worst of all, behind schedule.

The Army had an immediate need for firepower in Vietnam and top brass were impatient with the slow progress of the Cheyenne. By January 1965, the Army released a RFP for an interim Attack Helicopter, "escort gunship". Three systems competed for the contract, the Sikorsky Sea King, Kaman Seasprite and Bell Cobra. Bell won the flyoff and by October 1967, the first Cobra missions were flown in Vietnam. As the world's first attack helicopter, the Cobra's mission was direct fire support, armed escort and reconnaissance. It was armed with a 40 mm grenade launcher, 7.62 mm "minigun" and 2.75-inch rocket launchers. The Viet Cong named the Cobra "Whispering Death".

Figure 4. AH-1 Cobra Gun Ship

Stateside attention turned once again to the struggling Cheyenne program. Rollout of Lockheed's first prototype YAH-56 Cheyenne took place on May 3, 1967. The Air Force saw the Cheyenne as a threat to its close air, anti-tank mission. Secretary of the Air Force Harold Brown ordered the development of the A-10 Warthog to meet that need. As the Cheyenne continued to have technical problems, the Cobra was proving itself in battle. The Army soon realized that they would not win a turf war with the Air Force. With the A-10 project in full swing, the Army decided that they wanted a smaller, more agile Advanced Attack Helicopter (AAH) with a less complicated fire control and navigation system. The Cheyenne contract was terminated in May 1969. Through this period, the Army continued to desire fixed-wing close air support (CAS) from the Air Force. To that end, it was, relatively easy for the two services to agree that the attack helicopter did not perform CAS. Instead, it was an extension of organic firepower, and the Air Force would continue to provide CAS with fixed-wing aircraft. The two services agreed to consider the two types of aircraft as complementary rather than duplicative. Since that time, there have been no serious disagreements over aviation missions and functions between the Army and the Air Force. The new helicopter's mission would eventually be filled by the AH-64 Apache Attack Helicopter.

C. APACHE ATTACK HELICOPTER

The McDonnell Douglas (formally Hughes) AH-64 Apache is a twin-engine rotary wing aircraft, designed as a stable, manned aerial weapon system. With its two pilots and sophisticated computers, the Apache is capable of defeating a wide range of targets, including armored vehicles. It is capable of performing missions, day or night in adverse weather conditions. Combined with the integrated Target Acquisition Designation Sight / Pilot Night Vision Sensor (TADS/PNVS), the platform provides day and night acquisition and designation of targets and hand-off capabilities in support of Hellfire and other guided munitions. Aircraft armament includes the Hellfire anti-tank missile system, 30mm automatic chain gun and 2.75” rockets. The platform has a full range of aircraft survivability equipment with the ability to withstand hits from rounds up to 23mm in critical areas. Powered by two General Electric gas turbine engines, the Apache can cruise at an airspeed of 145 mph with a flight endurance of over three hours. The AH-64 is transportable in the C-5, C141 and C-17. The Apache Attack Helicopter contributes a highly mobile and effective firepower asset to the anti-armor capability in the field. The Apache development time line is depicted in figure 6, this chart was built from information contained in a number of sources[11] [12] [13].

Figure 5. Apache AH-64

D. DESERT STORM

In the early morning of 17 January 1991, an Army aviator fired the first shot of Operation Desert Storm from an Apache helicopter. Within a few minutes, two teams of Apaches totally destroyed two Iraqi air defense radar stations, paving way for the air war over Iraq.

Figure 6. Apache Armaments

During the 100-hour ground war, Army attack helicopters played their most decisive role ever in combat. Whatever doubts remained regarding combat effectiveness of attack helicopters were quickly dispelled. In addition to the attack role, helicopters were used for air assault, reconnaissance, transportation, combat search and rescue, and observation. Dozens of aviation units and several hundred helicopters of all types took part in the Gulf War.

		Standard Day	Hot Day
Length	58.17 ft		
Height	15.24 ft		
Wing Span	17.15 ft		
Primary Mission Gross Weight	15,075 lb		
Hover In-Ground Effect		15,895 ft	14,845 ft
Hover Out-of-Ground Effect		12,685 ft	11,215 ft
Vertical Rate of Climb		2,175 fpm	2,050 fpm
Maximum Rate of Climb		2,915 fpm	2,890 fpm
Maximum Level Flight Speed		150 kt	153 kt
Cruise Speed		150 kt	153 kt

Figure 7. AH-64A Specifications

Helicopters, as well as most other types of equipment, were adversely affected by sand and other environmental conditions; however, methods were devised to control the damage and to maintain a high rate of combat readiness. Operation Desert Storm was the first major military operation conducted on a largely electronic battlefield. Army aviation amply demonstrated its effectiveness in this environment and also proved again that it could “own the night” by carrying out many of its combat operations during darkness.

The reason that the Apache strike force team needed four Air Force MH-53J Pave Low helicopters to help start the Gulf War was that the Apaches needed to follow the Pave Lows into the desert due to the Apache’s lack of adequate navigation equipment capable of traversing the flat, featureless Mid Eastern terrain. The Apache is a system that continues to evolve; even today there are deficiencies and shortcomings that are being addressed.

Since Desert Storm, Army aviation has taken part in several other operations: Provide Comfort in northern Iraq, Restore/Continue Hope in Somalia, Uphold Democracy in Haiti, and the NATO operation in Bosnia. Aviation still continues to evolve, and Somalia provided important lessons learned relating to military operations in an urban environment. With the firepower of the Apache, Army aviation continues to demonstrate its unique worldwide capability through a combination of versatility, deployability, and lethality. The Apache's ability to evolve allows it to be an important ingredient of almost any type of contingency operation anywhere in the world.

1970 AAH work begun

January – August 1972: Marks Board formed, mission: To study requirements for an attack helicopter (Chartered to: "Revalidate the Advanced Aerial Fire Support System Qualitative Material Requirement")

September 1972: AAH Material Need approved

November 1972: AAH RFP released

February 1973: RFP responded to by 5 companies
(Sikorsky, Boeing-Vertol, Bell Helicopter, Hughes, and Lockheed)

April 1973: AAH PMO stood-up (BG Samuel G. Cockerham, 1st PM)

June 1973: Down select to competitive development with Hughes and Bell Helicopter

September 1975: First flight, Bell's YAH-63A & Hughes' YAH-64A

April 1976: New AAH PM (MG Edward M. Browne, April 1976 – December 1982)

June 1976: Prototypes delivered to Army for flyoff

December 10, 1976: Down select to Hughes YAH-64A

June 1981: Operational Test (OT II) @ Hunter Liggett (Ft. Ord, CA)

FY 1982: Congress approves LRIP, $444.5 M Contract for 11 aircraft

November 1982: Hughes completes $300 M AAH production facility in Mesa, AZ

November 1982: $106 Million low rate production contract for 48 aircraft

September 30, 1983: First production aircraft complete

December 30, 1983: Hughes Helicopter Company sold to McDonnell Douglas Corp

Spring 1984: $841Million production contract for 112 aircraft

Figure 8. Apache Development Time Line

THIS PAGE INTENTIONALLY LEFT BLANK

III. DATA

A. DATA COLLECTION

My primary research question is: “What were the key aspects of the Apache development that resulted in its successful employment in Desert Storm?” This question will be addressed by looking at a series of secondary questions. In order to answer these questions, data has been collected in a structured combination of “system” information and “technology” information. To facilitate the collection of data, I used a survey developed by a research team lead by The University of Alabama in Huntsville Research Institute and Massachusetts Institute of Technology Sloan School of Management an example of a completed survey can be found in Appendix C.

The research methodology is a case study. As such, surveys were sent to a very small number of people intimately involved with the development and production of the Apache Helicopter. The study must be done now because many of the men and women responsible for the development and eventual fielding of this weapon system are retiring, taking with them important knowledge that should be captured and codified into practical lessons for the future. The data has been collected from both a Government and a contractor Program Management team member. Responses from survey questions relevant to each of my research topics are organized below. This chapter is non-traditional, but that it will provide the foundation for my analysis and a combined survey for the research team.

The unique numbering system from the survey is maintained for reference and organizational purposes. The questions are organized by topic, the major phases of the program are defined as follows: The survey is centered around three phases in a major program. First is the systems planning and pre-development phase, “SP”, this is the stage where planning work began on the integrated system. Systems planning ended when contractors were selected for the development phase. The second stage is the development phase, “D”, in this phase contractors performed advanced engineering and development. A fly-off occurred in the development phase with the winner moving on to operational test. The third stage is referred to as transition to production, “TP”, this is when a producible system prototype has been demonstrated in an operational environment and is ready for low rate initial production. Questions are also divided into the following categories as defined by the first letter in the question:

- "T" stands for Technology
- "H" stands for project History
- "V" stands for Validation activities: testing and simulation
- "D" stands for team participants and communications during Development
- "F" stands for activity report during system development stage of the project
- "W" stands for When activity phasing occurred by stages of development and transition
- "B" stands for problem solving and team effort
- "O" stands for project Outcomes

The definitions of the various organizations of interest used throughout the document are defined in Table 1. Scales used for Technology and Production Readiness are defined in figures 9 and 10 respectively.

Prime's S&T org.	The Science and Technology group within system prime contractors organization responsible for doing internal research and development (IR&D) and developing new technology and concepts
Other prime org.	Any prime contractor organization other than the S&T organization
Supplier S&T	Same definition as for prime's S&T organization, but located at a supplier.
Other supplier org.	Any supplier organization other than the S&T organization.
Army Lab/Center	One or more of the Army laboratories or research, development and engineering centers.
Other DoD/S&T org.	An equivalent of an Army Lab/Center found elsewhere in DoD.

Table 1. Organization Definitions

B. RESEARCH QUESTION NUMBER 1: USER SUPPORT AND FUNDING

"To what extent was there user support and funding stability during system development?"

This question will be addressed by looking at the role of the user, requirements and funding stability. Information for user support comes from survey questions D18, F5, F6, W3, W4, and W5, requirements stability from F7, W6 and B13, and funding stability from questions H1, D11 and B2.

User support, survey questions D18, F5, F6, W3 through W5

D18. There was a lot of contact with Training & Doctrine Command (TRADOC) and/or other appropriate user representatives during the project?

Government Answer: Strongly Agree.

Contractor Answer: Somewhat Agree.

How often did the following occur during Development? (F5 & F6)

F5. Did TRADOC/other user organizations show strong support?

Government Answer: Many Times.

Contractor Answer: Don't know.

F6. Were there changes in key TRADOC or other user personnel?

Government Answer: Several Times.

Contractor Answer: Don't know.

<u>ACTIVITY PHASING BY STAGES OF DEVELOPMENT AND TRANSITION</u>

When did the team carry out the following activities?

W3. When was the TRADOC consulted on project questions?

Government Answer: Selection, between system planning phase and development phase.

Contractor Answer: Later Development, between development phase and transition to production phase.

W4. When was there change in key TRADOC/user representatives?

Government Answer: Early Development, between development and transition to production.

Contractor Answer: Do not know.

W5. When did TRADOC/other users show strong support?

Government Answer: Middle Development, between development and transition to production.

Contractor Answer: Transition, after transition to production.

Requirements stability: Survey questions F7, W6 and B13

F7. Were there changes in system requirements (e.g., threat)?

Government Answer: Several times.

Contractor Answer: Do not know.

W6. When was there change in the system requirements?

Government Answer: After development.

Contractor Answer: Do not know.

B13. Did this problem come up during this project? Threat definition or other requirements changed during the project.

Government Answer: Significant effort spent on this problem.

Contractor Answer: Do not know.

Funding stability: Survey questions H1, D11 and B2

H1. At some point, was the project either: 1. Slowed down? 2. Stopped and restarted? 3. Neither.

Government Answer: 1. Slowed down, due to funding cuts.

Contractor Answer: 3. Neither.

D11. There was often uncertainty about the future of project funding during the System Development stage?

Government Answer: Agree somewhat, the funding changes were a constant concern to the PMO, this caused the staff to be concerned at each major milestone.

Contractor Answer: Disagree somewhat, some uncertainty existed, but we were confident that the system filled a need.

B2. Did this problem come up during this project? Cut-backs in project resources forced changes/compromises.

Government Answer: Major effort spent on this problem.

Contractor Answer: Minor effort spent on this problem.

C. RESEARCH QUESTION NUMBER 2: CRITICAL TECHNOLOGIES

"To what extent did the maturity of critical technologies being integrated into the Apache influence development? How were the organizations that had developed the critical technologies involved during system development?"

This question will be addressed by looking at three critical technologies, central to the success of the developed for the Apache, in terms of technology readiness, the project timeline and project outcomes. Information for critical technologies comes from survey question T1, technology readiness, from survey questions on systems planning "S", development "D", transition to production "TP", and T5 through T7, and project outcomes from survey questions O1 through O9.

The second question will be addressed by looking at the involvement of development organizations throughout system development. Survey data includes, the role of the S&T organizations, integration difficulties, production readiness, the role of the prime contractor, and problem identification. The role of the S&T organizations comes from survey questions on page 1 and T8 through T10. Difficulties integrating technologies are addressed in survey questions T3, H3, B1, B4 through B8. While production readiness issues are in survey questions on page 1, T3, H6, B4 through B6 and B8.

Identify critical technologies: Survey question T1.

Now identify one or more (up to 3) technologies that were incorporated into the system you are studying. These technologies should be among those *central to the success of the system*.

	Government response:
Technology A	Visionics
Technology B	Computers
Technology C	Avionics
	Contractor response:
Technology A	Target Acquisition/Designation (TADS)
Technology B	Forward Looking Infrared System (FLIRS)
Technology C	Hellfire Missile Integration (Laser)

Table 2. Critical Technologies Response

NOTE: There were many new and critical technologies incorporated into the Apache. In order to compare answers, participants were asked to respond to a single set of critical technologies. Surveys were repeated for the three technologies in the table below.

Technology A	Target Acquisition/Designation (TADS/PNVS)
Technology B	Computers
Technology C	Avionics

Table 3. Critical Technologies Evaluated

Technology readiness: Survey questions SP, D, TP, and T5 through T7

SP. What was the approximate starting date of systems planning and pre-development work? This date is when planning work began on the integrated system. The systems concept and applications had been formulated, but applications were still speculative. There was no proof or detailed analysis to support the approach.

SP: SYSTEMS PLANNING START DATE (SP):

Government Answer: Cheyenne Development effort, begun in 1963, preceded Apache Development/Planning work begun approximately 09/69 (mo/yr). Much of this work helped jump-start the AAH program.

Contractor Answer: Approximately 1974.

SP. In what organization was the primary work leading up to this point accomplished?

Government Answer: CHEYENNE PM, with lead support from TRADOC.

Contractor Answer: Prime's S&T organization.

SP. Including that organization, what organizations had been involved up to this point?

Government Answer: Active support from both other prime organizations and other supplier organizations.

Contractor Answer: Lead/co-lead from other prime organizations. Active support from supplier S&T organizations, the Army lab centers, and other DoD/S&T organizations.

SP. What was the nature of the Army lab center's involvement? (Simulation? Concept formulation? Integration? Requirements development?)

Government Answer: Most of the behind the scene "effort" was competing contractors (Bell and Sikorsky), supporting their King Cobra and S-67 as replacement for the LOCKHEED CHEYENNE while supporting termination of the CHEYENNE Production contract as well as the eventual development contract. Definition of the Advanced Attack Helicopter was centered around what the Department of Army thought Bell Helicopter was capable of producing.

Contractor Answer: Did not know.

D. Date when Development started. Typically at this date, funding started for system advanced development or engineering development, a Government project office was formed and prime contractor(s) selected.

Government Answer: DEVELOPMENT START DATE: (D): June 1973.

Contractor Answer: DEVELOPMENT START DATE: (D): 1976.

D. What was the Technology Readiness Level (refer to page 8) for the SYSTEM on this date?

Government Answer: 6. System/subsystem model or prototypes were demonstrated in a relevant environment. Representative model or prototype systems were tested, which is well beyond the breadboard tested for TRL 5, tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in a simulated operational environment.

Contractor Answer: 3. The system is in the analytical and experimental critical function and/or characteristic proof of concept stage. Analytical and laboratory studies have physically validated analytic predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.

D. What was the Production Readiness Level (refer to page 8) for the SYSTEM on this date?

Government Answer: 2. The application is produced outside the lab with tools and processes used for producing very low quantities.

Contractor Answer: 2. The application is produced outside the lab with tools and processes used for producing very low quantities.

D. In what organization was the primary work in the period from systems planning to development accomplished?

Government Answer: Primary work was accomplished in the Project Management office.

Contractor Answer: Primary work was accomplished in the primes science and technology organization.

D. Including that organization, what organizations had been involved in the period systems planning to development?

Government Answer: Involved – Other prime organizations. Kept informed – Army lab center and other DoD/S&T organizations. Not Involved – Primes S&T organization, supplier S&T, and "other supplier organizations.

Contractor Answer: Lead/co-lead - Other prime organization and supplier S&T organizations. Active support from the Army lab center"

D. What was the nature of the Army Lab/Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?)

Government Answer: Technical consultation. The Night Vision Lab was the lead support for the TADS/PNVS.

Contractor Answer: Engineering support.

TP. Date the system started transition to production "TP". This is when the producible system prototype has been demonstrated in an operational environment.

Government Answer: TRANSITION TO PRODUCTION (TP) DATE**:** Apr 1982.

Contractor Answer: TRANSITION TO PRODUCTION (TP) DATE**:** 1980.

TP. What was the Production Readiness Level for the SYSTEM on this date?

Government Answer: 3.

Contractor Answer: 4.

TP. In what organization was the primary work in the period from development to transition to production accomplished?

Government Answer: Program Management.

Contractor Answer: Prime S&T organization.

TP. Including that organization, what organizations had been involved in the period development to transition to production?

Government Answer: Lead/co-lead – Prime S&T organization and other prime organizations. Active support - Supplier S&T organization. Involved - Other supplier organizations, the Army lab center, and other DoD/S&T organizations.

Contractor Answer: Lead/co-lead - Other prime organizations and supplier S&T organizations. Active support - Army lab center.

TP. What was the nature of the Army Lab Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?)

Government Answer: Simulation.

Contractor Answer: Engineering Support; Requirements Definition.

Now look at the SP, D, and TP dates you provided above for the System. Using the Technology Readiness (TRL) Scale (see end of this chapter), find the number that represents the readiness of the separate technologies the team was working with at each point in time. Please answer here for the state of development of each component technology. (NOT for the over-all system, which was the focus in the questions above.)

	Technology A TADS/PNVS	**Technology B** Computers	**Technology C** Avionics
Government response:			
T5. When System planning and pre-development began, technology TRL was:	2	3	7
T6. When System went into Development, technology TRL was:	3	3	7
T7. When System reached Transition to Production, technology TRL was:	8	9	9
Contractor response:			
T5. When System planning and pre-development began, technology TRL was:	2	2	6
T6. When System went into Development, technology TRL was:	4	7	7
T7. When System reached Transition to Production, technology TRL was:	8	8	8

Table 4. Technology Readiness

Project Outcomes: Survey questions O1 through O9

O1. Project Acceptance. Was the SYSTEM accepted to be put into production? This is initial acceptance, not whether it actually ended up in production.

Government Answer: 3. Yes, the System was accepted for production.

Contractor Answer: 3. Yes, the System was accepted for production.

O2. After the SYSTEM was accepted and was in Transition to Production, how many additional changes in the designs and processes were later required before the System was taken into full production?

Government Answer: 2. Significant changes were made.

Contractor Answer: 3. Minor changes were made.

O3. Did the SYSTEM go into full production?

Government Answer: 3. Yes, the System was put into full production.

Contractor Answer: 3. Yes, the System was put into full production.

O4. For each of the technologies A, B, and C above, to what extent was each used in the system as it was produced?

	Technology A TADS/PNVS	**Technology B** Computers	**Technology C** Avionics
Government response:			
4. Yes, the technology was used as planned.	X	X	X
Contractor response:			
4. Yes, the technology was used as planned.	X	X	X

Table 5. Technology Usage

O5. After the SYSTEM reached Transition to Production, did the project go to production as quickly as it should have?

Government Answer: 2. One to six months delay

Contractor Answer: 2. One to six months delay

O6. After the SYSTEM was actually in production, how many additional changes in designs and processes were required?

Government Answer: 2. Significant changes.

Contractor Answer: 3. Minor changes.

O7. Did the SYSTEM as it was implemented meet the program's cost goals?

Government Answer: 2. The results came close to achieving cost goals.

Contractor Answer: 2. The results came close to achieving cost goals.

O8. Did the System Development program, as implemented, come in on budget?

Government Answer: 3. The project significantly exceeded budget.

Contractor Answer: 9. Don't know.

O9. Did the System as it was implemented meet the project's technical goals and functional requirements?

Government Answer: 1. The results met or exceeded technical goals.

Contractor Answer: 1. The results met or exceeded technical goals.

O9x. Did the System have problems in the field under operational conditions in Desert Storm? IF YOU CHECKED "1" or "2", what did the field problems result from? Check all that apply.

Government Answer: 2. Yes, problems in the field caused minor problems in the system's effectiveness. 9b. Requirements did not reflect the field environment.

Contractor Answer: 4. No, the system was deployed and exceeded expectations of its effectiveness.

Role of the S&T organizations: Survey questions page 1 (addressed above), T8 through T10, and B11

For each of the technologies A, B & C, did an Army Laboratory or Center make a significant contribution to achieving any of the above levels of technology readiness?	**Technology A** TADS /PNVS	**Technology B** Computers	**Technology C** Avionics
Government response:			
T9. Yes, it contributed to Readiness for Development.	X		X
T10. Yes, it contributed to Readiness for Transition to Production.		X	
Contractor response:			
T8. Yes, it contributed to Readiness at start of Planning/Pre-development.	X	X	X
T9. Yes, it contributed to Readiness for Development.	X	X	X
T10. Yes, it contributed to Readiness for Transition to Production.	X	X	X

Table 6. Army Lab or Center Involvement

B11. Army Labs/Centers resisted project ideas or approaches. Did this problem come up during this project? IF YES, how much project effort had to be spent on this problem?

Government Answer: Yes, minor effort.

Contractor Answer: No, contractor not aware of any problems.

Difficulties integrating technologies: Survey questions T3, H3, B1, B4 through B8

T3. <u>Production Impact</u>. What was the impact of the technology on then existing production processes? (Answer for date you provided for Development start, D.)	**Technology A** TADS /PNVS	**Technology B** Computers	**Technology C** Avionics
Government response:			
Technology forced deep and serious production process change.	X	X	X
Contractor response:			
Technology caused significant production process change.	X	X	
Technology did not require much production process change			X

Table 7. Production Impact of Critical Technology

H3. <u>Key Skills</u>. This question asks about "key skills" essential to the success of the project, defined as skills "that if they were not available at all, would have stopped team progress at the point when they were needed." Were there any key skills <u>not</u> adequately represented on the team? IF YES, what were the missing key skills? Please check (✓) any and all that apply.

Government Answer: Yes, more than one. The team lacked producibility professionals from suppliers and Government logistics experts.

Contractor Answer: No.

For the following questions, did this problem come up during this project? IF YES, how much project effort had to be spent on this problem?

B1. It was harder than expected to take the risk out of the new technology.

Government Answer: No, much to the risk areas had been identified.

Contractor Answer: Minor effort.

B4. A critical production issue was uncovered very late in the process.

Government Answer: Significant effort.

Contractor Answer: Minor effort.

B5. Management pressure pushed technology prematurely into production.

Government Answer: Major effort.

Contractor Answer: No.

B6. There was a lack of acceptance standards for the new technology.

Government Answer: Minor effort.

Contractor Answer: No.

B7. The technology was hard to scale up from lab and pilot tests.

Government Answer: Minor effort.

Contractor Answer: Minor effort.

B8. Testing, quality control and/or acceptance took longer than planned.

Government Answer: Significant effort.

Contractor Answer: Minor effort.

Production Readiness: Survey questions Page1 (addressed above), T3, H6, B4 through B6 and B8

T3. Production Impact. What was the impact of the technology on then existing production processes? (These results are in Table 6 above.)

H6. Whose facilities were going to be the primary production site for the application of the new technologies?

Government Answer: 3. Supplier facilities.

Contractor Answer: 2. Both prime and supplier facilities.

For the following questions, did this problem come up during this project? IF Yes, how much project effort had to be spent on this problem?

B4. A critical production issue was uncovered very late in the process.

Government Answer: Yes, significant effort had to be spent on this problem.
Contractor Answer: Yes, minor effort had to be spent on this problem.

B5. Management pressure pushed technology prematurely into production.

Government Answer: Yes, major effort had to be spent on this problem.
Contractor Answer: No.

B6. There was a lack of acceptance standards for the new technology.

Government Answer: Yes, minor effort had to be spent on this problem.
Contractor Answer: No.

B8. Testing, quality control and/or acceptance took longer than planned.

Government Answer: Yes, significant effort had to be spent on this problem.
Contractor Answer: Yes, minor effort had to be spent on this problem.

D. RESEARCH QUESTION NUMBER 3: TEST STRATEGY

"Did the test strategy adequately evaluate the system for operational use?" This question will be addressed by looking at the test approach utilized supplemented with data from program files and test reports. The test approach is covered in survey questions V1 through V15.

Identify test approach: Survey questions V1 through V15

V1. Was a failure modes and effects analysis done on the system? If yes, was it used to help establish the test plan?

Government Answer: Yes. Yes, it was used to help establish the test plan.
Contractor Answer: Yes. Don't know.

<u>These questions are for individual components</u>:

V2. Was there testing to see if the individual components of the system worked? What organization(s) did this testing?

Government Answer: Yes. Prime and Suppliers did this testing.

Contractor Answer: Yes. Prime, Suppliers and Army center/lab did this testing.

V3. Were there simulations run to see if the individual components of the system worked? What organization(s) did these simulations?

Government Answer: Yes, Prime, suppliers and Army center lab did these simulations.

Contractor Answer: Yes, Prime and suppliers did these simulations.

<u>For integrated components in **controlled** setting</u>:

V4. Were the components tested working together <u>in a controlled setting</u>? What organization(s) did this testing?

Government Answer: Yes. Prime, Suppliers and Army center/lab did this testing.

Contractor Answer: Yes. Prime and Suppliers did this testing.

V5. Were there simulations of the components working together <u>in a controlled setting</u>? What organization(s) did this?

Government Answer: Yes. Prime, Suppliers and to limited degree, the Army center lab performed simulations.

Contractor Answer: Yes. Prime and Suppliers performed simulations.

<u>For integrated components in a **realistic** setting:</u>

V6. Was there testing of the components working together <u>in a realistic setting</u>? What organization(s) did this testing?

Government Answer: Yes. The prime, suppliers and the Army lab center performed testing in a realistic environment.

Contractor Answer: Yes. The prime and other Government organizations performed testing in a realistic environment.

V7. Was a hardware-in-the-loop type systems integration simulation laboratory used to see if the **individual components** of the system worked? To see if <u>integrated components</u> worked in **controlled setting?**

Government Answer: Yes / Yes.

Contractor Answer: Yes / Yes.

V8. Recalling the total effort (100%) spent on testing and simulations, please allocate the percent of that total that were:

Gov / Cont (Contractor had no response)
10 / ______% spent to see if the individual components of the **system worked.**
65 / ______% spent to see if integrated components worked **in controlled setting.**
20 / ______% spent to see if integrated components worked **in a realistic setting.**
05 / ______% spent on any other validation purpose.

Please evaluate the following statements about the use of testing and simulations:

V9. Knowledge from validation work was used consistently to improve components and system.

Government Answer: Neither agree nor disagree.

Contractor Answer: Agree somewhat.

V10. Project test philosophy was to "Break it big early."

Government Answer: Strongly disagree.

Contractor Answer: Neither agree nor disagree.

V11. Component and system maturity were validated at the right times in the program.

Government Answer: Disagree somewhat.

Contractor Answer: Agree somewhat.

V12. The project and the testing community had an adversarial relationship.

Government Answer: Agree somewhat.

Contractor Answer: Strongly disagree.

V13. Most project validation events produced quality results.

Government Answer: Disagree somewhat.

Contractor Answer: Agree somewhat.

V14. The project didn’t recognize important lessons that validation work uncovered.

Government Answer: Neither agree nor disagree.

Contractor Answer: Disagree somewhat.

V15. Sometimes the project settled for less than the best validation method.

Government Answer: Agree somewhat.

Contractor Answer: Disagree somewhat.

O3. Did the SYSTEM go into full production?

Government Answer: 3. Yes, the System was put into full production.

Contractor Answer: 3. Yes, the System was put into full production.

O5. After the SYSTEM reached Transition to Production, did the project go to production as quickly as it should have?

Government Answer: 2. One to six months delay

Contractor Answer: 2. One to six months delay

O9x. Did the System have problems in the field under operational conditions in Desert Storm? IF YOU CHECKED “1” or “2”, what did the field problems result from? Check all that apply.

Government Answer: 2. Yes, problems in the field caused minor problems in the system’s effectiveness. 9b. Requirements did not reflect the field environment.

Contractor Answer: 4. No, the system was deployed and exceeded expectations of its effectiveness.

E. RESEARCH QUESTION NUMBER 4: TEAMS

“How effectively were teams employed during development?” This question will be addressed by looking at the effectiveness of teams, proper staffing, and relationships between manufacturing and suppliers. Teaming approach utilized is addressed in survey questions H2, H4, H5, D1, D7, D9, D13, D14, D16, D19, and F4.

Teaming approach utilized: Survey questions H2, H4, H5, D7, D9, D13, D14, D16, D19, and F4

H2. Was the project set up as a cross-functional integrated product team (IPT), a project team drawn from different parts of the contractor's organization with most of the skills needed for the development?

Government Answer: No. However, it was used for production.

Contractor Answer: No. We used smaller concentrated teams with PM over site.

H4. During the Development stage of the project, how many people on the team were collocated very close together? (On the same floor of a building within a one-minute walk of each other.)

Government Answer: None.

Contractor Answer: Some, over a third.

H4a. Including the above, how many people on the team were collocated in the same building?

Government Answer: Few were collocated in the same building.

Contractor Answer: Most, 2/3rds or more were collocated in the same building.

H5. How many people on the team involved in the development stage had worked before with others on the project?

Government Answer: Most, two thirds of the people or more had worked before with others on the project.

Contractor Answer: Some, over a third had worked before with others on the project.

Team Participants & Communications during Development.

Here are some statements about the people on the project during the system development stage. Please indicate your level of agreement or disagreement that each statement is a description of team processes on this project.

D7. Team meetings were sometimes frustrating and non-productive.

Government Answer: Strongly agree.

Contractor Answer: Neither agree or disagree.

D9. Project results did <u>not</u> take advantage of the team's best ideas.

Government Answer: Disagree somewhat.
Contractor Answer: Disagree somewhat.

D13. Management project reviews were constructive & helpful.

Government Answer: Neither agree or disagree.
Contractor Answer: Agree somewhat.

D14. Formal reviews were conducted at key decision points.

Government Answer: Strongly agree.
Contractor Answer: Agree somewhat.

D16. Usually team knew right away <u>where</u> to get necessary outside help.

Government Answer: Agree somewhat.
Contractor Answer: Agree somewhat.

D19. The Government PM was reluctant to share problems with Army leaders.

Government Answer: Agree somewhat.
Contractor Answer: Disagree somewhat.

<u>Activity Report during System Development Stage of Project.</u>

How often did team members do the following during Development?

F4. Needed management help to resolve project team disagreements?

Government Answer: Many times.
Contractor Answer: Several times.

Proper Staffing: Survey questions H3, D1 – D6, D8, D10

H3. <u>Key Skills</u>. Defined as skills "that if they were not available at all, would have stopped team progress at the point when they were needed." Were there any key skills <u>**not**</u> **adequately represented** on the team?

Government Answer: Yes, more than one. The team lacked producibility professionals from suppliers and Government logistics experts.

Contractor Answer: No.

D1. The team leader was good at resolving technical disagreements.

Government Answer: Strongly agree.

Contractor Answer: Neither agree or disagree.

D2. The team leader was good at getting necessary resources.

Government Answer: Strongly agree.

Contractor Answer: Agree somewhat.

D3. There was a lot of turnover in team membership.

Government Answer: Strongly disagree.

Contractor Answer: Neither agree or disagree.

D4. The <u>team leader</u> had both design & production experience.

Government Answer: Strongly disagree.

Contractor Answer: Neither agree or disagree.

D5. The <u>team leader</u> had very high technical competence.

Government Answer: Agree somewhat.

Contractor Answer: Agree somewhat.

D6. Some key technical skills were <u>not</u> represented on the team itself.

Government Answer: Strongly disagree.

Contractor Answer: Disagree somewhat.

D8. Professionals were split across too many different tasks & teams.

Government Answer: Neither agree or disagree.

Contractor Answer: Neither agree or disagree.

D10. Key members continued through pre-production planning and testing.

Government Answer: Strongly agree.

Contractor Answer: Agree somewhat.

Relationships with manufacturing and suppliers: Survey questions F1-F3, F10-F13, W1-W2, W16-W18

Activity Report during System Development Stage of Project.

How often did team members do the following during Development?

F1. Went to the shop floor to meet about related production processes.

Government Answer: Many times.

Contractor Answer: Several times.

F2. Asked for supplier comments & suggestions on design choices.

Government Answer: Many times.

Contractor Answer: Several times.

F3. Showed and discussed physical models of new components with suppliers.

Government Answer: Many times.

Contractor Answer: Several times.

SHARED DESIGN-PRODUCTION ACTIVITIES during System Development. Here **only count joint** meetings or discussions that included **both DESIGN** and people from **PRODUCTION** and/or from the **PROGRAM** concerned with production of the System. **How often** did team members do the following **during Development**?

F10. Passed around physical prototypes during joint discussions.

Government Answer: Several times.

Contractor Answer: Several times.

F11. Held planning meetings that included both design & production people.

Government Answer: Several times.

Contractor Answer: Several times.

F12. Explored choices together with computational models or analytic tools.

Government Answer: Several times.

Contractor Answer: Several times.

F13. Had test articles or pre-production parts to discuss and examine jointly.

Government Answer: Several times.

Contractor Answer: Several times.

ACTIVITY PHASING BY STAGES OF DEVELOPMENT AND TRANSITION.

When did the team carry out the following activities?

W1. When did production representatives participate regularly?

Government Answer: Later in development.

Contractor Answer: Later in development.

W2. When did team members meet with production on shop floor?

Government Answer: During Transition to Production.

Contractor Answer: Later in development.

Relationship & Activities between Engineering Design & Production/Program

These questions are different because they focus **only** on **joint meetings or discussions** that included **both DESIGN personnel and people from PRODUCTION and/or PROGRAM** people concerned with production.

W16. When did the team & technical professionals from **Production** have unscheduled & informal **joint** conversations about the project?

Government Answer: During Transition to Production.

Contractor Answer: Later in development.

W17. When were analytic engineering tools used **jointly** by design?

Government Answer: During Transition to Production.

Contractor Answer: Later in development.

W18. When were prototypes and parts used in **joint** discussions?

Government Answer: During Transition to Production.

Contractor Answer: Later in development.

F. RESEARCH QUESTION NUMBER 5: KEY PM ISSUE

What was the key issue that the PM had to deal with during the project and how was it dealt with? This question will be addressed by looking at the primary issue that the PM focused most attention and resources. The key PM issue is addressed in survey question I2.

Key PM Issue: Survey question I2

Government Answer: The PM controlled/dictated the R&D Program. Had he not dictated the R&D program there would not be an AAH today. That does not make it correct or acceptable. Control of the production project was, in my estimation, the biggest fundamental problem the PM had to deal with in managing the overall program. Problem of control was basically the external environment, i.e., the sheer number of agencies, that were to be contended with on a regular basis under the "team" approach. Like the internal organization, each had their own axe to grind and each had some level of input. As an example, meetings were inordinately large and therefore more difficult to control. Decisions that should have been made instantly were negotiated to death leaving cost and schedule impacts to be resolved. Each PM's style was significantly different and varied. During R&D the military were given no more than lip service. During initial/early production the military were the only ones to input to the PM. The period 1990-1996 were years of the very best management in the program. The military were competent leaders and did pay close consideration to the civilian technical support.

Contractor Answer: Don't know.

1. **Basic principles observed and reported**. Scientific research begins to be translated into applied research and development concepts. There have been paper studies of technology's basic properties.
2. **Technology concept and/or application formulated.** Practical applications have been invented. Application is speculative and there is no proof or detailed analysis to support the assumptions. Examples are still limited to paper studies.
3. **Analytical & experimental critical function and/or characteristic proof of concept**. Analytical and laboratory studies have physically validated analytic predictions of separate elements of the technology. Examples include components that are not yet integrated or representative
4. **Component and/or bread board validation in lab environment.** Basic technological components are integrated to establish that pieces will work together, e.g., integration of ad hoc parts in lab. This is relatively "low fidelity" compared to the eventual system.
5. **Components and/or bread board validation in relevant environment**. Fidelity of breadboard technology is significantly increased**.** Basic components integrated with reasonably realistic supporting elements so the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. **System/subsystem model or prototype demonstrated in a relevant environment.** Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in a simulated operational environment.
7. **System prototype demonstrated in an operational environment**. Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. **Actual system completed and qualified in test and demonstration**. Technology proven to work in final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation in its intended weapon system to determine if it meets design specification.
9. **Actual system proven in successful operational environment**. Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Figure 9. Technology Readiness Level Scale

1. The subsystem or component application embodying the technology is produced inside the lab by engineers, scientists or laboratory technicians to demonstrate principles for breadboard validation and testing.
2. The application is produced outside the lab with tools and processes used for producing very low quantities.
3. The application is produced in low quantities with tools and processes planned to be used in production systems. Testing procedures for components and subsystems are established.
4. The system involving the technology application(s) is engineered for production. All components are identified, integration, assembly and test planning is complete.
5. Low rate production has been run using the production processes planned for full rate production, complete with validated procedures for integration, assembly and test of the system.

Figure 10. Production Readiness Scale

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS

A. INTRODUCTION

My analysis is divided into two parts, a combined survey contained in Appendix C that will be used by the University of Alabama Huntsville / Massachusetts Institute of Technology researchers for a crosscutting analysis, comparing several systems used in Desert Storm, and the written analysis contained in this chapter.

The first step in my analysis is to build a composite questionnaire of the Government and contractor responses. To complete this task, I first looked at all of the questions that had the same response. If this answer corresponded to my research, I accepted it. Where responses differed from my research, I considered the sources and made a logical decision as to which was the best answer. This mainly occurred with actual dates. To resolve conflicts among responses I looked at several factors. My first judgment was based on the resources; the reference documents that I used are contained in Appendix A. If no additional data was available, I considered the position of the respondents with respect to the question at hand. For example, when discussing user support, I relied more on the Government response, as they most likely had much more contact with the user community. On the other hand, I was more apt to use the contractors' response for questions dealing with supplier issues. Where more information was required, I conducted follow-up interviews with either the survey respondents or other employees familiar with the project during the specific time frame in question.

This chapter provides an in-depth analysis of the data obtained from the survey questions supplemented with other research data as necessary to clarify the results. All data was organized by topic in the previous chapter – this method of organization will be carried forth, survey question numbers, [#], are annotated throughout so the reader can reference the combined questionnaire in Appendix C, research citation references are listed in Appendix A {ref #}. Historical events from Chapter II are used to keep the information in context of the timeframe wherein events occurred.

B. RESEARCH QUESTION NUMBER 1: USER SUPPORT AND FUNDING

"To what extent was there user support and funding stability during system development?" This question will be addressed by looking at the role of the user, requirements and funding stability. I will primarily focus on the answers from the Government side of the Program Management Office (PMO) as they had direct contact with the Army user community.

The PM staff had a good working relationship with the users and frequently consulted them on key project issues [D18, F5, & W3]. The user organizations showed strong support during Apache development [W5]. As discussed in Chapter 2, a sense of urgency came over the Army leadership following the rise of the Air Force A-10 program and the demise of the Army's Cheyenne program. Survey respondents concurred that combat development representatives of the troops in the field were on board early in the program and supported the program as it evolved [W3, F5 & W5]. Once the Apache PM office was established in April 1973 [D], the PM kept in close contact with Training and Doctrine Command (TRADOC) and user representatives during the remaining phases of the project [D18]. That close working relationship helped user support to grow as the program progressed toward production. As is usual with the military rotation cycle, there were several changes in key user personnel during the program [F6 & W4]. Top leadership helped made sure that these changes occurred early in development and between development and the transition to production [F6 & W4]. Keeping key user personnel on board through major milestones helped to minimize the effect of these inevitable changes.

Initially, clear requirements helped to keep the program on course [F7, W6 & B13]. The Advanced Attack Helicopter (AAH) Mission Needs Statement (MNS) and operational requirements were the result of a revalidation of the Advanced Aerial Fire Support System qualitative material requirements that spawned the Cheyenne program. The new mission needs statement (MNS) stipulated that the AAH would be in production by 1978. {ref 2} This put the program on a tight schedule from the start. There were several new technologies on the horizon that could not be integrated in time to meet the fielding date; the Hellfire missile contained such technology [T1]. The PM worked closely with the user community to build a program that would meet their needs [W3 & D18] (e.g., being able to fight a cold war battle in all weather conditions) and still meet the first unit equipped (FUE) timeline.

It was said that the PM ruled with an iron fist as the system progressed through development. This caused great consternation throughout the technical community, but kept the program on course [I2]. Significant effort was spent on controlling the problem of requirements creep [F7, W6 & B13]. Although there were changes in system requirements [F7] as the program evolved, such as the laser guided Hellfire missile added in February 1976 {ref 2}, the close working relationship between the user and PM office [F5] helped foster a mutual trust. Most significant requirement changes were kept to a minimum as the program progressed through development and on into production [W6]. Many requirement changes were addressed as preplanned product improvements after the system transitioned to production {ref 3}.

The project significantly exceeded initial budget estimates [O8]. Prior to approval of a large program by the Defense Acquisition Board (DAB), the Office of the Secretary of Defense has their Cost Analysis Improvement Group (CAIG) provide a per unit cost estimate. The CAIG is chartered to provide an independent review of life-cycle cost estimates and to determine if additional analysis is required. The CAIG's flyaway cost estimate for the Apache was $1.7 million in fiscal 1972 dollars. {ref 2}

The program was slowed down, due to funding cuts [H1]. As the Carter administration took the reins of Government in Washington in 1976, the Apache flyaway cost had significantly increased. The new Secretary of Defense in the Carter Administration, Harold Brown, formerly the Secretary of the Air Force, was specifically the one who pushed for the A-10 that helped kill the Cheyenne program. Brown cut the Apache budget by one half on the second week of the Carter Presidency. {ref 2} To make up for the funding shortfall, the development program was stretched [H1, D1, & B2] an additional ten months {ref 1}.

There was often uncertainty about the future of project funding during the system development stage [D11]. Flyaway costs hit $6.4 million in FY 1977 dollars {ref 1}. The 1978 DoD appropriations bill contained only half the requested funding for the Apache; the program was almost cancelled {ref 2}. Despite the cuts the program pressed on and the platform proved itself during subsequent user testing. The high marks that the Apache received from the test community helped greatly when the program moved for production approval. In 1982, Congress authorized $444.5 million for low rate initial production. {ref 1}

C. RESEARCH QUESTION NUMBER 2: CRITICAL TECHNOLOGIES

"To what extent did the maturity of critical technologies being integrated into the Apache influence development? How were the organizations that had developed the critical technologies involved during system development?"

This question will be addressed by looking at three critical technologies central to the success of the development for the Apache in terms of technology readiness, the project timeline and project outcomes. I will also evaluate the involvement of various organizations during system development. Survey data includes: the role of the various science and technology (S&T) organizations, integration difficulties, production readiness, the role of the prime contractor and problem identification.

AAH systems planning and pre-development work started in 1970, soon after the Cheyenne contract was terminated. Government respondents stated that they never even changes offices, they went from working Cheyenne one day, to the AAH program the next. As documented in chapter 2, the Cheyenne had tried to push too far beyond the current state-of-art technology; this caused serious cost over runs and schedule slips. The new AAH program quickly distanced itself from the Cheyenne. {ref 2} Technology readiness was a key factor in determining the capabilities needed for the new aircraft [SP].

The Apache program wanted to integrate several new technologies onto its platform [T1]. These were highly sophisticated subsystems from as many as eight different PMO’s along with a number of subsystems developed by the prime contractor and other suppliers {ref 2}. Initial surveys identified several of these different technologies, all in the area of mission equipment [T1]. Government interviewees, in response to the survey, identified the following technologies: visionics, computers and avionics [T1]. Interviewees from the contractor community responded with the Target Acquisition/Designation (TADS), Forward Looking Infrared System (FLIRS), and the Hellfire Missile Integration [T1]. In order to have a clear view of technology integration, I will concentrate my analysis on just three of these critical technologies. In order to have consistent answers, participants were asked to respond to this single set of critical technologies [T1].

These technologies are considered to be among those central to the success of the Apache system, that is, the program may have failed if these technologies were not available for production. They are as follows: the Target Acquisition Designation System/Pilot Night Vision System (TADS/PNVS) [T1], used to acquire targets in all battlefield conditions. Second are the computer systems [T1]. These are the processors used to control the flow of information on the platform. The third critical technology addressed is the avionics used to control aircraft flight [T1].

The systems planning stage of the program started with a revalidation of the requirements. The Government respondent noted that the definition of the Advanced Attack Helicopter was centered around what the Department of the Army thought the helicopter industry was capable of producing [SP]. Great care was taken to assure that the technologies were feasible prior to sending requests for proposals to industry. The system technology readiness level (TRL) was at level 2 [SP]. A complete definition of the nine TRLs can be found in figure 9, page 44. At level 2 the technology concept and application had been formulated. Practical applications had been invented. However, the application was speculative and there was no proof or detailed analysis to support the assumptions. Examples were still limited to paper studies. At the subsystem level, the TADS/PNVS and computer systems needed the most work as they were both rated at level 2 on the TRL scale. Some systems were taken off the critical path at the beginning of development, only to be added later as they matured {ref 2}. The avionics system was rated a level 6. Avionics system and subsystem models and prototypes were demonstrated in a relevant environment. Representative models and prototype systems, which were well beyond the breadboard tested for TRL 5, had been tested in a relevant environment. This represented a major step up in a technology's demonstrated readiness. Avionics prototypes had been tested in high fidelity laboratory environments and in simulated operational environments, that is, TRL 6 [D].

The Government respondent confirmed that the Army labs at CECOM and TRADOC accomplished the primary work performed in the period from system planning to development with oversight from the Government program management team remaining from Cheyenne. Much of the behind the scenes effort was done by potentially competing contractors vying for the replacement of the Lockheed Cheyenne [SP]. Five companies submitted proposals for the AAH. They were: Sikorsky, Boeing-Vertol, Bell Helicopter, Hughes, and Lockheed. {ref 1}

The development program started in April 1973 [D], as the AAH PMO was first stood-up; BG Samuel G. Cockerham was the first PM {ref 1}. The first task of the new PMO was to down-select the proposals received towards the end of the systems planning stage. Hughes and Bell Helicopter were selected for competitive development {ref 1}. Each would build prototypes that would compete in a "winner take all" fly-off for the production contract. The new PMO had a lot of work to do in a very short period of time.

At the start of development, the technology readiness level (TRL) for the overall system was estimated to be at level 5 [D], that is, components and/or breadboard validation had been done in a relevant environment. Fidelity of breadboard technology was significantly increased. Basic components were integrated with reasonably realistic supporting elements so the technology could be tested in a simulated environment. Examples included "high fidelity" laboratory integration of components. The production readiness level (PRL) for the system at this point was at best level 2 [D]. A complete definition of the five PRL's can be found in figure 10, page 45. Level 2 is defined as the maturity of process technology sufficient to be produced outside the lab with tools and processes used for producing very low quantities. During development, the Army lab center's involvement at CECOM evolved around engineering support and requirements interpretation [D]. However, in the case of the TADS/PNVS, the Army's Night Vision and Electro-Optic Lab had much of the expertise in this new technology [D].

Critical technologies were in several different levels of readiness at development start [D]. Suppliers were quickly trying to bring their subsystems up to maturity levels that would support integration into other systems [D]. The TADS/PNVS and computer systems were both rated at level 4 on the TRL scale at the start of this phase [D]. Each had been through component and/or breadboard validation in a lab environment. Basic technological components were integrated to establish that pieces would work together, e.g., integration of ad hoc parts in lab. This was still relatively "low fidelity" compared to the eventual system. The avionics systems were much more advanced, level 7, as many had been integrated into other platforms to some degree [D]. Avionics prototypes had been demonstrated in an operational environment. These prototypes were near or at a planned operational state. This represented a major step up from level 6, requiring the demonstration of an actual system prototype in an operational environment in an aircraft. Avionics prototypes were being used in test bed aircraft [D].

Apache transition to production occurred in April 1982 [TP]. This was defined as the period when the producible system prototype had been demonstrated in an operational environment. The prototype was near or at the planned operational system and capable of being produced on a small scale. Each of the three critical technologies had also reached technology readiness level 8 [TP]. The Production Readiness Level for the system on this date had grown to level 3, as it was produced in low quantities with tools and processes that had been planned to be used in the production systems [TP]. Testing procedures for components and subsystems were established, while subsystems and support had not been finalized. The competing prime contractors' science and technology organizations accomplished the primary work in the period from development to this point. Other organizations that had been involved in the period included active support from component suppliers and the CECOM and Night Vision Army Lab Centers [TP]. The nature of the Army Lab Center's involvement was engineering support, simulation and testing [TP]. Also involved were other supplier organizations while other DoD science and technology organizations were kept informed of the progress [TP].

After the system was accepted and was in the transition to production phase, significant changes in the designs and processes were later required before the system was taken into full production [TP]. Each of the critical technologies was used as planned in the final system [TP]. After the system was actually in production, significant changes in designs and processes were also required. However, the results of the system as it was implemented, met or exceeded the project's technical goals [TP].

Survey respondents noted that the system experienced some problems in the field under operational conditions in Desert Storm [TP]. Sand and dust played a significant role in many of the problems {ref 3}. The Government respondent felt that these problems were caused from the requirements not reflecting the true field environment [TP].

D. RESEARCH QUESTION NUMBER 3: TEST STRATEGY

"Did the test strategy adequately evaluate the system for operational use?" This question will be addressed by looking at the test approach utilized.

The test strategy for the Apache was divided into several phases [SP, D, TP]. The initial testing for Phase I of the program involved two competing contractor designs. As documented in chapter 2, Hughes Helicopter and Bell Helicopters were each awarded a contract in June of 1973 to proceed into development. The designs would compete in a fly-off. The first flight for both aircraft occurred in September 1975 followed by six months of contractor testing. Prototype aircraft were delivered to the Army in June 1976 for evaluation. The Hughes design won the competition and was awarded the phase II contract in December 1976. {ref 1}

The Apache program entered testing with the failure of the Cheyenne program fresh on everyone's mind {Ch 2}. A failure modes and effects analysis was done on the system. This analysis was performed early enough for the results to be used to establish the test plan. The failure analysis also helped establish the critical test parameters for both the system and key components. [V1]

Several organizations were involved in testing the various components that were about to be integrated onto the Apache [V2 – V7]. Testing and simulations were performed first to see if the individual components of the system worked [V3, V5 & V7]. The prime contractor, component suppliers and Army labs at both CECOM (Avionics) and the Night Vision lab (TADS/PNVS) performed the bulk of this testing with oversight from the PMO [V2 – V7].

The integrated components were tested working together in a controlled setting [V4]. This testing takes the most time, as problems are found, fixed and retested. To reduce the cost of retest, simulations were also performed with the components working together in a controlled setting [V5]. The prime contractor, suppliers and to a limited degree, Army labs performed these simulations [V5]. A hardware-in-the-loop type systems integration simulation laboratory was used to see if the individual components of the system worked and to see if integrated components worked in a controlled setting [V7].

As the system evolved, testing was performed on the components working together in a realistic setting [V6]. The organizations that performed this testing included the prime, suppliers and Army labs [V6]. Once all the bugs were worked out, the system was turned over to the Government operational testers for their independent evaluations. The Apache OT II was performed by Army pilots and occurred from June to August 1981 at Ft. Hunter Liggett. {ref 8} The program managers' office kept a constant vigil over the testing. To accomplish this, the Apache PMO established a field office at the test area. {ref 1 & 8} This office kept the PM aware of what was going on at the test site, quickly resolved problems and facilitated the flow of spare parts {ref 8}. This relationship helped the Apache program stay on course and get through operational testing on schedule and within budget. The system soon advanced to Milestone III and approval to enter into production [O3 & O5].

There were several environmental issues found when the Apaches were first deployed [O9x]. When they fought in a jungle, water intrusion was a major problem {ref 2}. During the Gulf War, the fine sand particles caused new challenges {ref 3}.

E. RESEARCH QUESTION NUMBER 4: TEAMS

“How effectively were teams employed during development?” This question will be addressed by looking at the use of teams, proper staffing, and interrelationships between the government, manufacturing and suppliers.

The project was not set up with a cross-functional IPT, that is, a project team drawn from different parts of the organization with most of the skills needed for the development [H2]. The current trend in project organization is to form cross-functional integrated product teams (IPT). This is used to assure that all aspects of process integration are addressed. The Apache program development occurred during the 1970’s, about 20 years prior to the use of the formal IPT process [D]. Instead the project team had smaller technical cells each concentrating their own specific piece of the program. The contractor’s program management office had oversight of the cells and was responsible for pulling all of the pieces together [H2].

According to the survey results, nearly two thirds of the people on the contractor’s team were new employees and thus, had never even worked with others in the company until the Apache development [H5]. Attack helicopter development was new to Hughes Helicopters {ref 2}. During the development stage of the project, the contractor had just over one third of the people on the team collocated in the same building [H4a]. Few were collocated very close together, that is, on the same floor of a building within a one-minute walk [H4]. However, key technical skills were well represented on the team itself [H3]. Key members stayed with the team through pre-production planning and testing [D10].

The team leaders were skillful at getting necessary resources [D2]. Team leaders were fairly effective at resolving technical disagreements during development [D1]. Turnover in team membership was minimized [D3 & D10]. Team leaders needed management help to resolve project team disagreements several times [F4]. Usually the team knew right away where to get necessary outside help [D16].

Formal reviews were conducted at key decision points [D14]. The primary goal of these meetings was to pass high-level data among the key players and the Government. These management project reviews were only minimally constructive [D13]. These reviews tended to take away from the flow of the project as personnel spent extra time with the rigid documentation requirements. Reviews for major weapon systems tend to attract large numbers of participants. Meetings were sometimes unwieldy, frustrating and non-productive [D7].

Later in development team members started to go to the shop floor to meet about related production processes [F1]. Planning meetings were held that included both design and production people [F11]. Physical prototypes were passed around during these joint discussions [F10]. They asked for supplier comments and suggestions on design choices [F2]. Team members showed and discussed physical models of new components with suppliers [F3]. Design and production technicians explored choices together with computational models and analytical tools [F12]. They used test articles or pre-production hardware to discuss and examine problems [F13]. Just prior to the production transition phase, production representatives participated regularly in development meetings [W1]. Team members also began to meet regularly with production personnel out on the shop floor [W2]. Technical professionals from production started to have unscheduled, informal joint conversations about the project with design personnel [W16]. At that point, analytic engineering tools were being used jointly by design and production [W17]. Prototypes and parts were being used regularly in joint discussions [W18].

As the program was readied for production, it became evident that logistics skills were lacking from the program [H3]. Realizing the deficiencies, a cross-functional working arrangement was key for the transition into production [H2]. Logistics is traditionally pushed off until the end of the program. This can have serious, long lasting effects on the user if not addressed. Although the team leader was technically competent [D5], he had little experience in both design and production [D4]. By the time the program entered production, a form of IPT approach was used to resolve problems [H2]. Project results benefited from the team’s best ideas [D9].

F. RESEARCH QUESTION NUMBER 5: KEY PM ISSUE

What was the key issue that the PM had to deal with during the project and how was it dealt with? This question will be addressed by looking at the primary issue where the PM focused most of his attention and resources.

The Government survey respondent rated control of the production project as, the biggest fundamental problem the PM had to deal with in managing the overall program [I2]. Problems of control were basically the external environment, i.e., the sheer number of agencies that were to be contended with on a regular basis under the "team" approach. Like the internal organization, each had their own axe to grind and each had some level of input and "veto" power. As an example, meetings were inordinately large and therefore difficult to control. Decisions that should have been made instantly were negotiated to death leaving cost and schedule impacts to be resolved. [I2]

The PM controlled and dictated the R&D Program. Had he not dictated the R&D program there would not be an AAH today [I2]. An example of this control was brought to the researcher's attention during a Government employee interview. This occurred shortly after the initial production contract was awarded to Hughes. At that time, Hughes Helicopters was headquartered in Culver City, CA. Hughes management was looking for a site in the traditional California manufacturing corridor to build a production facility. Fearing high labor costs due to greater competition, the Apache PM, General Browne ordered a cost-analysis study of the area. They found that if Hughes located in this high cost area, that the personnel and manufacturing costs could reduce the total Apache buy nearly in half. With strong urging from top brass, and a few political incentives, Hughes chose Mesa, AZ to build their $300 million facility that would eventually employ two thousand workers. {ref 2}

V. CONCLUSIONS

A. INTRODUCTION

The purpose of this chapter is to provide conclusions and recommendations for further study. I will address significant issues found in the analysis that helped make the program a success or that caused problems or delays. Key areas from question 1 are: user representatives, requirements, and funding. Technology readiness from question 2, testing from question 3 and teaming from question 4 are also addressed in this chapter.

B. LESSONS LEARNED:

User Representatives:

The Apache program survived in a difficult political climate because the Program Manager and user representative worked closely together. It is really important to get the user representatives on board early and it is most beneficial if the PM's relationship extends to form a close working relationship with the user community. Good user support is crucial throughout the program, and including the user in all major reviews can reinforce it. This relationship must be based on trust.

Requirements:

The Apache program manager kept requirements under control by working together with the user. Requirements creep must be managed but can be kept in check if stakeholders have a clear understanding of the evolutionary path of the system. With most program developments, there are a lot of contractors who will try to sell their systems to the user. The PM must be ready to manage the technological side of the program to help the user sort through the "smoke and mirrors" that contractors use to hype their wares.

Funding:

The Apache program experienced several funding fluctuations; the PM was ready and dealt with each as it occurred. Funding stability is an issue in any large program spread out over many years. People are constantly out to get your money. You need to be on the lookout for internal suitors from your own service, those from other services and outside forces from Congress. The slightest schedule slip or problem in a program will bring its competitors to its doorstep ready to take funds that it no longer can execute.

Technology:

The Apache program had several changes in technology throughout development. They were able to track technology readiness in key areas and mitigate risk by moving certain enhancements off the critical path. Technology readiness also played a vital role when adding capabilities such as the Hellfire missile. The technology readiness levels of advanced systems must be clearly articulated to the user by the PM experts to assure that the users requirements can be met. Technology readiness should be evaluated throughout the program to assure that the system can stay on schedule. Slips in technology readiness can greatly cost the program.

Teaming:

The Apache program was developed before the advent of formal integrated product teams (IPT). However, survey respondents stated that a form of IPT was used for early production. Until then, the program was put together in smaller pieces, with teams concentrating solely on their individual area. This caused delays in the schedule when key components were not ready for system level testing. The IPT process should be utilized to assure that all aspects of the project are addressed. Good leadership and a clear vision are keys to a successful IPT. Membership must be addressed early so that decision makers are consistently present.

Testing:

The Apache program manager made test readiness a primary goal. The test team was properly staffed with the proper resources at their disposal. The test plan is an important document that helps lay out the program schedule. By performing a Failure Modes Effects and Criticality Analysis (FMECA) early, the Apache PM was able to use the results to help build the test plan. This information also feeds into the Test Evaluation Master Plan (TEMP) required for Milestone reviews. Testing on the Apache followed a traditional approach of test-fix-test. The system had clear transitions from development to operational testing. The test plan was modified with funding and schedule slips. It’s the program manager’s job to make sure that the system is ready for test. In the end, the fact that the system was able to demonstrate its operational capability in real world environments helped save the program from cancellation.

The survey respondents documented several operational problems. It's impractical to test out every potential operational scenario. Unforeseen problems and systems deficiencies are found nearly every time a new system is fielded.

C. AREAS FOR FURTHER RESEARCH

This thesis addressed mission equipment systems integrated into the Apache Attack Helicopter. There were several other Apache-related technologies that could be addressed by future studies. Possible areas of study might include: engines, 30 mm gun, and advanced materials.

Funding: Evaluate the effects of delaying funding and stretching the schedule. Another potential area is the overall effect of quantity cuts on the per-unit cost of major weapon systems.

Testing: Evaluate the traditional test methods of separate development test and operational test versus the combined testing philosophy used today. Does the new method really save time and money in a large program?

Readiness: Evaluate the use of Technology Readiness Levels developed and used in the Air Force.

Leadership: Evaluate the effectiveness of civilian leadership in the early stages of a complex acquisition category ACAT 1D program.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. REFERENCES

1. Apache PMO, Apache Selected Acquisition Report (SAR), 30 September 1992

2. Bradin, James W. From Hot Air to Hellfire. Presidio, 1994

3. Butler, Howard K. Desert Shield and Desert Storm, An Aviation Logistics History. US AVSCOM Command Historian, June 1991

4. Chandler, Charles D. & Lahm, Frank P. How Our Army Grew Wings: Airmen and Aircraft Before 1914. NY: Ronald, 1943.

5. DRC-P-H4002, Prime Item Product Fabrication Specification for the Advanced Attack Helicopter AH-64A. Hughes Helicopters, Inc. April 15, 1982

6. FAS, Military Analysis Network – Apache. http://www.fas.org/dod-101/sys/ah-64.html, October 2002

7. Ference, Edward W. Sr., Boeing Vertol Structural Engineer, interviews with author June 2002

8. FTR OT-046, Advanced Attack Helicopter Operational Test II, April 1982

9. House, Jonathan M. Towards Combined Arms Warfare. U.S. Army Staff College, 1984

10. How Stuff Works, How Apache Helicopters Work. http://www.howstuffworks.com/apache-helicopter.html, October 2002

11. Sikorsky, Igor I. Historical Archives, Incorporated First in the Air, http://www.sikorskyarchives.com/timeline.html, October 2002

12. TACOM-R1 http://www-acala1.ria.army.mil/LC/cs/csa/aahist.html#CH47 October 2002

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B: FOOTNOTES

---

[1] Chandler, Charles D. & Lahm, Frank P. How Our Army Grew Wings: Airmen and Aircraft Before 1914. NY: Ronald, 1943.

[2] Igor I. Sikorsky Historical Archives, Incorporated First in the Air, http://www.sikorskyarchives.com/timeline.html, October 2002

[3] Ibid, http://www.sikorskyarchives.com/timeline.html, October 2002

[4] House, Jonathan M. Towards Combined Arms Warfare. U.S. Army Staff College, 1984

[5] U.S. Army TACOM-R1, Historic U.S. Army Helicopters, http://www-acala1.ria.army.mil/LC/cs/csa/aahist.html#WWII, October 2002

[6] Ibid http://www-acala1.ria.army.mil/LC/cs/csa/aahist.html#WWII, October 2002

[7] Sikorsky Archives, http://www.sikorskyarchives.com/timeline.html, October 2002

[8] TACOM-R1, http://www-acala1.ria.army.mil/LC/cs/csa/aahist.html#CH47 October 2002

[9] TACOM-R1, http://www-acala1.ria.army.mil/LC/cs/csa/aahist.html#WWII, October 2002

[10] Edward W. Ference Sr., Boeing Vertol Structural Engineer, interviews with author June 2002

[11] Apache PMO, Apache Selected Acquisition Report (SAR), 30 Sep 1992

[12] Bradin, James W. From Hot Air to Hellfire. Presidio, 1994

[13] FAS, Military Analysis Network – Apache. http://www.fas.org/dod-101/sys/ah-64.html, October 2002

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C: COMBINED QUESTIONNAIRE

DESERT STORM CASE STUDY CHECKLIST: LESSONS FOR TECHNOLOGY MANAGEMENT

The U.S. Army Materiel Command is supporting a hindsight study of how technologies were developed, integrated into systems, and produced in the years leading up to Desert Storm, the last large-scale deployment of U.S. military force. It is believed that in the years leading up to that conflict, there were both successful and unsuccessful applications of technology to military systems that contain lessons for future defense technology development. The study can be done now because the intervening years allow more objectivity, and allow open examination of what were once classified projects. The study must be done now because many of the men and women responsible for the development and eventual fielding of those systems in Gulf region are retiring, taking with them important knowledge that we believe should be captured and codified into practical lessons for the future.

Our method began with a list of military systems including both successes and failures judged to be broadly representative of the systems that were under development in the years prior to Desert Storm. Then experienced students (such as those found at senior military schools and mid-career management programs) are being asked to create a single case study for a project on that list. Each case will include both (1) a narrative case history to capture the richness of the case and identify any factors that determined a project's success or failure, and (2) answers to structured questions that ask about organization, technology and process issues in a consistent way across all cases.

Participants in the selected projects are being asked to complete this survey form as background information for the students to use in their projects, and we hope you can cooperate with our research.

This is not a traditional questionnaire. If you do not remember the details we are asking about, or if you feel that the answer would be misleading or somehow inappropriate for the project we are asking you about, feel free to leave the answer blank. You may rewrite the question so it fits better. If you have comments to add, or want to suggest a better answer than what is provided, feel free to do so.

While the students conducting this research may be cleared to discuss classified material, it should be stressed that the narratives and the answers to structured questions should never include any classified information. The results will be used in unclassified reports.

You may request a copy of any report of the findings by providing your business card, or providing a separate sheet of paper with your name and address information, including your e-mail address. If you have any questions, contact:

Richard G. Rhoades
Research Institute
The University of Alabama in Huntsville
Rhoadesr@email.uah.edu (256) 824-6343

William A. Lucas
Sloan School of Management
Massachusetts Institute of Technology
walucas@mit.edu (617) 253-0538

TO BEGIN: The first set of questions defines three dates, keyed to technology readiness levels (see last page), and then asks about the roles played by different organizations at three stages of your project leading up to those dates. The organizations of interest are:

Prime's S&T org.:	Group within system prime contractor responsible for doing IR&D and developing new technology and concepts.
Other prime org.:	Any prime contractor organization other than the S&T organization.
Supplier S&T:	Same definition as for prime's S&T organization, but located at a supplier.
Other supplier org.:	Any supplier organization other than the S&T organization.
Army Lab/Center:	One or more of the Army laboratories or research, development and engineering Centers.
Other DoD/S&T org.:	An equivalent of an Army Lab/Center found elsewhere in DoD.

SP. What was the approximate starting date of systems planning and pre-development work? This date is **when planning work began on the integrated system**. The systems concept and applications had been formulated, but applications were still speculative. There was no proof or detailed analysis to support the approach.

SYSTEMS PLANNING START DATE (**SP**): __January / 1970__ (mo/yr) [TRL2 at system level]

In what organization was the primary work leading up to this point accomplished? _CHEYENNE PM, with lead support from TRADOC.

Including that organization, what organizations had been involved up to this point? (Check the role of each)

Prime's S&T org.	___ Lead/co-lead	___Active support	___Involved	___Kept informed	_X_Not involved	___DK
Other prime org.	___ Lead/co-lead	_X_ Active support	___Involved	___Kept informed	___Not involved	___DK
Supplier S&T org.	___ Lead/co-lead	___Active support	_X_Involved	___Kept informed	___Not involved	___DK
Other supplier org.	___ Lead/co-lead	_X_ Active support	___Involved	___Kept informed	___Not involved	___DK
Army Lab/Center	_X_ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Other DoD/S&T org.	___ Lead/co-lead	_X_ Active support	___Involved	___Kept informed	___Not involved	___DK

What was the nature of the Army Lab/Center's involvement? (Simulation? Concept formulation? Integration? Requirements development?) Most of the behind the scene 'effort' was competing contractors (Bell and Sikorsky), supporting their King Cobra and S-67 as replacement for the LOCKHEED CHEYENNE while supporting termination of the CHEYENNE Production contract as well as the eventual development contract. Definition of the Advanced Attack Helicopter was centered around what the Department of Army thought the helicopter industry was capable of producing.

D. Date when Development started. Typically at this date, funding started for system advanced or engineering development, a gov't project office was formed and prime contractor(s) selected.

DEVELOPMENT START DATE: (**D**): _April / 1973___ (mo/yr)

What was the Technology Readiness Level (refer to page 8) for the SYSTEM on this date? _5: **Components and/or bread board validation in relevant environment**. Fidelity of breadboard technology is significantly increased. Basic components integrated with reasonably realistic supporting elements so the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.

What was the Production Readiness Level (refer to page 8) for the SYSTEM on this date? _2: The application is **produced outside the lab** with tools and processes used for producing very low quantities.

In what organization was the primary work in the period from **SP** to **D** accomplished? Army Lab / PM

Including that organization, what organizations had been involved in the period SP to D? (Check the role of each.)

Prime's S&T org	___ Lead/co-lead	___Active support	___Involved	___Kept informed	_X_Not involved	___DK
Other prime org	___ Lead/co-lead	___Active support	_X_Involved	___Kept informed	___Not involved	___DK
Supplier S&T	___ Lead/co-lead	___Active support	_X_Involved	___Kept informed	___Not involved	___DK
Other supplier org	___ Lead/co-lead	___Active support	_X_Involved	___Kept informed	___Not involved	___DK
Army Lab/Center	_X_ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Other DoD/S&T org.	___ Lead/co-lead	_X_Active support	___Involved	___Kept informed	___Not involved	___DK

What was the nature of the Army Lab/Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?) _Engineering support & Requirements interpretation

TP. Date of achieving "Transition to Production" when **producible system prototype has been demonstrated in an operational environment**. Prototype is near or at planned operational system, produced on small scale. TRANSITION TO PRODUCTION (**TP**) DATE**:** __April / 1982__ (mo/yr) (TRL7 at system level)

What was the Production Readiness Level for the SYSTEM on this date? 3: The application is produced in low quantities with tools and processes planned to be used in production systems. Testing procedures for components and subsystems are established.

In what organization was the primary work in the period from D to TP accomplished? Prime S&T Organization

Including that organization, what organizations had been involved in the period D to TP? (Check the role of each.)

Prime's S&T org	_X_ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Other prime org	___ Lead/co-lead	_X_Active support	___Involved	___Kept informed	___Not involved	___DK
Supplier S&T	___ Lead/co-lead	_X_Active support	___Involved	___Kept informed	___Not involved	___DK
Other supplier org	___ Lead/co-lead	___Active support	_X_Involved	___Kept informed	___Not involved	___DK

What was the nature of the Army Lab/Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?) _Engineering support, Simulation & Testing

Please note: **Here we shift away from the system as a whole, and move to its component technologies.**

T1. Now identify one or more (up to 3) technologies that were incorporated into the system you are studying. These technologies should be among those *central to the success of the system*.

Technology A Target Acquisition/Designation/Pilot Night Vision System (TADS/PNVS)
Technology B _ Computers
Technology C _ Avionics

T2. How new was each technology to the prime contractor? For each technology A, B, and C, was the technology: **(Answer for date you provided for Development start , D.)**

	Technology A	Technology B	Technology C
	TADS/PNVS	**Computers**	**Avionics**
New and unproven for the prime contractor?	1. X	1. X	1. X
Technology had been used by prime contractor but it was **new to to this kind of application**?	2. ___	2. ___	2. ___
Technology had been used by prime contractor in similar applications and **was well understood**?	3. ___	3. ___	3. ___
Don't know, can't remember, or would have to guess	9. ___	9. ___	9. ___

T3. Production Impact. What was the impact of the technology on then existing production processes?
(Answer for date you provided for Development start , D.)

	Technology A	Technology B	Technology C
	TADS/PNVS	**Computers**	**Avionics**
Technology forced deep and serious production process change?	1. ____	1. X	1. ____
Technology caused significant production process change?	2. X	2. ____	2. X
Technology did not require much production process change	3. ____	3. ____	3. ____
Don't know, can't remember, or would have to guess	9. ____	9. ____	9. ____

T4. Looking back **at the Development start date,** at that time how important were these technologies to the prime?

Check (√) the best answer for each technology.

	Technology A	Technology B	Technology C
	TADS/PNVS	**Computers**	**Avionics**
This system was the Prime's only planned application of the technology.	1. X	1. ___	1. ___
Prime was planning or had started follow-on uses of the technology.	2. ___	2. X	2. X
Technology was being used in other applications and it was expected to be significant area of competence for the Prime.	3. ___	3. ___	3. ___
Don't know, can't remember, or would have to guess.	9. ___	9. ___	9. ___

Now look at the SP, D, and TP dates you provided above for the System. Using the Technology Readiness (TRL) Scale on page 8, find the number that represents the readiness of the separate technologies the team was working with at each point in time. Please answer here for the **state of development of each component technology**. (NOT for the over-all system which was the focus in the questions above.)

	Technology A	**Technology B**	**Technology C**
	TADS/PNVS	**Computers**	**Avionics**
T5. When **System** planning and pre-development began, technology TRL was:	# __2___	# __2___	# __6___
T6. When **System** went into Development, technology TRL was:	# __4___	# __4___	# __7___
T7. When **System** reached Transition to Production, technology TRL was**:**	# __8___	# __8___	# __8___

T8. For each of the technologies A, B & C, did an Army Laboratory or Center make a significant contribution to achieving any of the above levels of technology readiness?

	Technology A	**Technology B**	**Technology C**
	TADS/PNVS	**Computers**	**Avionics**
T8. Yes, it contributed to Readiness at start of Planning/Pre-development.	8a **Y**	8b. ____	8c. **Y**
T9. Yes, it contributed to Readiness for Development.	9a. **Y**	9b. ____	9c. **Y**
T10. Yes, it contributed to Readiness for Transition to Production.	10a . **Y**	10b. **Y**	10c. **Y**
Tn. No, an Army lab or center did not make a significant contribution.	No a ____	No-b ____	No-c ____
Tdk. Don't know, can't say, don't remember.	DKa. ____	DKb ____	DKc ____

Project History, Staffing and Location

H1. At some point, was the project either: _X_ 1. Slowed down? ___ 2. Stopped and restarted? ___ 3. Neither

H2. Was the project set up as a cross-functional integrated product team (IPT), a project team drawn from different parts of the contractor's organization with most of the skills needed for the development? ___ Yes _X__ No

If YES, was it: ____ 1. Set up by management, with different functions & departments tasked to provide team members.
____ 2. Set up informally, with team expected to ask departments for help as needs emerged.

H3. Key Skills. This question asks about "key skills" essential to the success of the project, defined as skills "that if they were not available at all, would have stopped team progress at the point when they were needed."

Were there any key skills **not adequately represented** on the team? ___No. _X_ Yes, one. ___ Yes, more than one.

IF YES: H35. What were the missing key skills? Please check (✓) any and all that apply.

___ 1. Internal technical professionals
___ 2. Producibility professionals (DFM, other)
___ 3. Financial/contracts professionals
___ 4. Technical/development people from Suppliers
___ 5. Producibility professionals from Suppliers
_X_ 6. Other. Please specify _Logistics____

H4. **During the Development stage** of the project, how many people on the team were collocated **very close** together? (On the same floor of a building within a one minute walk.)

___1. All ___2. Most (2/3rds or more) ___3. Some (over a third) _X__4. Few ____5. None ____DK/can't say

H4a. Including the above, how many people on the team were collocated **in the same building**?

___1. All ___2. Most (2/3rds or more) _X__3. Some (over a third) ___4. Few ____5. None ____DK/can't say

H5. How many people on the team involved in the **Development stage** had worked before with others on the project?

___1. All ___2. Most (2/3rds or more) _X__3. Some (over a third) ___4. Few ____5. None ____DK/can't say

H6. **Whose facilities** were going to be the primary production site for the application of the new technologies?

___1. Prime contractor's facilities _X_2. Both prime and supplier facilities ___3. Supplier facilities

Validation Activities: Testing and Simulation

V1. Was a failure modes and effects analysis done on the system? 1.__X__ Yes 2.____ No 3. ___ Don't know

V1a. If yes, was it used to help establish the test plan? 1.__X__ Yes 2.____ No 3. ___ Don't know

For **individual components**:

V2. Was there **testing to see if the individual components of the system worked**? What organization(s) did this testing?

_X_ Prime _X_ Suppliers _X_ Army center/lab ___Other govt org. ___Not done on project ___ Don't know

V3. Were there **simulations run to see if the individual components of the system worked**? What organization(s) did these simulations?

_X_ Prime _X_ Suppliers _X_ Army center/lab ___Other govt org. ___Not done on project ___ Don't know

For integrated components **in controlled setting**:

V4. Were **the components tested working together in a controlled setting**? What organization(s) did this testing?

_X_ Prime _X_ Suppliers _X_ Army center/lab ___Other govt org. ___Not done on project ___ Don't know

V5. Were there **simulations of the components working together in a controlled setting**? What organization(s) did this?

_X_ Prime _X_ Suppliers X limited Army center/lab __Other govt org. __Not done on project __ Don't know

For integrated components **in a realistic setting**:

V6. Was there **testing of the components working together in a realistic setting**? What organization(s) did this testing?

_X_ Prime _X_ Suppliers _X_ Army center/lab _X_Other govt org. ___Not done on project ___ Don't know

V7. Was a hardware-in-the-loop type systems integration simulation laboratory used?

V7a. To see **if the individual components of the system worked:** _X_1. Yes ___2. No ___9. Don't know
V7b. To see if integrated components worked **in controlled setting:** _X_1. Yes ___2. No ___9. Don't know

V8. Recalling the total effort (100%) spent on testing and simulations, please allocate the percent of that total that were:

__10__ % spent to see **if the individual components of the system worked**
__65__ % spent to see if integrated components worked **in controlled setting**
__20__ % spent to see if integrated components worked **in a realistic setting**
__05__ % spent on any other validation purpose.
100 %

Please evaluate the following statements about the use of testing and simulations on the project.	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Don't know
V9. Knowledge from validation work was used consistently to improve components and system.	1	2	3	X	5	9
V10. Project test philosophy was to "Break it big early."	1	X	3	4	5	9
V11. Component and system maturity were validated at the right times in the program.	1	2	X	4	5	9
V12. The project and the testing community had an adversarial relationship.	1	X	3	4	5	9
V13. Most project validation events produced quality results.	1	2	X	4	5	9
V14. The project didn't recognize important lessons that validation work uncovered.	1	2	X	4	5	9
V15. Sometimes the project settled for less than the best validation method.	1	2	X	4	5	9

Team Participants & Communications **during Development**

Here are some statements about the people on the project **during the System Development stage**. Please circle a number to indicate your level of **agreement or disagreement** that each statement is a description of team processes on this project.

	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree Somewhat	Strongly Agree	Don't know
D1. The team leader was good at resolving technical disagreements.	1	2	3	X	5	9
D2. The team leader was good at getting necessary resources.	1	2	3	X	5	9
D3. There was a lot of turn-over in team membership.	1	X	3	4	5	9
D4. The team leader had both design & production experience.	1	X	3	4	5	9
D5. The team leader had very high technical competence.	1	2	3	X	5	9
D6. Some key technical skills were not represented on the team itself.	1	X	3	4	5	9
D7. Team meetings were sometimes frustrating and non-productive.	1	2	3	X	5	9
D8. Professionals were split across too many different tasks & teams.	1	2	X	4	5	9
D9. Project results did not take advantage of the team's best ideas.	1	X	3	4	5	9
D10. Key members continued through pre-production planning and testing.	1	2	3	X	5	9
D11. There was often uncertainty about the future of project funding.	1	2	3	X	5	9
D12. The team was reluctant to share concerns with gov't PM.	1	X	3	4	5	9
D13. Management project reviews were constructive & helpful.	1	2	X	4	5	9
D14. Formal reviews were conducted at key decision points.	1	2	3	4	X	9
D15. At the prime contractor, the project was a management priority.	1	2	3	4	X	9
D16. Usually team knew right away where to get necessary outside help.	1	2	3	X	5	9
D17. Project had a visible & supportive champion in the Prime's management.	1	2	3	4	X	9
D18. There was a lot of contact with TRADOC* during the project.	1	2	3	4	X	9
D19. The gov't PM was reluctant to share problems with Army leaders	1	2	X	4	5	9

* By TRADOC here and elsewhere, we mean Training & Doctrine Command and/or other appropriate user representatives.

D20. Who besides the team usually attended formal reviews? (Check all that apply.)

D20a. Any Prime upper management (Director or VP level)? _X_ 1. Yes ___ 2. No ___ 8. Not appl. ___ 9. DK
D20b. Any Army Program management representatives? _X_ 1. Yes ___ 2. No ___ 8. Not appl. ___ 9. DK
D20c. Any TRADOC or other user representatives? _X_ 1. Yes ___ 2. No ___ 8. Not appl. ___ 9. DK

Activity Report during System Development Stage of Project

How often did team members do the following **during Development**? (If you feel the activity is Not Applicable to your project, check NA.)	Never	Once or twice	Several times	Many times	Don't know, Not appl
F1. Went to the shop floor to meet about related production processes.	____	____	____	X	(___)
F2. Asked for supplier comments & suggestions on design choices.	____	____	____	X	(___)
F3. Showed & discussed physical models of new components with suppliers.	____	____	____	X	(___)
F4. Needed management help to resolve project team disagreements.	____	____	____	X	(___)

How often did the following occur **during Development**?

F5. Did TRADOC/other user organizations show strong support?	____	____	____	X	(___)
F6. Were there changes in key TRADOC or other user personnel?	____	____	X	____	(___)
F7. Were there changes in system requirements (e.g., threat)?	____	____	X	____	(___)

SHARED DESIGN-PRODUCTION ACTIVITIES during System Development. Here **only count joint** meetings or discussions that included **both DESIGN** and people from **PRODUCTION** and/or from the **PROGRAM** concerned with production of the System.

How often did team members do the following **during Development**?	Never	Once or twice	Several times	Many times	Don't know, Not appl
F10. Passed around physical prototypes during joint discussions.	____	____	X	____	(___)
F11. Held planning meetings that included both design & production people.	____	____	X	____	(___)
F12. Explored choices together with computational models or analytic tools.	____	____	X	____	(___)
F13. Had test articles or pre-production parts to discuss and examine jointly.	____	____	X	____	(___)

SHARED DESIGN-SUPPLIER ACTIVITIES during System Development. Now **only count joint** meetings or discussions that included personnel from **both DESIGN and SUPPLIERS.**

How often did team members do the following **during Development**?	Never	Once or twice	Several times	Many times	Don't know, Not appl.
F20. Passed around physical prototypes during joint discussions.	____	____	X	____	(___)
F21. Held planning meetings that included both design and suppliers.	____	____	X	____	(___)
F22. Explored choices together with computational models or analytic tools.	____	____	X	____	(___)
F23. Had test articles or pre-production parts to discuss and examine jointly.	____	____	X	____	(___)

ACTIVITY PHASING BY STAGES OF DEVELOPMENT AND TRANSITION

When were the following activities carried out by the team? For example, if for W1, Production was involved regularly in the Selection/Planning stage, dropped out, and then came back in late in the Development work and continued to participate after that, check (✓) first, fourth and fifth columns.

Please check (✓) all stages when the activity occurred.	**SP** Selection	**D** Development Early	Middle	Later	**TP** Transition	(DK/ (Never)	NA)
W1. When did production representatives participate regularly?	____	____	____	X	X	(___)	(___)
W2. When did team members meet with production on shop floor?	____	____	____	X	X	(___)	(___)
W3. When was the TRADOC consulted on project questions?	X	X	X	X	X	(___)	(___)
W4. When was there change in key TRADOC/user representatives?	____	X		____	X	(___)	(___)
W5. When did TRADOC/other users show strong support?	____	____	X	X	X	(___)	(___)
W6. When was there change in the system requirements?	____		X	___	X	(___)	(___)

Relationship & Activities **between Engineering Design & Production/Program**

These questions are different because they focus **only** on **joint meetings or discussions** that included **both DESIGN personnel and people from PRODUCTION and/or PROGRAM** people concerned with production.

	SP	D			TP		
	Selection	Development Early	Middle	Later	Transition	(Never)	(DK/ NA)
W16. When did the team & technical professionals from **Production** have unscheduled & informal **joint** conversations about the project?	____	____	____	X	____	(___)	(___)
W17. When were analytic engineering tools used **jointly** by Design and **Production** to explore options together?	____	____	____	X	____	(___)	(___)
W18. When were prototypes and parts used in **joint** discussions?	____	____	____	X	____	(___)	(___)

Relationship & Activities **between Engineering Design & Suppliers**

Focus **only** on **joint meetings or discussions** that included **both DESIGN personnel** and **SUPPLIERS**:

	SP	D			TP		
	Selection	Development Early	Middle	Later	Transition	(Never)	(DK/ NA)
W26. When did the team & technical professionals from **Suppliers** have unscheduled & informal **joint** conversations about the project?	____	____	X	____	____	(___)	(___)
W27. When were analytic engineering tools used **jointly** by Design and **Suppliers** to explore options together?	____	____	X	____	____	(___)	(___)
W28. When were prototypes and parts used in **joint** discussions?	____	____	X	____	____	(___)	(___)

Problem Solving and Team Effort

Here are a series of statements about problems that are said to occur with technology development. For each statement, we are asking you to make two separate judgments to help us understand what problems require substantial team effort:

❶ First, did this problem ever come up in the specific project being reported on? If "No", then circle the "0".

❷ If "Yes," how serious was the impact of this problem on the process of the project's work? Here we are concerned with **how much effort** in attention, time and energy did the project have to spend solving or compensating for this problem.

❶ Did this problem come up during this project?	**No.**	**Yes.** The problem came up. ❷ IF YES, how much project effort had to be spent on this problem?				
		Very minor effort	Minor effort	Signif. effort	Major effort	Very major effort
B1. It was harder than expected to take the risk out of the new technology.	0	1	X	3	4	5
B2. Cut-backs in project resources forced changes/compromises.	0	1	2	X	4	5
B3. Changes in company strategies and goals hurt the project.	0	1	2	X	4	5
B4. A critical production issue was uncovered very late in the process.	0	1	X	3	4	5
B5. Management pressure pushed technology prematurely into production.	0	1	2	X	4	5
B6. There was a lack of acceptance standards for the new technology.	0	1	X	3	4	5
B7. The technology was hard to scale up from lab & pilot tests.	0	1	X	3	4	5
B8. Testing, quality control and/or acceptance took longer than planned.	0	1	2	X	4	5
B9. Departments at the prime resisted project ideas & approaches.	0	1	2	X	4	5
B10. One or more suppliers did not meet their commitments.	0	1	X	3	4	5
B11. Army Labs/Centers resisted project ideas or approaches.	0	1	X	3	4	5
B12. Army program offices resisted project ideas or approaches.	0	1	X	3	4	5
B13. Threat definition or other requirements changed during the project.	0	1	2	X	4	5

Project Outcomes

O1. Project Acceptance. Was the SYSTEM **accepted** to be put into Production? This is **initial acceptance**, not whether it actually ended up in production.

___ 1. No, the System was abandoned.
___ 2. No, but concept/technology was used later.
_X_ 3. Yes, the System was accepted for production
___ 8. NA, not applicable
___ 9. DK, don't know/can't remember

O2. After the SYSTEM was accepted and was in Transition to Production, **how many additional changes in the designs and processes** were later required **before the System was taken into full production**?

___ 1. Many serious changes _X_ 2. Significant changes ___3. Minor changes ___4. No or almost no changes
___ 7. Did not reach production, was not implemented ___ 8. Not Applicable ___ 9. Don't know

O3. Did the SYSTEM **go into full production**?

___ 1. No, the System was abandoned.
___ 2. No, but concept/some technology was used later.
_X_ 3. Yes, the System was put into full production.
___ 8. NA, not applicable
___ 9. DK, don't know/can't remember

O4. For each of the technologies A, B, and C above, to what extent was each used in the System as it was produced:

	O4a. **Technology A**	O4b. **Technology B**	O4c. **Technology C**
No, the technology was not used in the System.	1. ____	1. ____	1. ____
No, but the technology was used later(elsewhere)	2. ____	2. ____	2. ____
The technology was used but not to extent originally planned.	3. ____	3. ____	3. ____
Yes, the technology was used as planned.	4. _X_	4. _X_	4. _X_
Don't know.	9. ____	9. ____	9. ____

O5. After the SYSTEM reached Transition to Production, **did the project go to Production as quickly as it should have**?

___ 1. No delay _X_ 2. One to six months delay ___ 3. Seven to twelve month delay ___ 4. Over a year late
___ 5. Did not reach production, was not implemented ___ 8. Not Applicable ___ 9. Don't know

O6. **After the SYSTEM was actually in Production**, how many additional changes in designs and processes were required?

___ 1. Many serious changes _X_ 2. Significant changes ___3. Minor changes ___4. No or almost no changes
___ 7. System did not reach production ___ 8. Not Applicable ___ 9. Don't know

O7. Did the SYSTEM as it was implemented meet the program's cost goals?

___ 1. The results met or exceeded cost goals
_X_ 2. The results came close to achieving cost goals
___ 3. The results fell far short of achieving cost goals
___ 7. System did not reach production.
___ 8. Not applicable.
___ 9. Don't know.

O8. Did the System Development program, as implemented, come in on budget?

___ 1. The project met or under-ran budget.
___ 2. The project slightly exceeded budget.
_X_ 3. The project significantly exceeded budget.
___ 9. Don't know.

O9. Did the System as it was implemented meet the project's technical goals and functional requirements?

_X_ 1. The results met or exceeded technical goals
___ 2. The results came close to achieving technical goals
___ 3. The results fell far short of achieving technical goals
___ 7. Did not reach production, was not implemented.
___ 8. Not applicable.
___ 9. Don't know.

O9. Did the System have problems in the field under operational conditions in Desert Storm?

___ 1. Yes, problems in the field significantly limited the system's effectiveness.
_X_ 2. Yes, problems in the field caused minor problems in the system's effectiveness.
___ 3. No, the system was deployed and encountered no noticeable loss of effectiveness.
___ 4. No, the system was deployed and exceeded expectations of its effectiveness.
___ 9. Don't know, question not applicable to this system.

IF YOU CHECKED "1" or "2" to question O9, what did the field problems result from? Check all that apply.

O9a. ___ The System did not meet its requirements.
O9b. _X_ Requirements did not reflect the field environment.
O9c. ___ The System was not deployed in its intended role.
O9d. ___ Personnel not adequately trained/prepared to use the System.
O9e. ___ Other: ________________________
(Please explain.) ________________________

I1. Now that you have had a chance to think about the project and provide some answers, how well do you think you feel you have captured the details of the project? Are you: (Check ✓ one.)

_X_1. Very confident that you captured the project well?
___2. Fairly confident you understand the main things well, but not as confident about the details?
___3. Not confident of your information about the project, so we should only use your answers with caution.

I2. Finally, what was the most difficult problem the Project Manager faced, how was the problem dealt with, and what was the impact of the problem on the project outcome?

Funding Issues
Production Control

Technology Readiness Level Scale

1. **Basic principles observed and reported**. Scientific research begins to be translated into applied research and development concepts. There have been paper studies of technology's basic properties.
2. **Technology concept and/or application formulated.** Practical applications have been invented. Application is speculative and there is no proof or detailed analysis to support the assumptions. Examples are still limited to paper studies.
3. **Analytical & experimental critical function and/or characteristic proof of concept**. Analytical and laboratory studies have physically validated analytic predictions of separate elements of the technology. Examples include components that are not yet integrated or representative
4. **Component and/or bread board validation in lab environment.** Basic technological components are integrated to establish that pieces will work together, e.g., integration of ad hoc parts in lab. This is relatively "low fidelity" compared to the eventual system.
5. **Components and/or bread board validation in relevant environment**. Fidelity of breadboard technology is significantly increased**.** Basic components integrated with reasonably realistic supporting elements so the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. **System/subsystem model or prototype demonstrated in a relevant environment.** Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in a simulated operational environment.
7. **System prototype demonstrated in an operational environment**. Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. **Actual system completed and qualified in test and demonstration**. Technology proven to work in final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation in its intended weapon system to determine if it meets design specification.
9. **Actual system proven in successful operational environment**. Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D: ACRONYMS AND ABBREVIATIONS

AAH	Advanced Attack Helicopter or Apache Attack Helicopter
AAFSS	Advanced Aerial Fire Support System
CAIG	Cost Analysis Improvement Group
CAS	Close Air Support
D	Development (survey definition)
DoD	Department of Defense
FMECA	Failure Modes Effects and Criticality Analysis
FUE	First Unit Equipped
IPT	Integrated Product Team
IR&D	Internal Research and Development
MNS	Mission Needs Statement
PM	Program Manager
PMO	Program Management Office
RFP	Request for Proposal
SP	System planning phase (survey definition)
S&T	Science and Technology
TEMP	Test Evaluation Master Plan
TP	Transition to Production (survey definition)
TRL	Technology Readiness Level

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Dr. Richard G. Rhoades
   University of Alabama at Huntsville
   Huntsville, Alabama