NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

CASE STUDY OF THE DEVELOPMENT OF THE TARGET ACQUISITION DESIGNATION / PILOT NIGHT VISION SYSTEM

by

Jerome A. Oelrich

December 2002

Thesis Advisor: David F. Matthews
Associate Advisor: Richard Rhoades

Approved for public release; distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2002	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Title (Mix case letters) Case Study of the Development of the Target Acquisition Designation System / Pilot Night Vision System (TADS/PNVS)			**5. FUNDING NUMBERS**
6. AUTHOR(S) Oelrich, Jerome A.			
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 thesis is a case study of the extent to which a series of factors influenced development of the U.S. Army Target Acquisition Designation System/Pilot Night Vision System (TADS/PNVS). This study is one of a series being prepared under an ongoing research effort sponsored by Headquarters U.S. Army Material Command (AMC). These studies will look at various weapon systems that participated in Operation Desert Storm (ODS) and will study the effectiveness of their Development Strategies, for the purpose of later comparing system effectiveness in ODS. The TADS/PNVS was developed for the AH-64A Apache Helicopter, as a sighting system for the Hellfire missile system. This case study focuses on the system's three critical technologies, evaluates their technical maturity at various stages versus Technology Readiness Levels, and analyzes how that affected the later development and testing. The study also highlights funding stability, user involvement, integrated product teams, and testing strategies. The thesis focuses particular attention on testing, and whether testing of the TADS/PNVS system was sufficient and timely during development.

14. SUBJECT TERMS Acquisition, AH-64, AMC, AMCOM, Bore Sight, Development, IPT, LOSS, Night Vision, ODS, PM, PMO, PNVS, Program Management, Stabilization, TADS, Test, TRADOC, TRL			**15. NUMBER OF PAGES** 116
			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

Approved for public release; distribution is unlimited.

CASE STUDY OF THE DEVELOPMENT OF THE TARGET ACQUISITION DESIGNATION / PILOT NIGHT VISION SYSTEM

Jerome A. Oelrich
DB-03, United States Army
B.S., University of Illinois, 1980

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: Jerome A. Oelrich

Approved by: David F. Matthews
Thesis Advisor

Richard G. Rhoades
Associate Thesis Advisor

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

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This thesis is a case study of the extent to which a series of factors influenced development of the U.S. Army Target Acquisition Designation System/Pilot Night Vision System (TADS/PNVS). This study is one of a series being prepared under an ongoing research effort sponsored by Headquarters U.S. Army Material Command (AMC). These studies will look at various weapon systems that participated in Operation Desert Storm (ODS) and will study the effectiveness of their Development Strategies, for the purpose of later comparing system effectiveness in ODS. The TADS/PNVS was developed for the AH-64A Apache Helicopter, as a sighting system for the Hellfire missile system. This case study focuses on the system's three critical technologies, evaluates their technical maturity at various stages versus Technology Readiness Levels, and analyzes how that affected the later development and testing. The study also highlights funding stability, user involvement, integrated product teams, and testing strategies. The thesis focuses particular attention on testing, and whether testing of the TADS/PNVS system was sufficient and timely during development.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I would like to thank Professor Dave Mathews for his guidance and support during the preparation of this thesis.

I would like to thank Dr. Richard Rhoades for agreeing to be my associate thesis advisor. His time, patience and professionalism were greatly appreciated.

I would like to thank my supervisor, Dr. Willie Fitzpatrick; former supervisor, Fred Reed; and director, Bill Craig for giving me the opportunity to advance my career through education.

I would also like to thank the following individuals for taking the time to provide me with information.

Steven P. Smith
Milton Fluker
Dave Sullivan
Pat McIngvale

Lastly, I would like to thank the whole Comanche PMO for being understanding of the time needed to complete this thesis and Master's Degree program.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to study the extent to which a series of factors influenced development of the Target Acquisition Designation System/Pilot Night Vision System (TADS/PNVS). The research findings and conclusions will be primarily based upon answers to a questionnaire completed by the Government and Contractor Program Managers (PM) or Deputy Program Managers (DPM) and their staffs, supplemented by interviews with these individuals.

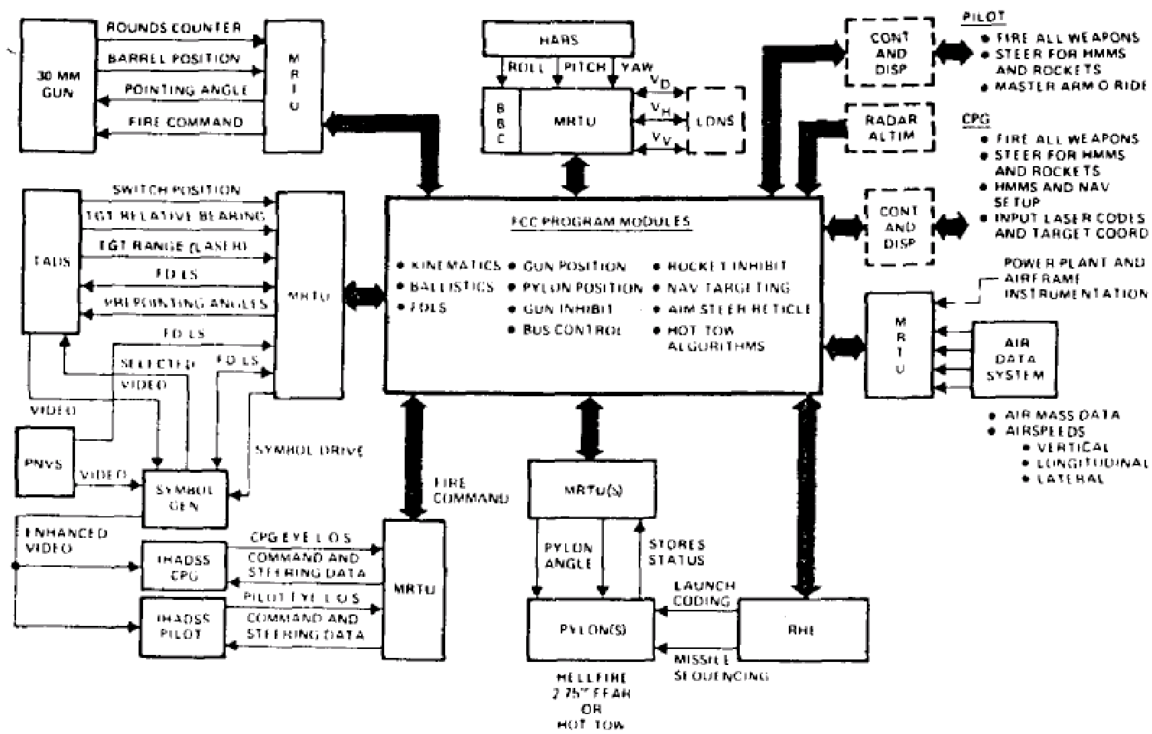

Figure 1. AH-64A Mission Equipment Package Architecture from TADS/PNVS Interfaces with other Mission Equipment of the AH-64 Helicopter, Martin Marietta Aerospace International, May 1983.

B. BACKGROUND

The U.S. Army developed a variety of systems in the 1970s and 1980s, based on experience gained in the Viet Nam War. Many of these systems did not see significant actual combat usage until 1991, during Operation Desert Storm in Iraq.

The first shots of Operation Desert Storm were fired by AH-64A Apache Helicopters (Task Force Normandy) on "January 17, 1991". The TADS/PNVS was used to acquire the targets. At first, they used the heat from the target to guide the missiles. When a flash was distracting some missiles, they switched to optical guidance (From Hot Air to Hellfire - James W. Bradin, © 1994).

The targets, two state-of-the-art Soviet-built radar sites, which threatened to give early warning of the initiation of the air campaign, were simultaneously attacked at 2:38 am. The targets were completely destroyed. This allowed the allies to fly surreptitiously right in and bomb Iraq (Bradin, 1994).

Originally, the Target Acquisition Designation System / Pilot Night Vision System (TADS/PNVS) was conceived by The U.S. Army Missile Command (MICOM), which initially led the developmental effort. It was subsequently transitioned to the Apache Attack Helicopter Program Manager's Office (AAH PMO). The U.S. Army developed TADS as a sensor for the Hellfire missile system. TADS/PNVS was developed in the 1970s and 1980s under control of the TADS Program office, which was a part of the AAH Program Management Office.

C. RESEARCH QUESTIONS

1. Primary Question:

What was the simulation and testing strategy for the system, and did that strategy adequately evaluate the system for its ultimate operational use?

2. Secondary Questions:

a. To what extent did the maturity (at project initiation) of the critical technologies being integrated into the TADS/PNVS system influence the development?

b. How were the organizations that had developed these critical technologies involved during system development?

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

d. How effectively were (what we now call) integrated product teams employed during development?

e. What was the key issue that the PM had to deal with during program development and how was it dealt with?

D. SCOPE OF THE THESIS

The thesis will focus on TADS/PNVS development, will note how well it met its cost, schedule, and performance goals, and will also touch briefly upon its successful use in DESERT STORM. It will consider the critical technologies of TADS / PNVS and whether they were effectively implemented in this system. The research method will be a case study, developed by use of questionnaires and interviews.

This thesis explores the interrelationship of players such as users, Government PMO, contractors, technology developers, and testers in carrying out the development, production, and fielding of the system. In addition, factors such as the effective use of integrated product teams, the maturity and production readiness of the critical technologies, the role played by testing and simulation, the relationship between testing and operational use, and the key issue faced during the program and its resolution are examined. Project outcomes, in cost, schedule and performance in terms of Desert Storm, are identified.

E. METHODOLOGY

Research approach consists of determining three TADS/PNVS Critical Technologies in consultation with the TADS/PNVS technology community; sending questionnaires out to current and former Government and Contractor Program Managers and their staffs; then conducting interviews with them; and analyzing this data. I used a tape-recorder attached to the telephone, when the interviewee consented to being recorded. Additionally, I analyzed the testing of these systems to determine if it were adequate to prove the system's combat readiness. The results of the initial interviews were written up and I determined where I had coverage or gaps in my data. I then conducted follow-up interviews, or questioned alternate personnel, who filled in data gaps. Next I used my overall understanding of the development to integrate the results from all survey questionnaires into one composite response survey result, to be used for the subsequent crosscutting analysis.

F. ORGANIZATION

Chapters II through VI discuss the secondary research questions, and Chapter VII addresses the primary research question. In each chapter, I summarize the data collected from the survey. I will introduce the data, and also mention briefly the way in which it was acquired.

I analyzed the data, comparing responses to various questions, and between the Government and contractor respondents, as well as advantages and disadvantages, analyzing them in terms of the primary and secondary questions. Then I will discuss lessons learned, and draw conclusions and make recommendations.

Chapter II: Mature Technologies: To what extent did the maturity (at project initiation) of the critical technologies being integrated into the TADS/PNVS system influence the development?

Chapter III: Development Organizations: How were the organizations that had developed these critical technologies involved during system development?

Chapter IV: User Support and Funding Stability: To what extent was there user support and funding stability during system development?

Chapter V: Integrated Product Teams: How effectively were (what we now call) integrated product teams employed during development?

Chapter VI: Key Program Manager Issue: What was the key issue that the PM had to deal with during program development and how was it dealt with?

Chapter VII: <u>Primary Question – Simulation and Testing Strategy</u>: What was the simulation and testing strategy for the system, and did that strategy adequately evaluate the system for its ultimate operational use?

In the back, there is a list of Acronyms and Definitions.

In Appendix A, I will provide the Composite Questionnaire Response. This will be a composite of the Government and developer / contractor responses.

G. BENEFITS OF THE STUDY

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

THIS PAGE INTENTIONALLY LEFT BLANK

II. MATURE TECHNOLOGIES

A. RESEARCH QUESTION

This chapter answers the research question, “To what extent did the maturity (at project initiation) of the critical technologies being integrated into the TADS/PNVS system influence the development?” This chapter will look at the maturity of the critical technologies in terms of (1) project outcomes, (2) technology readiness, and (3) project timeline. I will introduce the data, then analyze it, and finally draw conclusions.

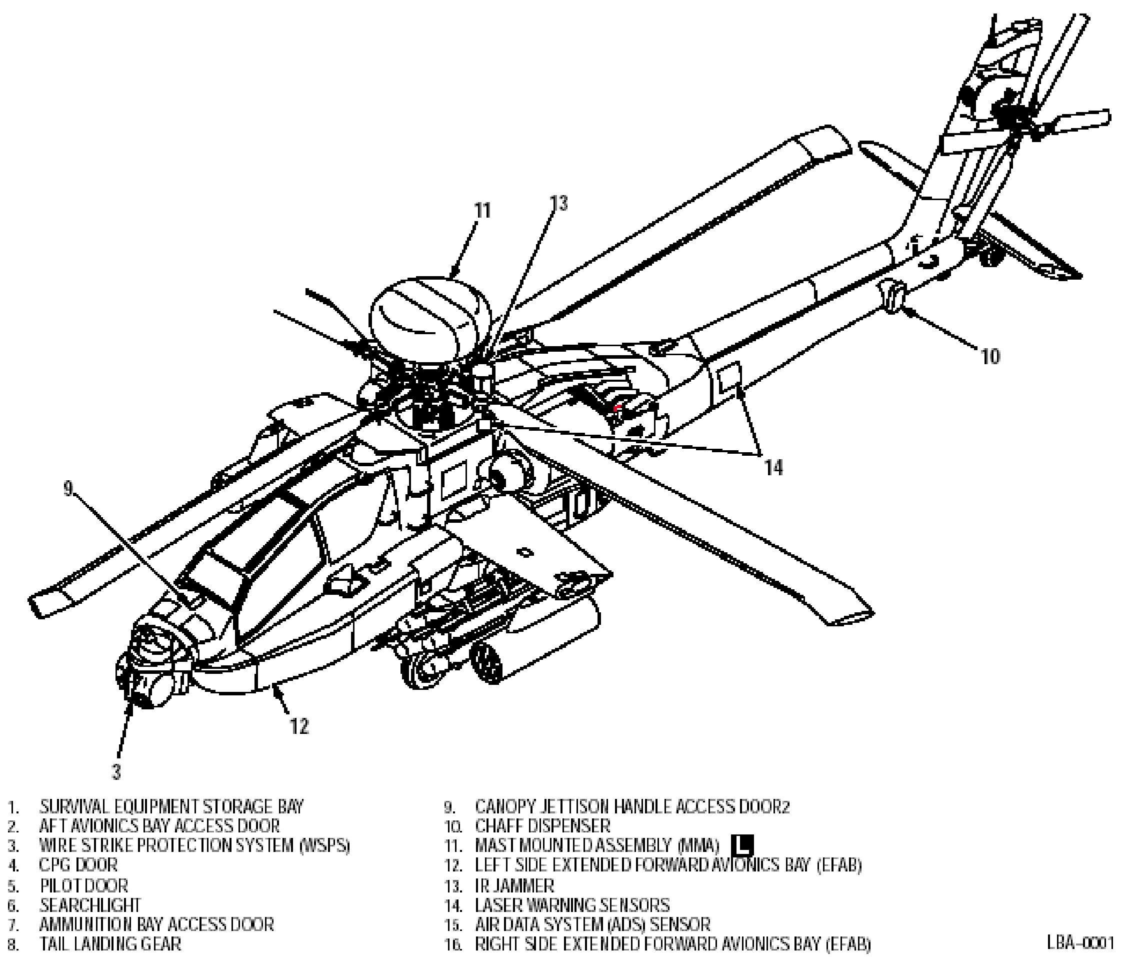

Figure 2. Longbow Apache General Arrangement, from TM 1-1520-251-10, Technical Manual, Operator's Manual for Helicopter, Attack, AH-64D Longbow Apache, 15 Dec 1998

B. DATA

Data was acquired using questionnaires / survey and interviews. From all this data, a combined survey was created (see Appendix A.) I extracted the data in this and subsequent chapters from the combined survey.

In the survey, each question has a letter and number (i.e. T1) except for questions on page 1. In the survey, the format is: question, then multiple-choice answers for some questions, and possibly a blank for answers. When I extract information from the data, it will always reference this numbering system, and give the question and the ***answer*** that was chosen, not all possible choices (i.e. _***X***_ 4. All of the above.) Responses to questions are in ***italics***.

To better understand this data, I include the **critical 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 (**critical**).

Technology A	***Line-of-Sight Stabilization***
Technology B	***FLIR target acquisition***
Technology C	***Laser to sensor bore sight***

Table 1. Critical Technologies

1. Outcomes?

This contains survey questions O1 through O9, Project Outcomes.

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.

_***X***_ 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? _***X***_ 1. Many serious changes

There was a large amount of work. TADS pointing angle accuracy was a big problem. They had to work on getting a noise-free FLIR. And they needed to work on consistency of Line-of-Sight (LOS) Stabilization – they made repeated changes to meet this specification requirement. The delivery rate of 10, and then 12 per month exacerbated the problem.

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

_*X*_ 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	**B**	**C**
4. Yes, the technology was used as planned.	4. ***X***	4. ***X***	4. ***X***

After the early stages of development, LOS stabilization never really became an issue any more. FLIR acquisition ranges were met in the later stages of development and were not a problem in the production hardware. Bore-sight performance continued to be an issue into the early stages of production. The cost of the fixes were not major but took a lot of time to work out. All three technologies were essential to the performance of the TADS and thus had to be successfully used in the final system.

O5. After the SYSTEM reached Transition to Production, **did the project go to Production as quickly as it should have**? _*X*_ 2. One to six months

O6. **After the SYSTEM was actually in Production**, how many additional changes in designs and processes were required? _*X*_ 3. Minor changes

"Again, the contractor was incentivised to make reliability improvement changes and under the warranty program could make changes to improve reliability and thereby save the contractor (and ultimately the Government) money. Producibility changes were also made mostly because of parts that were no longer available."

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

_*X*_ 3. The project significantly exceeded budget.

"As stated above there were significant overruns to the development contracts. The "Maturity phase contract with Martin Marietta started off at about $45M and ended up at about twice that. However, TADS/PNVS was not a separate line item in the budget but was just part of the AH-64 budget and this overrun was covered within the AH-64 budget."

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.

O9. (Note: there are two questions designated O9.) Did the System have problems in the field under operational conditions in Desert Storm?

_*X*_ 3. No, the system was deployed and encountered no noticeable loss of effectiveness.

2. Technology Readiness?

This contains survey questions T5, T6 T7, and Page 1 (SP, D, and TP questions.)

Check (√) the best answer for each technology.	Technology A	Technology B	Technology C
T5. When **System** planning and pre-development began, technology TRL was:	***4***	***4***	***3***
T6. When **System** went into Development, technology TRL was:	***5***	***5***	***4***
T7. When **System** reached Transition to Production, technology TRL was**:**	***9***	***9***	***8***

Table 2. Data for Questions T5, T6, and T7

TRL = Technology Readiness Level (TRL numbers are defined at the end of Appendix A, Combined Survey)

When SP (System Planning phase) *started, stabilization technology was not new and had had many applications, but none to this difficult an application in a helicopter flight environment. Likewise, due to the work on FLIR technology by NVL [U.S. Army Night Vision Labs] there was a significant technology base to draw on; however, meeting target detection and recognition requirements was a very difficult goal and integration of a FLIR meeting these requirements into the stabilized turret was a real challenge. The bore-sight problem was recognized as critical from the very beginning, but achieving a bore-sight, which met accuracy requirements and remained stable over environmental extremes proved very difficult and tenuous. Since bore-sight stability is impacted by many factors in all sensors, bore-sighting components and the stabilized turret, it was not possible to address bore-sight shortcomings until the entire TADS system was designed, built, and tested for other areas of performance.*

SP. In what organization was the primary work leading up to this point accomplished? *There were really three important organizations that contributed. The ASH PM (Advanced Scout Helicopter) prior to being cancelled and the AAH PM were the driving force for establishing and planning the program. The technology work was being led by the MICOM G&C* (Guidance and Control) *lab and The Night Vision Lab (NVL). Contractor S&T* (Science and Technology) *organizations were doing their own work in response to the anticipated requirement for the ASH and AAH programs.*

"The MICOM G&C lab was the developer of the Hellfire missile (concept) *for which the TADS acquires and designates targets. Major systems requirements such as Total Pointing Error (TPE) for the laser designator were defined by the G&C lab based on testing and simulations. They also did early work on the laser hardware that does the designation. NVL was the developer of FLIR technology, which was used in the TADS night sight and the PNVS. They were responsible for the development and eventually production of the FLIR common modules, which are used in the TADS Night Sight. Significant support was given by these labs and Frankfort Arsenal (fire control, optics) in formulating requirements, evaluating proposals, and monitoring development progress."*

D. What was the Technology Readiness Level (refer to page 8) for the SYSTEM on this date? *Level 3: The system met the spec, but not consistently. They had proved* *that the gimbals would meet the LOS* (Line-of-Sight) *Stabilization. A prototype was built in the proposal phase.*

What was the nature of the Army Lab/Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?) *G&C Lab, NVL, and Frankfort Arsenal provided engineering support, simulation, and requirements interpretation.*

TP (Transition to Production). In what organization was the primary work in the period from D to TP accomplished? *Martin Marietta, Orlando, the Prime Contractor. This work was done under a project management (PM) organization.*

What was the nature of the Army Lab/Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?) *MICOM G&C, NVL, and Frankfort Arsenal continued to provide engineering support, simulation, test witnessing, and requirements interpretation.*

3. Timeline?

This covers survey questions on Page 1. The timeline data from page 1 is as follows:

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**): _____/***1976*** (mo/yr) [TRL2 at system level]

D. Date when Development started. Typically at this date, funding started for system advanced or engineering development, a Government project office was formed and Prime Contractor(s) selected. DEVELOPMENT START DATE (**D**): _____/***1977*** (mo/yr)

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**:** _____/***1980*** (mo/yr) (TRL7 at system level)

Additional Timeline data is found in From Hot Air to Hellfire - James W. Bradin, © 1994.

Date	**Event**
10 Dec 1976:	Down select to Hughes YAH-64A
FY 1982:	Congress approves LRIP, $444.5 M Contract for 11 aircraft

Table 3. From Hot Air to Hellfire Timeline

Further timeline data was found in "Selected Acquisition Report (SAR), 30 September 1992", an annual report on the status of the AH-64 Apache Helicopter development program.

Date	Event
22 June 1973	Competitive Phase I, Development Contracts awarded to Hughes Helicopters and Bell Helicopters Textron, Inc
7 Dec 1976	DSARC approved AAH entry into full scale development (Phase II) and Secretary of the Army selected Hughes Helicopters, Model YAH-64
10 Mar 1977	TADS/PNVS directed for development, contracts awarded to Martin Marietta and Northrop Corporation.
30 Jan 1981	Army awarded Long Lead Time contract to MMOA (TADS/PNVS)
20 Feb 1981	Army LLTI contract to Hughes (AH-64)
Jun-Aug 1981	Operational Test (OT II) was completed on time at Ft. Hunter-Ligett
18 Nov 1981	Army System Acquisition Review Council (ASARC) III was completed
26 Mar 1982	DSARC III held, initial production of Apaches approved
April 1982	Production contracts awarded to Hughes, MMOA, and General Electric (engines)
Early 1984	McDonnell Douglas acquired Hughes Helicopter
26 Jan 1984	McDonnell Douglas Helicopter Company (MDHC) first production aircraft (PV01) rolled out
22 July 1986	Initial Operational Capability

Table 4. Selected Acquisition Report (SAR) Timeline

Test Plan for TADS/PNVS Competitive Development

1 Dec 1979 to 29 Feb 1980	The TADS/PNVS competitive development test was conducted at Yuma Proving Grounds (YPG). It was a fly-off between the Martin Marietta Corporation and Northrop Corporation TADS/PNVS advanced prototypes, each mounted on AH-64 aircraft.

Table 5. TADS/PNVS Competitive Development Timeline

C. ANALYSIS

This section will analyze the maturity of the critical technologies in terms of (1) Outcomes, (2) Technology Readiness, and (3) Timeline.

1. Outcomes?

The three critical technologies of the TADS/PNVS are: Laser to sensor bore-sight (LSBS), Line-of-Sight Stabilization (LOSS), and Forward-looking Infra Red (FLIR) Target Acquisition (FTA). The critical technologies were used as originally planned. All three of the technologies were essential; TADS would not have worked without them. LOS Stabilization was fixed in early development, FTA in later development. Bore sighting wasn't finalized until early production – a lot of time was needed, but not all that much money. Although the technologies were immature at the beginning of development, the developer persevered and the system was eventually accepted for full production.

Developing a system such as TADS/PNVS is a tremendous amount of work. This work paid off and the system was very mature when it transitioned to production. A lot of work had to be done to both get ready for production, and in the transition to production and the early stages of production. Changes included work on pointing angle accuracy, noise-free FLIR, and consistency of Line-of-Sight (LOS) Stabilization, which required repeated changes. The required delivery rates of 10, and then 12 per month, ramping up from 1 per month, increased the level of difficulty.

In going to production, the system only experienced a short delay of one to six months. There were some minor changes during TP, in order for the system to meet or improve performance. Similarly, there were some minor changes to the system while in production, mostly to increase system reliability. The contractor had a financial incentive to improve reliability (which eventually saves the Government money also.) They also made producibility changes due to parts becoming obsolete.

There was a significant increase in development costs. The original TADS/PNVS contract was for $45 million, and it ended up costing twice that amount. However, the system met or exceeded technical performance goals. The system was deployed on the AH-64A Apache Helicopter, and performed effectively in Operation Desert Storm.

2. Technology Readiness?

When system planning and pre-development began, two of the three critical technologies (Line-of-Sight Stabilization and FLIR target acquisition) had been verified in breadboard form in a laboratory environment (Technology Readiness Level 4). LOSS had never been tried on a helicopter – a high-vibration environment. The third technology (Laser to sensor bore-sight (LSBS)) had only been verified by a combination of laboratory work and analytical studies (TRL 3). Three groups did most of the technical work: the MICOM Guidance and Control (G&C) lab, the US Army Night Vision Lab (NVL), and contractor science and technology group. Additionally, Frankfort Arsenal gave support in fire control and optics.

By the time the system was in development, Laser to sensor bore-sight had been verified completely in a laboratory environment, and the other two technologies had been verified in a realistic, though simulated environment (TRL 5). This TRL indicates the technologies were advanced enough for the development phase to start, but not yet ready for fielding. They had built a prototype, and the system met the specification, though not consistently. The U.S. Army's contribution came from the G&C Lab, NVL, and Frankfort Arsenal, which provided engineering support, simulation, and requirements interpretation.

When the system reached the transition to production, the technologies were considerably more advanced. An actual system had been tested, and the Laser to sensor bore-sight had been qualified in test and demonstration. The technology was proven in its final form. The other two technologies, in final form, had also been successfully tested in a realistic operational environment. At this point the system was given the go-ahead for production.

There were still some production reliability and manufacturability issues to work out, but the essential system was ready. Bore-sight stability is affected by a number of characteristics of all sensors, bore-sighting components, and the stabilized turret. This makes doing the bore-sight design difficult until after the rest of the TADS system has been designed, built and tested. During this phase, Martin Marietta did the primary work. The PMO oversaw this effort, and G&C, NVL, and Frankfort Arsenal provided support.

3. Timeline?

The following table is a timeline of the TADS/PNVS Program from Systems Planning (SP), though Development (D), to the Transition to Production (TP). As you can see from the table, the Technology Readiness Level (TRL) of the three critical technologies gradually increased as the program progressed. [See definitions of TRL at end of Appendix A, Combined Survey.]

Key Program Start Dates	**Year**	**Technology A &B TRL**	**Technology C TRL**
Systems Planning (SP)	1976	**4**	**3**
Development Start (D)	1977	**5**	**4**
Transition to Production (TP)	1980	**9**	**8**

Table 6. Program Timeline

The following timeline is compiled by merging these dates in with data from other TADS documents (From Hot Air to Hellfire, Selected Acquisition Report (SAR), and Test Plan for TADS/PNVS Competitive Development).

Date	Event	Ref.
22 June 1973	Competitive Phase I, Development Contracts awarded to Hughes Helicopters and Bell Helicopters Textron, Inc	SAR
1976	Systems Planning (SP)	Survey
7 Dec 1976	DSARC approved AAH entry into full scale development (Phase II) and Secretary of the Army selected Hughes Helicopters, Model YAH-64	SAR
10 Dec 1976:	Down select to Hughes YAH-64A	Bradin
10 Mar 1977	TADS/PNVS directed for development, contracts awarded to Martin Marietta and Northrop Corporation.	SAR
1977	Development Start (D)	Survey
1 Dec 1979 to 29 Feb 1980	The TADS/PNVS competitive development test was conducted at Yuma Proving Grounds (YPG). It was a fly-off between the Martin Marietta Corporation and Northrop Corporation TADS/PNVS advanced prototypes, each mounted on AH-64 aircraft.	CD Test Plan
1980	Transition to Production (TP)	Survey
30 Jan 1981	Army awarded Long Lead Time contract to MMOA (TADS/PNVS)	SAR
20 Feb 1981	Army LLTI contract to Hughes (AH-64)	SAR
Jun-Aug 1981	Operational Test (OT II) was completed on time at Ft. Hunter-Ligett	SAR
18 Nov 1981	Army System Acquisition Review Council (ASARC) III was completed	SAR
FY 1982	Congress approves LRIP, $444.5 M Contract for 11 aircraft	Bradin
26 Mar 1982	DSARC III held, initial production of Apaches approved	SAR
April 1982	Production contracts awarded to Hughes, MMOA, and General Electric (engines)	SAR
Early 1984	McDonnell Douglas acquired Hughes Helicopter	SAR
26 Jan 1984	McDonnell Douglas Helicopter Company (MDHC) first production aircraft (PV01) rolled out	SAR
22 July 1986	Initial Operational Capability	SAR

Table 7. Overall Program Timeline

D. CONCLUSIONS

This section will draw conclusions concerning the maturity of the critical technologies. Conclusions concerning the timeline will be interspersed with other sections.

1. Outcomes?

The critical technologies were all essential to the TADS/PNVS program: Laser to sensor bore-sight (LSBS), Line-of-Sight Stabilization (LOSS), and Forward-looking Infra

Red (FLIR) Target Acquisition (FTA). The TADS/PNVS was significantly beyond existing technology, and there was a good deal or risk to overcome. The amount of work required was greater than planned, but the developer and the PMO were able to complete the development and deliver a functioning system.

This additional work effort carried over into the transition to production, and in early production, but the reward was that they were at a fairly good level of readiness. Operational Testing was completed on time at Fort Hunter-Ligett in June-August 1981. Changes to the system were critical, to meet or improve performance, to increase system reliability and to improve reliability, but did not delay system production very much. The TADS/PNVS contract cost twice the amount originally contracted, from $45 million to about $90 million; but the system met its technical objectives and performed well in Operation Desert Storm.

2. Technology Readiness?

At the start of system planning (1976) and pre-development, the TADS/PNVS critical technologies were verified at Technology Readiness Levels 3 or 4 (in a lab environment or by analytical studies.) By the time the system was in development (1977), this had advanced to TRL4 or TRL5 (verified in realistic, though simulated environment.) When the system reached the transition to production (1980), the critical technologies were at TRL8 (qualified in test and demonstration) or TRL9 (an actual system had been tested.)

The TADS/PNVS transition to production phase was successful because the system was at a sufficiently mature technology readiness level for the transition. A lot of work was needed to meet remaining performance requirements and on manufacturability and reliability, but most requirements already had been met at this point. The developer and many Government labs contributed to the success of the TADS / PNVS system.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. Technology Maturation:

Study the various processes of technology maturation, including technology developed for civilian industry, Research Development partnering development efforts by Defense contractors, and technology developed specifically for a program. Study the technical and financial processes, and the risk to overall project funding.

2. Technology Readiness:

Study technology readiness at the beginning, during, and after each of the major wars of this century (World War I, World War II, Korean War, and the Viet Nam War) and compare these readiness levels to those of Operation Desert Storm and the war in Afghanistan.

3. Technology Readiness Level Measurement:

Study various methods used to measure technology readiness level, by whatever names they are known, and how well each technique works to give the program manager knowledge of the status of the program.

III. DEVELOPMENT ORGANIZATIONS

A. RESEARCH QUESTION

This chapter answers the secondary research question, "How were the organizations that had developed these critical technologies involved during system development?" This chapter will look at the involvement of the organizations that had developed the critical technologies during system development, in terms of (1) the role of S&T organization that developed technology, (2) role of Government S&T organization, (3) difficulties in integrating technology, (4) production readiness, (5) importance of technology to Prime Contractor, (6) familiarity of Prime with technology, and (7) timely problem disclosure. I will list the data, then analyze it, and finally draw conclusions.

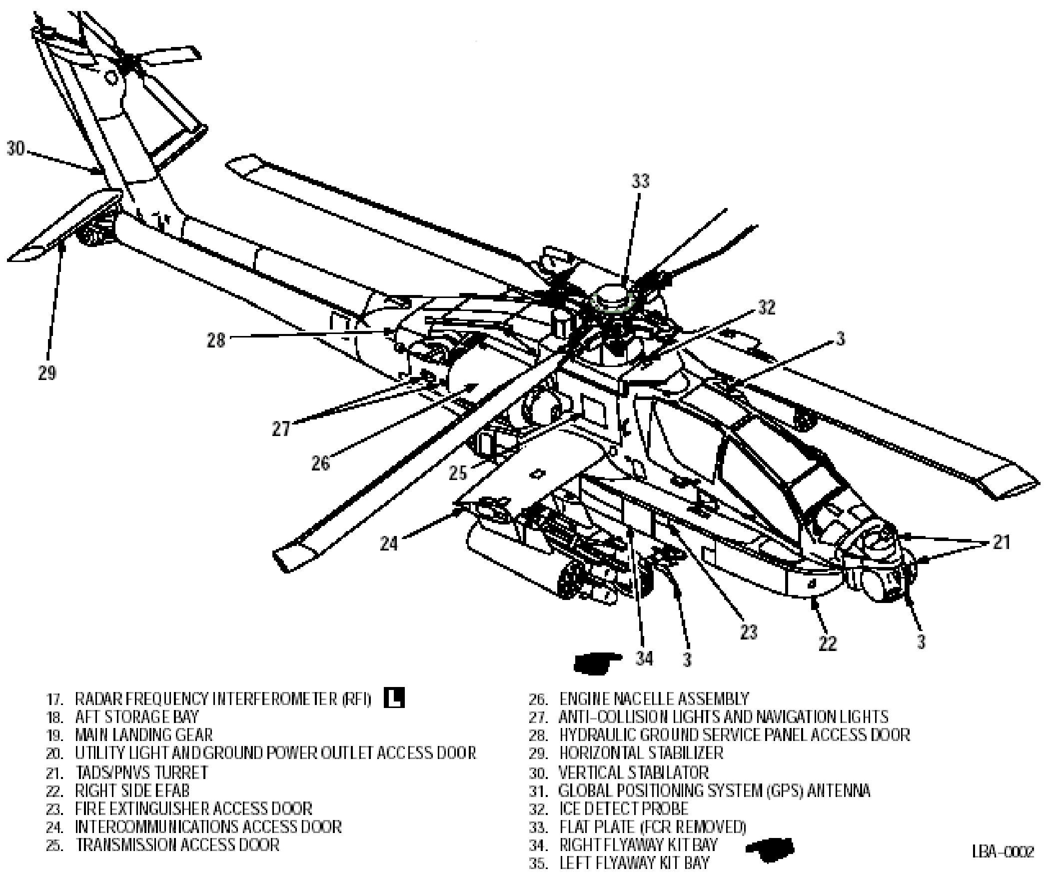

Figure 2-1. General Arrangement (Sheet 2 of 2)

Figure 3. General Arrangement page 2, fromTM 1-1520-251-10, Operator's Manual for Helicopter, Attack, AH-64D, Longbow Apache, 15 Dec 1998

B. DATA

1. Role of S&T Organization that Developed Technology?

This covers survey questions T8, T9, T10, and Page 1. Page 1 data is listed in Chapter II.

T8. For each of the technologies A, B & C, did <u>an Army Laboratory or Center</u> make a significant contribution to achieving any of the above levels of **technology readiness?**	<u>Technology A</u>	<u>Technology B</u>	<u>Technology C</u>
T8. Yes, it contributed to Readiness at start of Planning/Pre-development.		***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 8. Data for Questions T8, T9, and T10

2. Role of Government S&T Organization?

This covers survey questions T8 through T10, B11, and Page 1. Page 1 data is listed in Chapter II; and T8 through T10 are listed above in '2. Role of S&T organization that developed technology?'

B11. Army Labs/Centers resisted project ideas or approaches. _*X*_ (No)

3. Difficulties in Integrating Technology?

This covers survey questions T3, H3, B1, and B4 through B8.

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	B	C
1. Technology forced deep and serious production process change?	***X***	***X***	
2. Technology caused significant production process change?			***X***

Table 9. Data for Question T3

This level was chosen because the contractor was not producing other systems like this at the time. At the component level, production processes were not significantly different and did not require much change; however, and the system and major subsystem-level (FLIR, Day Sight, bore-sight) production acceptance test stations had to be created to insure that delivered hardware was meeting system-level specifications. Also, an effort was made to identify component tests and processes, which would reduce *the failures that would be seen at system-level and major subsystem-level acceptance tests. These component tests were unique and different some of the times because they were driven by system-level specifications, which were unique at this time to the TADS/PNVS.*

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? _*X*_ No.

The design chief could draft people from other groups. It was as good as "DX brick bat" priority, which same individual had later on, at least within the company in Orlando. However, they didn't have the microwave electronics hybrids design group, nor the printed circuit layout design people on the project. Those were both functional groups, and the TADS/PNVS group didn't have enough work to justify keeping them on their team. But they had as good of a priority with these groups as any other project in the company in Orlando.

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

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

B5. Management pressure pushed technology prematurely into production. *Minor effort*

B6. There was a lack of acceptance standards for the new technology. *Very minor effort*

B7. The technology was hard to scale up from lab & pilot tests. *Significant effort*

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

4. Production Readiness?

This covers survey questions Page 1, T3, H6, B4, B5, B6, and B8. Page 1 data is listed in Chapter II; T3, B4, B5, B6, and B8 are listed above in '4. Difficulties in integrating technology?'

H6. **Whose facilities** were going to be the primary production site for the application of the new technologies? _*X*_ 1. Prime contractor's facilities ___2. Both Prime and supplier facilities ___3. Supplier facilities

5. Importance of Technology to Prime?

This covers survey questions Page 1 and T4. Page 1 data is listed in Chapter II.

Check (√) the best answer for each technology.	Technology A	Technology B	Technology C
T4. Looking back **at the Development start date,** at that time how important were these technologies to the Prime?			
Prime was planning or had started follow-on uses of the technology.	2. ***X***	2. ***X***	2. ***X***

Table 10. Data for Question T4

6. Familiarity of Prime with Technology?

This covers survey questions Page 1, T2, and T3. Page 1 data is listed in Chapter II; and T3 is listed above in '4. Difficulties in integrating technology?'

T2. How new was each technology to the Prime Contractor? For each technology A, B, and C, was the technology:

Technology	A	B	C
1. **New and unproven** for the Prime Contractor?	***X***		***X***
2. Technology had been used by Prime Contractor, but it was **new to this kind of application**?		**X**	

Table 11. Data for Question T2

7. Timely Problem Disclosure?

This covers survey questions D12, D16, and D19.

D12. The team was reluctant to share concerns with Government PM. 1 ***X*** *(Strongly disagree)*

D16. Usually team knew right away where to get necessary outside help. 4 ***X*** *(Agree somewhat)*

D19. The Government PM was reluctant to share problems with Army leaders. 1 ***X*** *(Strongly disagree)*

C. ANALYSIS

This section will analyze the involvement of the organizations that had developed the critical technologies during system development in terms of (1) role of S&T organization that developed technology, (2) role of Government S&T organization, (3) difficulties in integrating technology, (4) production readiness, (5) importance of technology to Prime, (6) familiarity of Prime with technology, and (7) timely problem disclosure.

1. Role of S&T Organization that Developed Technology?

The U.S. Army Night Vision Labs (NVL) was the original developer of the FLIR technology used in the TADS night sight and the PNVS. They provided support to the TADS/PNVS program from the very start of the System Planning phase, and they continued to provide support through development and the Transition to Production phase.

The MICOM Guidance and Control (G&C) Lab was involved in system requirements for Total Pointing Error (TPE) for the laser designator, which is a component of laser to sensor bore-sight. G&C labs did a lot of testing and simulation work to develop these requirements and early work on the laser hardware.

Martin Marietta Corporation Science and Technology organizations were doing their own work in response to the anticipated requirement for the ASH and AAH programs. They needed to develop the technology and to create a manufacturing plan.

2. Role of Government S&T Organization?

In addition to the involvement listed above, Frankfort Arsenal, as well as U.S. Army Night Vision Labs (NVL) and MICOM Guidance and Control (G&C) Lab, gave significant support in fire control and optics in developing requirements, evaluating proposals and monitoring development progress. These labs were quite open to requirements changes and other project ideas.

Army labs contributed to readiness at the start of the planning phase for FLIR target acquisition. They continued to provide readiness support for the three critical technologies throughout development and the transition to production phases.

3. Difficulties in Integrating Technology?

The contractor had to make serious changes in their production process for two of the three most critical technologies (LOSS and FLIR Target Acquisition) and significant changes for the third (Laser to sensor bore-sight). The contractor, Martin-Marietta, was not then producing similar systems. Components were similar, but new types of system tests had to be developed in order to guarantee meeting system specifications.

Using a novel testing philosophy to find system faults earlier, some requirements were flowed down to lower level modules and components to eliminate failures earlier in the process. These tests were often unique because they were driven by system-level requirements.

The TADS / PNVS was a critical contract for Martin-Marietta, and the upper management put a high priority on it. They provided personnel in adequate numbers with the skills needed for the project. Some specialties were from functional groups that gave the TADS/PNVS group a high priority, but didn't transfer personnel – because their full time services were not necessary.

Various risk factors caused the program major difficulties. For example, taking the risk out of the new technologies was a major effort. Also, significant effort was needed both to scale the technology up from lab and pilot tests and to run tests successfully. However, only minor effort was needed to deal with critical production issues, with management pressure pushing technology too quickly into production, and with the lack of acceptance standards for the new technologies.

4. Production Readiness?

Because the Prime Contractor's facility was the planned production site, there was no need to transfer the technology to a new facility, with the consequent learning curve. A sizable portion of the development was done by the Prime Contractor, so they already had a lot of experience with these technologies.

The TADS/PNVS was ready for production. Some of the risk factors (listed in paragraph 4 above) such as scaling technology and running tests successfully, slowed the program down and took considerable effort to overcome. However, other factors required only minor effort.

The three critical technologies forced significant or even serious production process changes, however these changes were not all unexpected since the developer was also the production company. Some of these changes did cause some delay (about 6 months) in production. Components were similar to other production systems, but the system was not. The system-level tests forced them to try to reduce failures by instituting unusual component tests to catch system failures earlier.

5. Importance of Technology to Prime?

At the time of the start of Development, the Prime was planning or had actually started follow-on uses of all three critical technologies: Line-of-Sight Stabilization (LOSS), FLIR target acquisition (FTA), and Laser to sensor bore-sight (LSBS). Martin Marietta did have some follow-on contracts that made use of this technology (e.g. U.S. Air Force LANTIRN). Many problems had to be overcome to get the TADS / PNVS operational; but the knowledge gained helped the Prime establish itself in this technology and gain a foothold in a profitable market.

6. Familiarity of Prime with Technology?

The Laser to sensor bore-sight and Line-of-Sight (LOS) Stabilization were new and unproven technologies for the Prime Contractor, Martin Marietta. They had used FLIR target acquisition, but they were new to this kind of application. The contractor struggled quite a bit in getting this technology working.

Technology forced deep and serious production process changes for both stabilization and bore sighting. FLIR target acquisition required significant production process changes. Production acceptance test stations for these technologies were created to test hardware to the system-level specifications. They tried to identify component tests and processes that would catch both system-level failures and major subsystem failures. The component-level tests were unique in that they were developed to find system-level failures.

7. Timely Problem Disclosure?

When there were problems, usually the development team knew immediately where to get outside help. The development team was open about sharing concerns with the Government PM, and the PM shared problems with Army leaders. This open communications helped the Government stay informed and fix problems before they became too big. Any problems the team couldn't handle directly, or with help they could get, the Army was in a position to know about the problem and take steps to resolve it.

D. CONCLUSIONS

This section draws conclusions concerning the involvement of the organizations that had developed these critical technologies during system development.

1. Role of S&T Organization that Developed Technology?

The U.S. Army Night Vision Labs (NVL), the MICOM Guidance and Control (G&C) Lab, and Martin Marietta Corporation Science and Technology organizations, all of which developed important TADS/PNVS technology, were actively supporting the program with reviews and additional lab work.

2. Role of Government S&T Organization?

Additionally, Frankfort Arsenal gave further technical support. These labs gave assistance in the areas of requirements changes and they were open to other project ideas throughout the development and transition to production phases.

3. Difficulties in Integrating Technology?

Martin Marietta made significant changes to accommodate production of TADS/PNVS, in their process and in new, more stringent component tests. TADS/PNVS was able to get most of the personnel they needed permanently on their team, and high priority for some functional specialties that were needed for only part of the time.

Major effort was needed to take the risk out of the new technologies, although the project team was eventually successful; and significant effort was needed both to scale the technology up from lab and pilot tests and to run tests successfully. However, only minor effort was needed to deal with other development and production problems.

4. Production Readiness?

The Prime Contractor was ready for production, since they also participated in development. Some technological risk factors took some time and effort to overcome, but nothing out of the ordinary. There were production process changes required by the three critical technologies, but delays were minimal – about six months. System-level testing also caused some additional production readiness problems.

5. Importance of Technology to Prime?

The critical technologies in the system were of great value to the developer, both for TADS/PNVS contracts, and for other follow-on contracts. The problems that the Prime overcame established it in a profitable market.

6. Familiarity of Prime with Technology?

The critical technologies of the TADS/PNVS system were mostly new to the developer at the start of the program, causing some struggle to master these technologies. FLIR target acquisition had been used before, but in a dissimilar application. This high technology also forced production changes to their factory. In addition, Martin-Marietta adopted new subsystem and component testing to ferret out system-level problems.

7. Timely Problem Disclosure?

Problems were freely reported from developer to Government PM, and from PM to Army leaders. This open communications helped the Government stay informed and fix problems before they became too big. If a problem occurred which was outside team members' capabilities, the team was always able to get outside help.

Development Organizations: In summary, both Government agencies and the developer contributed greatly to the success of the TADS / PNVS program. Significant effort was needed to develop the system, in some cases major effort. Significant effort also was needed for production readiness. But the new technology field of TADS/PNVS was a strong motivator to Martin Marietta. The critical technologies were mostly new to the developer, but their effort paid off. And any problems they encountered were freely reported by the developer to the PMO, and by the PMO to Army higher headquarters, which allowed additional resources to be used to head off some potential problems.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. Market Share Over Time:

Examine the market share that Martin-Marietta Corporation, now Lockheed Martin Corporation, enjoyed with the three critical technologies over time.

2. Technology Buy-In:

Examine how some companies buy into certain technologies, by buying a company in the field or by bidding below cost on a contract, and whether the venture was financially successful for the company in the long run. Also, examine the effect on their customer(s) of using 'novices' in this technical area.

3. Science and Technology Role:

Examine scientific groups in various companies, and how they contribute to developing financially successful products.

IV. USER SUPPORT AND FUNDING STABILITY

A. RESEARCH QUESTION

This chapter answers the research question, “To what extent was there user support and funding stability during system development?” This chapter will cover the extent of user support and funding stability during system development in terms of (1) user support (or role of user), (2) requirements stability, and (3) funding stability. I will introduce the data, then analyze it, and finally draw conclusions.

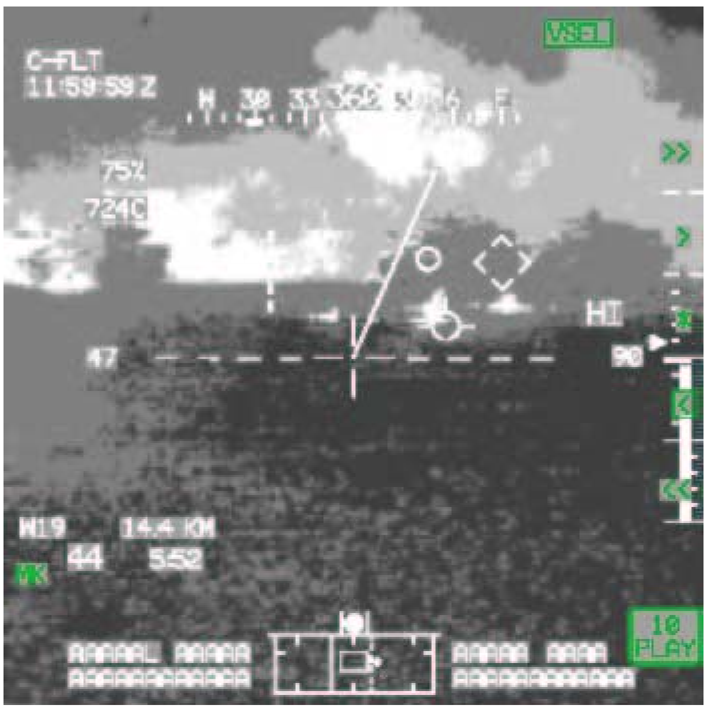

Figure 4. TADS Sighting System Image, from TM 1-1520-251-10, Operator’s Manual for Helicopter, Attack, AH-64D Longbow Apache, 15 Dec 1998

B. DATA

1. User Support? (Or Role of User?)

This covers survey questions D18, F5, F6, W3, W4, and W5.

D18. There was a lot of contact with TRADOC* during the project. *Strongly Agree*

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

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

Questions F5-F7 use the following possible answers:	Never	Once or Twice	Several times	Many Times	Don't know N/A

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

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

Please check (✓) all stages when the activity occurred.

	SP	D			TP		
	Selection	Development			Transition		
		Early	Middle	Later		(Never)	(DK/ N/A)
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**
W5. When did TRADOC / other users show strong support?	**X**	**X**	**X**	**X**	**X**		
W6. When was there change in the system requirements?						**X**	

Table 12. Data for Questions W3, W4, W5, and W7

"The TRADOC Systems Manager and other military personnel changed about every three years... However, I don't think this was ever a problem."

2. Requirements Stability?

This covers survey questions F7, W6, and B13. W6 is listed above with W3, W4, and W5 for legibility.

How often did the following occur **during Development**?
F7. Were there changes in system requirements (e.g., threat)? ***Never***

Did this problem come up during this project?
B13. Threat definition or other requirements changed during the project. _*X*_ No

3. Funding Stability?

This covers survey questions H1, D11, and B2.

H1. At some point, was the project either (slowed down or stopped and restarted)? ***X*** 3. Neither

The TADS/PNVS program was originally part of the ASH (Advanced Scout Helicopter) program, which was cancelled. This happened prior to 1977, the start of SP phase. AAH (Apache AH 64 PMO) was already involved when ASH left the program, as was MICOM. AAH and MICOM support of TADS/PNVS continued on, after ASH left the program.

D11. There was often uncertainty about the future of project funding. *Strongly agree*

B2. Cutbacks in project resources forced changes/compromises. *Very minor effort*

C. ANALYSIS

This section analyzes the data, comparing the two individual responses, as well as advantages and disadvantages, analyzing them in terms of the primary and secondary questions. This section will analyze the extent there was user support and funding stability during system development in terms of (1) User support? (Or role of user?), (2) Requirements stability, and (3) Funding stability.

1. User Support? (Or Role of User?)

The TADS/PNVS Program Office had a lot of contact with the Training & Doctrine Command (TRADOC) during development. TRADOC is the primary interface to the users. TRADOC frequently showed strong support of the project. Occasionally, there were changes in key TRADOC personnel, approximately every three years, but this never affected the program much.

TRADOC was consulted on project questions throughout the program, from earliest systems planning, through development, and into the transition to production. And TRADOC responded by showing strong support for the TADS/PNVS program throughout the same period.

2. Requirements Stability?

The system-level requirements were very stable during development. The threat definitions (detail requirements) that the TADS/PNVS was required to counter were stable, as well. Requirements changes in the development period can radically change the design. Sometimes the contractor has to get extra money or time to effect these changes.

3. Funding Stability?

Project funding was frequently uncertain. The project required almost twice the contracted amount, and the extra money had to be provided by the AAH Program Manager.

The project usually had all the resources needed for development. Occasionally, some minor effort was needed to make changes or compromises because of resource shortages.

Although the Advanced Scout Helicopter (ASH) program, which was leading the TADS /PNVS program, was cancelled, the AAH (Apache AH-64 PMO) was already involved as was MICOM. There was really no affect on the program, other than a change in leadership. Also, instead of needing to meet the demands of two PMOs, the developer now only had to satisfy one, which lowered the technical risk.

D. CONCLUSIONS ON USER SUPPORT AND FUNDING STABILITY

This section will draw conclusions concerning the extent there was user support and funding stability during system development.

1. User Support? (Or Role of User?)

The Training & Doctrine Command (TRADOC) provided strong support to the TADS/PNVS Program Office during development. TRADOC was consulted on the program, and provided worthy user representation.

2. Requirements Stability?

TADS/PNVS program had good requirements stability at the system level and stable threat definitions.

3. Funding Stability?

Funding was quite unstable on the TADS/PNVS program. However, they usually had most of the resources they needed when funding was stable. Although the Advanced Scout Helicopter (ASH) program was cancelled, this affected neither program funding, nor program continuity.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. Funding Stability and Program Effectiveness:

Study various programs with good and poor funding histories, and how the program has been effective in developing a useful product.

2. Requirements Stability and Program Effectiveness:

Study various programs with good and poor requirements stability, and how the program has been effective in developing a useful product.

3. User Support and Program Effectiveness:

Study various programs with good and poor user support, and how the program has been effective in developing a useful product.

THIS PAGE INTENTIONALLY LEFT BLANK

V. INTEGRATED PRODUCT TEAMS

A. RESEARCH QUESTION

This chapter answers the research question, “How effectively were (what we now call) integrated product teams (IPT) employed during development?” This chapter will look at the effectiveness of IPTs in terms of (1) IPT approach used, (2) Proper staffing of IPT, (3) Design to manufacturing linkage, and (4) Design to supplier linkage. I will introduce the data, then analyze it, and finally draw conclusions.

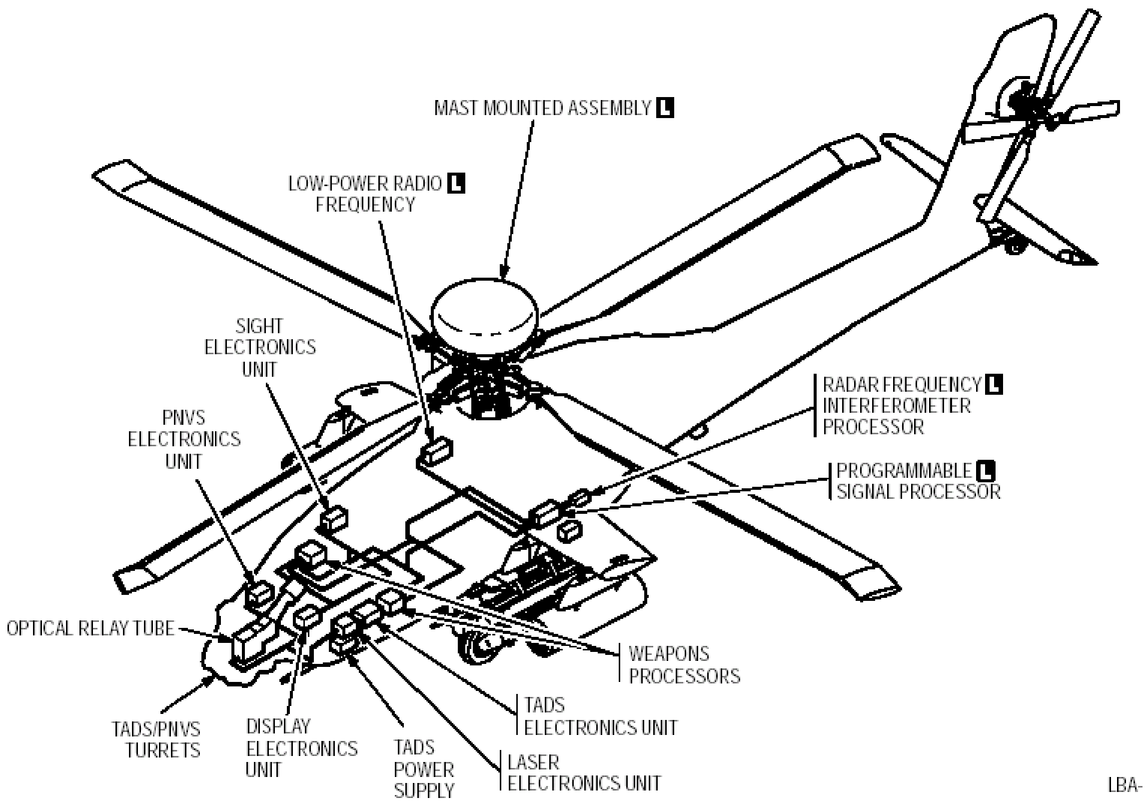

Figure 4-1. Sight Subsystem

Figure 5. TADS / PNVS Sight Subsystem, from TM 1-1520-251-10, Operator’s Manual for Helicopter, Attack, AH-64D, Longbow Apache, 15 Dec 1998

B. DATA

1. IPT Approach Used?

This covers survey questions H2, H4, H5, D1, 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? ***Yes***.

If YES, was it: _***X***_ 1. Set up by management, with different functions & departments tasked to provide team members.

In the interview, the government respondent goes on to explain that they did not call them IPTs then, but they were essentially the same thing.

"*This concept of an integrated product team (IPT), really came more into vogue about or after the time we first went into production. At that time there was a big emphasis to bring in production people, logistics, and so forth in the very early stages of the design program. In the early stages of the TADS PNVS program, we did have those people involved.*

*We did not call it IPT and they didn't organize it that much, but there were reliability, logistics, maintenance, and production requirements. In the beginning of the program in 1977, when they did this initial primary design with seven different contractors and then the fly-off, there was much heavier emphasis … on the performance aspects of TADS/PNVS, because it is something that no one had ever done before, so the rest of (*the program*) doesn't matter if you cannot do the performance part.*"

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.) _***X***_ 2. Most (2/3rds or more)

H4a. Including the above, how many people on the team were collocated **in the same building**? ***X*** 2. Most (2/3rds or more)

Most were in the same building, about 90%, and the rest were in another building in the same city.

H5. How many people on the team involved in the **Development stage** had worked before with others on the project? _***X***_ 2. Most (2/3rds or more)

Team Participants & Communications **during Development** (D1-D19)

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.

D1. The team leader was good at resolving technical disagreements. *Strongly Agree*

D7. Team meetings were sometimes frustrating and non-productive. *Neither agree nor disagree*

D9. Project results did not take advantage of the team's best ideas. *Disagree somewhat*

D13. Management project reviews were constructive & helpful. *Agree somewhat*

D14. Formal reviews were conducted at key decision points. *Strongly Agree*

D16. Usually team knew right away where to get necessary outside help. *Agree somewhat*

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

How often did team members do the following **during Development**?

F4. Needed management help to resolve project team disagreements? _***X***_ (Once or Twice)

2. Proper Staffing of IPT?

This covers survey questions H3, D3 through D6, D8, and D10. H3 data is in Chapter III.

D3. There was a lot of turnover in team membership. *Disagree somewhat*

D4. The team leader had both design & production experience. *Neither agree nor disagree. Developer team leader had* ***excellent*** *design experience; but production experience was associated with smaller systems.*

D5. The team leader had very high technical competence. *Strongly agree*

D6. Some key technical skills were not represented on the team itself. *Disagree somewhat*

D8. Professionals were split across too many different tasks & teams. *Neither agree nor disagree*

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

3. Design to Manufacturing Linkage?

This covers survey questions F1, F2, F3, F10 through F13, W1, W2, W16, W17, and W18.

Questions F1 through F13 use the following responses:

Never	Once or Twice	Several times	Many Times	Don't know Not Applicable

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

F2. Asked for supplier comments & suggestions on design choices. *Several times*

F3. Showed & discussed physical models of new components with suppliers. *Once or Twice*

F10. Passed around physical prototypes during joint discussions. *Many Times*

F11. Held planning meetings that included both design & production people. *Once or Twice*

F12. Explored choices together with computational models or analytic tools. *Never The Manufacturing engineers reviewed prints all throughout the project, but they didn't use computational models or analytic tools. Computer tools didn't exist at the time, and they didn't have any manufacturing analytical tools – 1970s and early 1980s.*

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

Please check (✓) all stages when the activity occurred.

	SP	**D**			**TP**		
	Selection	Development			Transition		
		Early	Middle	Later		(Never)	(DK/ N/A)
W1. When did production representatives participate regularly?		***X***		***X***			
W2. When did team members meet with production on shop floor?				***X***	***X***		

Table 13. Data for Questions W1 and W2

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.

Please check (✓) all stages when the activity occurred.

	SP	**D**			**TP**		
	Selection	Development			Transition		
		Early	Middle	Later		(Never)	(DK/ N/A)
W16. When did the team & technical professionals from **Production** have unscheduled & informal **joint** conversations about the project?		***X***	***X***	***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***	***X***		

Table 14. Data for Questions W16, W17, and W18

4. Design to Supplier Linkage?

This covers survey questions F20 through F23, W26, W27, W28, and B10.

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

Questions F20 through F23 use the following responses:

Never	Once or Twice	Several times	Many Times	Don't know Not Applicable

F20. Passed around physical prototypes during joint discussions. *Never*

F21. Held planning meetings that included both design and suppliers. *Once or Twice*

F22. Explored choices together with computational models or analytic tools. *Never*

F23. Had test articles or pre-production parts to discuss and examine jointly. *Many Times*

Design engineers and suppliers worked closely together. This was a very unique design so the suppliers were designing/tailoring their hardware for this specific job in many cases.

Please check (✓) all stages when the activity occurred.

	SP	**D**			**TP**		
	Selection	Development			Transition		
		Early	Middle	Later		(Never)	(DK/ N/A)
W26. When did the team & technical professionals from **Suppliers** have unscheduled & informal **joint** conversations about the project?	***X***	***X***	***X***	***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***	***X***		

Table 15. Data for Questions W26, W27, and W28

Did this problem come up during this project?

B10. One or more suppliers did not meet their commitments. *Significant effort* (was needed)

C. ANALYSIS OF INTEGRATED PRODUCT TEAMS

This section will analyze the effectiveness of Integrated Product Teams (IPT) in terms of (1) IPT approach used, (2) Proper staffing of IPT, (3) Design to manufacturing linkage, and (4) Design to supplier linkage.

1. IPT Approach Used?

This was before the advent of the formally-recognized IPT system that has totally transformed the Government and business. However, there was then a realization that integrating people from many disciplines was a useful technique. Though they did not call them IPT's, the TADS / PNVS program frequently used multidisciplinary working groups to solve problems. These groups were not formally established, though people from different groups were invited. This often happens in IPT's today – certain disciplines may not be represented either because there is no interest or due to lack of funds to attend IPT meetings.

A similar problem both then and today is that often the membership of an IPT varies. The membership charter may call for one (or more) person from a specific organization, but it may be a different person each time. If this happens, there is no gradual increase in either the working relationship between members or the skill of members. Different people from the same organization may have completely different backgrounds and styles, and can cause disruption when they contradict previous members of their own organization. These changes of direction can be very disruptive.

Also, such teaming was more likely on critical aspects of the program. Performance of the system was critical, so a multidisciplinary team was used.

Multidisciplinary work is not confined to meetings and formal groups. Most of the people on the program were in the same building, within a short walk of each other. This fosters quick, informal meetings and also camaraderie and group cohesion. Additionally, many people had worked there for some time, even before the project began. Thus, they were undoubtedly experienced with working together. Some people were in another building in the same city, so it was not too difficult to have face-to-face team meetings on short notice.

The success of any team depends on the leadership of the team leader(s) and also the skills of the team members. During development of the TADS/PNVS, the team leader was good at resolving technical disagreements.

But the path can be rocky in arriving at agreement. When you are trying to integrate a lot of technology and the requirements they actualize, there are often trade-offs. Compromising can be difficult for some people. Occasionally, someone feels that their idea must take precedence, and some good (competing) ideas can be lost. Once or twice, it was necessary to get management help to resolve disagreements.

Usually management reviews were constructive. They had formal reviews at key decision points. The Government PM reported problems that went up to Army leaders. Most of the time, it was easy to get outside help.

In the days before IPTs, there were lots of meetings. These meetings may not have been the most effective solution to solving problems, but they did solve some. The table below lists a range of types of Pre-IPT Groups.

Type of Group	**Level of Analysis**
Staff Meeting	Information passing / Problem solving
Program Status Meeting (Dog and Pony Show)	Information passing –Very high-level / Critical review
Product / Functional Status Meeting (Low-level)	Information passing –Lower-level / Critical review
Working Groups	Problem Solving and Information passing –Lower-level
Board Approvals: Emergency ECP	Problem solving / Critical review

Table 16. Pre-IPT Groups

These groups differ from each other in the level of the group, the level of analysis, and whether they include both Government and contractors. Typical staff meetings were simply for information transfer, mostly downwards. It was a way to pass the word to the troops with the least work for the chief. But occasionally, there were problems the boss brought up and people would work on them together, suggesting strategies, evaluating alternatives, offering related information, etc. Both Government and contractors had their own staff meetings, typically with no outsiders.

The typical Program Status Meeting (a.k.a. "Dog and Pony Show") was a contractor to Government interchange. It was for passing very high-level information. It really was not possible to solve many problems because of the large number of people present, although action items could be assigned.

Product / Functional Status Meetings were more low-level. They were also for information passing, but at a lower level. Occasionally they were conducted like working group meetings. Often both have Government and contractors.

Working group meetings were where lots of problems were resolved. Sometimes all the necessary functional specialties were present. However, most only contained one or two specialties, and other functional types were ignored. Often there were both Government and contractor personnel in these groups.

2. Proper Staffing of IPT?

Because this was a major program for the developer, most “key skills” essential to the project were available. Some key skills were not on the team itself, but had to be requested when needed. Some people were split across too many different tasks & teams. This was limited to the microwave electronics hybrids design group and the printed circuit layout design people. Those were both functional groups, and the TADS/PNVS group didn’t have enough work to justify keeping them on their team. But they had as good of a priority with these groups as any other project in the company in Orlando.

There was some personnel turnover, which can disrupt the schedule of the team. Many people continued on the project through pre-production planning and testing.

The developer team leader had high technical competence. He had excellent design experience; however, his production experience was mostly on smaller systems.

3. Design to Manufacturing Linkage?

The developer had a good relationship with suppliers, production, design, and upper management. Designers asked suppliers for their comments and suggestions. Occasionally, they passed around the models to the suppliers for their comments.

Getting feedback from suppliers often has a good affect on buyer-supplier relations. Instead of being just a customer, the supplier sees the buyer as somebody who produces a useful product. The product has value, and therefore manufacturing and delivering the supplies needed to make it, also has value. Additionally, the feedback can generate improvements in use of the supplied parts, or in manufacture of those parts.

Production processes are very important. Design engineers went to the shop floor many times to discuss them with manufacturing specialists. The team members met with production on the shop floor during the latter part of the development phase and during the transition to production phase. The production representatives participated regularly in the early and latter parts for the development phase.

Though the manufacturing engineers in the production group reviewed engineering drawings, they did not use computational models or analytic tools. Computer tools were not yet available, nor were there any of the manufacturing tools which exist today.

During joint discussions, they passed around prototypes of smaller components. This facilitated understanding and stimulated discussion. A few times, they held planning meetings with both design & production people. The design team and technical professionals from production held unscheduled and informal joint conversations about the project throughout the development phase.

Occasionally, they had test articles or pre-production parts to discuss and examine jointly. Prototypes and parts were used in joint discussions late in the development phase and in the transition to production phase.

4. Design to Supplier Linkage?

During system development, the design engineers and suppliers worked closely together. During joint discussions, they frequently had test articles or pre-production parts to discuss and examine jointly. The suppliers modified their hardware for this specific job to satisfy the developer. They invited suppliers to planning meetings a few times. However, this teamwork did not extend to using computational models or analytic tools.

The design team and technical professionals from suppliers had unscheduled and informal joint conversations about the project during the selection phase and all though the development phase. Prototypes and parts were used in joint discussions during the latter development phase and the transition to production. Significant effort was needed to overcome suppliers' not meeting delivery commitments.

D. CONCLUSIONS ON INTEGRATED PRODUCT TEAMS

This early usage of teams, similar to IPT's, was fairly successful. The teams often did not work as well as they could have because there was no firm policy to have all needed disciplines present. However, because the program was large and important for the developer, they got most of the people and equipment that they needed. This section draws conclusions concerning the maturity of the critical technologies.

1. IPT Approach Used?

TADS/PNVS employed multidisciplinary teams, also known as cross-functional groups. Because these groups were not formally chartered, if an organization did not send anyone – due to lack of manpower or travel funding – then that group's views and expertise might not be included.

A change in membership can cripple the effectiveness of an IPT. The synergism that comes from working with known people over time is lost – people are not interchangeable parts. Varying direction from an organization can also cause all their directions to be ignored. This often happens in IPTs today.

The successful use of multidisciplinary teams on this and other commercial and DoD programs led to the large-scale adoption of Integrated Product Teams. Multidisciplinary teams were used on the more important projects. Because they were successful, they began to be used on more and more projects. Additionally, the close proximity of the team also fostered informal multidisciplinary effort. It also engendered camaraderie and group cohesion.

The TADS/PNVS developer had strong leadership. Usually the group was able to resolve differences of opinion, but occasionally upper management had to get involved. Program reviews were fairly good at eliciting problems, and the channels to upper Army management were quite effective.

Pre-IPT groups addressed a variety of problems, large and small, with a fair amount of success. Groups differed in the formality of their organization, in the level of analysis they required, and whether they include both Government and contractors. Since there was no formal structure, some groups were only able to handle smaller problems, while others handled larger problems with considerable success.

2. Proper Staffing of IPT?

Most of the necessary skills needed for the project were actually on the project team, and a few other skills were provided from outside with a sufficiently high priority. Many of the personnel continued working on the program throughout the development and testing period, though there was some turnover. The developer team leader had excellent technical development skills, though his production experience was mostly on smaller systems.

3. Design to Manufacturing Linkage?

The developer worked and communicated well with internal groups (production, design, and upper management) as well as suppliers. They involved suppliers in the design process to good effect. Occasionally, smaller prototype components, assemblies, test articles or pre-production parts were passed around to facilitate understanding. Production representatives participated in the design process; and production and design groups met many times to discuss production processes. Manufacturing engineers also reviewed engineering drawings; the more automated verification techniques that are available today didn't exist then.

4. Design to Supplier Linkage?

The developer and its suppliers worked fairly well together, on either a formal or an informal basis, examining prototype parts together and participating in joint planning. However, they didn’t use computational models or analytic tools, which were only just becoming available. And significant effort was needed for suppliers to overcome problems in meeting delivery commitments.

In summary, the multidisciplinary teams eventually evolved into integrated product teams. These teams were useful TADS/PNVS development tools. These teams possibly were not as effective as a formal IPT, but by integrating many disciplines, they were able to solve many complex problems.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. IPT Representation:

Study past and present IPTs, or groups not formally chartered, to determine how representation of functional disciplines affects the IPTs effectiveness. If an organization didn't send anyone to IPT meetings – due to lack of manpower or travel funding – then that group's views and expertise might not be included.

2. Varying Membership:

Study effectiveness of past and present IPTs, or groups not formally chartered. Some organizations send a different person to represent them to each meeting. Changes in membership can cripple the effectiveness of an IPT. Varying instructions from an organization can also cause all their directions to be ignored.

3. Prime Contractor / Subcontractor Cooperation:

Study how Prime and subcontractors are exchanging more information on their process and products. Compare the efficiency of the design process in terms of problems found early versus late in the process. Also, compare this to the Japanese lean manufacturing model for supplier relations.

4. Manufacturing Processes:

Study how prime contractors and subcontractors employ mass production techniques, craft production techniques, and lean production techniques across industries and technologies.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. KEY PROGRAM MANAGER ISSUE

A. RESEARCH QUESTION

This chapter answers the secondary research question, "What was the key issue that the PM had to deal with during the project and how was it dealt with?" I will introduce the data, then analyze it, and finally draw conclusions.

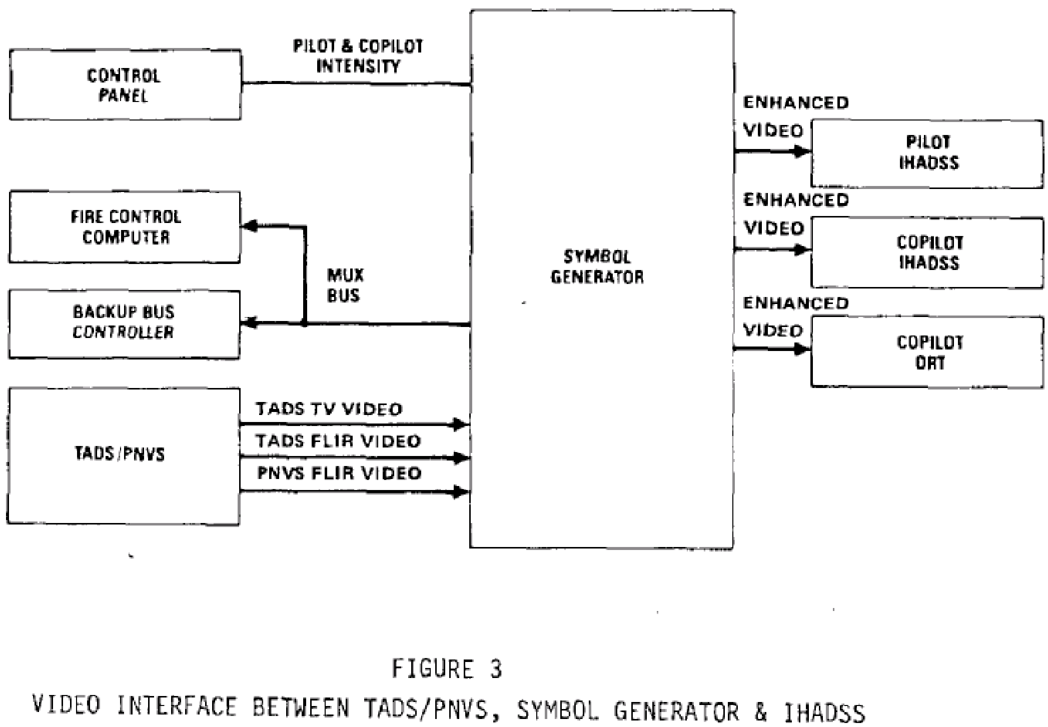

Figure 6. AH-64A Video Interfaces, from TADS/PNVS Interfaces with other Mission Equipment of the AH-64 Helicopter, Martin Marietta Aerospace International, May 1983

B. DATA

1. Key Issue for PM?

This contains survey question I2, only.

I2. 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?

This quote is from the government responder.

"The biggest problem was the cost overruns and the underlying reasons for these overruns in development. The source of these cost overruns was due to a couple of factors. The primary problem was probably associated with the acquisition approach. After the fly-off, there was a down select to the winning contractor. That down select was made in the form of the contract award for the maturity phase of the development program.

Each contractor submitted a proposal for the maturity phase as part of the down-select competition. It certainly was not in the contractor's best interest at that stage to cost the program in their proposals to fully cover all risk areas. First, the contractor would not go out of his way to highlight areas of risk that the Government team had not identified and secondly, for those areas of risk that were identified the contractors did not want to indicate the full cost of the risk thereby putting themselves at a substantial competitive disadvantage for the down-select (both by proposing a higher cost than their competitor and by highlighting greater technical risk with their designs that required greater funding in the maturity phase to correct).

Having said all of this, I do not feel that the acquisition approach was necessarily the wrong one because the approach with the competitive fly-off and a subsequent maturity phase is designed to significantly reduce the risk that the developed systems will not meet performance goals.

Since the TADS/PNVS was the number one riskiest technology in the AAH program, this was an appropriate approach, and one that was ultimately successful. I think that both the Government team and the contractor underestimated the effort it would take to implement the maturity phase design changes, meet all performance goals, develop test equipment, and transition to production. The project manager, therefore, had to deal with all the issues that came up because there was more effort required to get the job done in the required time frame than had been planned for. The solutions to almost all problems resulted in increased cost."

C. ANALYSIS OF KEY PROGRAM MANAGER ISSUE

What was the key issue that the PM had to deal with during the project and how was it dealt with? The key issue was cost overruns, which were due to several factors. The developers needed to win a competitive contract based on cost. And if a contractor explored and expounded the risks, their cost would realistically be higher than their competitors. Please note that Chapter IV, User Support and Funding Stability, also relates to funding.

Cost overruns and lowest bidder who hides risks:

Developers downplayed risks brought up by the Government, because by fully expounding the risks of their design, the developer would have shown that their proposal was under-funded, so risks were not really explored or mentioned. This scoring of risks was held against the contractor's design, rather than recognizing that the risks are inherent in the Government's project requirements. This may have been the best contract vehicle at the time, but it does tend to reward the hiding of information.

It was in the interests of neither the Government PMO nor the Prime contractor, to have a reasonable program cost at the beginning of the contract. The Prime wanted to win the contract in a competitive environment. The Government PMO was trying to get the best value for the Government.

Reprogramming funds for a program is expensive. Besides the schedule loss while you are going through the effort, there is the schedule loss due to going back and doing risk reduction you should have done earlier, acquiring parts/equipment/facilities on short notice, and also redesigning the system. Each of these four activities has an associated cost. Additionally, there is the cost of materials acquired but no longer needed. Doing all these cost and schedule activities later in the program always costs more than if they were on the program schedule from day one.

Even though the PMO 'knew' that the program probably could not succeed at the initial cost, and that the Government would have to provide more money, the strategy was that the profit to the contractor was based on the initial program cost. It is arguable whether this savings in profit to the contractor was offset by the cost of the inefficiency of the total program turbulence and review resulting from cost overruns and reprogramming additional funds. Sadly, cost overruns on the TADS/PNVS were a common occurrence, given the way the financial system was set up.

Although making contract decisions based entirely upon cost was common at the time, today more contracting decisions are based upon a variety of other factors, including technical parameters.

The TADS / PNVS was recognized as the number one riskiest technology on the AAH program, and the system was ultimately successful, though at double the original contract price. However, significant process improvements are possible in the development and contracting strategy. For example, development contracts are routinely based on more than just cost. Reporting risks can be scored as value-added information. And these risks can be used to evaluate all contracts, not just the contractor who mentioned them – although they may not be inherent in other contractors' designs.

The Government and developers should enter teaming relationships early to identify risk areas, and the developers should be rewarded for this value-added activity. Finding technical risks later in the program is a common occurrence, but it should be minimized as much as possible. Some programs are cancelled because technical risks grow beyond the end worth of the system. Finding risks earlier saves money, because fixing something is always less costly at the beginning of a program. Going back to the Government for more funds, or to the PM, to higher headquarters, or to Congress, could be a decision point for canceling the program.

The Prime and Subcontracts:

TADS/PNVS Development contract was a Prime contract, not a subcontract to Hughes Helicopters. Both the TADS/PNVS and the Hughes Apache contract had clauses in them for an Integration and Configuration Working Group. Integration is a potential problem.

Having direct contract with a developer of a subsystem has advantages and disadvantages. It gives the Government more control to have a direct contract, more control over their development processes, and over the contract type. TADS/PNVS was the highest risk item on the Apache development program, and warranted a separate project office. Having this separate office, and a separate prime contract is more work, but it increases the Government's ability to control the risk.

But then there are questions concerning how you integrate the subsystem into the prime contractor's system or vehicle. You can put a clause in the prime's contract that they must integrate the subsystem, and work with the other contractor to do so, but there are still some liability issues that may arise. If redesign is necessary in order to interface the subsystem, then the Government could be liable for the cost. The solution that the TADS/PNVS program chose handled this problem very well.

Primes still use fixed-cost contracts for subcontracts today. The Government has sworn off fixed-cost contracts, because development is too high risk. However, subcontracts are frequently where the highest risk parts of the program lie. Often the prime's share of the work, wiring the vehicle, and installing the components, is a much lower risk activity.

Cost Probabilities:

The probable program cost at the start, based on risk and cost drivers, can be graphed – see the figure below. It would probably be some type of bell-shaped curve, with maximum probability in the middle. The four vertical lines represent the 1st, 5th, 50th, and 99th percentile probabilities of the program cost. Starting off the program with a budget at the 5th percentile probability is quite risky.

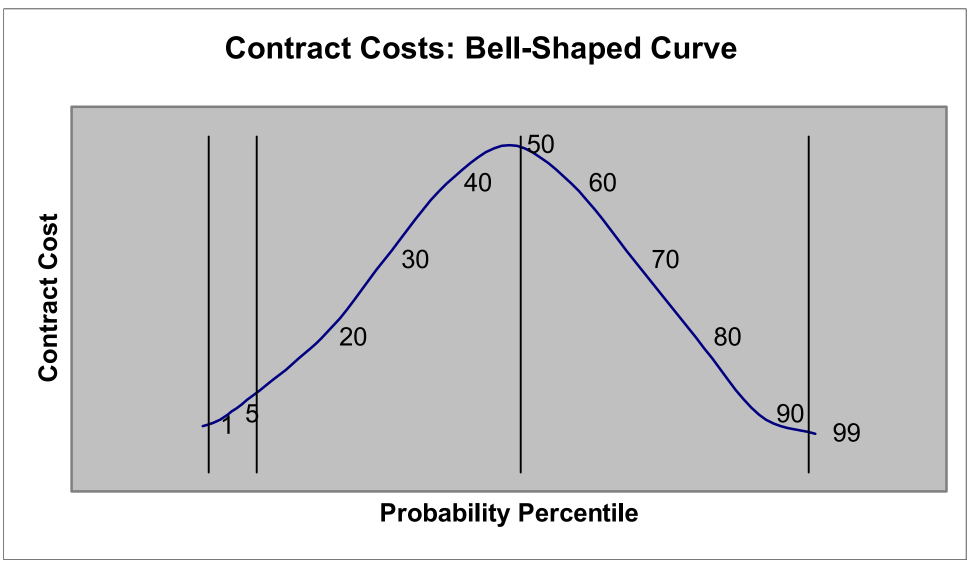

Figure 7. Contract Costs Graph

One problem with setting the contract price at the 5th percentile probability point is that it forces the program to "restructure," "realign," or "reprogram" too often. This effort is a financial drain on the program's cost and schedule, as well as an embarrassment to all concerned. And of course, little program work is done while you are involved in the meetings and discussions of the restructuring, though you are 'burning' cost and schedule.

Starting off at the 5th percentile probability level also causes some risky behavior. If you had more money, you could undertake some risk-diminishing strategies earlier in the program, and possibly avoid some schedule slips. Doing risk reduction later on costs more, because it may invalidate design decisions, and all later design and development work based on those decisions. At the lower budget cost, you are required to allocate almost all your resources on well-understood requirements, which generally have predictable costs, and very little for risk reduction efforts.

It is better to start the program off with a budget nearer the 50th percentile probability. This will allow funding risk reduction studies and an emergency funding reserve. Just as the AAH PMO had a financial reserve, the contractor PMO will establish a financial reserve within his own budget.

D. CONCLUSIONS

Cost overruns are a large concern in Government programs. TADS / PNVS cost concerns stemmed from hiding or downplaying risks even before the contractor won the contract.

Playing the game to get a contract started for less than the contractor needs is risky – cost overruns are likely. Most companies that have sued the Government to recover cost overruns have succeeded. Realistic contract prices at the beginning are more cost effective, avoiding costly reprogramming/restructuring, the political turmoil inherent in asking congress for more money, and the risk of contract disputes in court.

Programs are very rarely cancelled for cost considerations. Once a program is started and gains its military, congressional, and defense contractor adherents, it is difficult to cancel. Although making contract decisions based entirely upon cost was common at the time, today more contracting decisions are based on a variety of other factors, including technical parameters.

Best Value is not always guaranteed by choosing the lowest bidder on a contract. Program managers need to reduce risks, if their program is to succeed. One possibility is that the request for proposal could request that the technical risks inherent in the project requirements be listed separately by a contractor, and compared to other contractors' proposals. This could be scored in favor of the contractor – they should get the contract because they understand the problem better. Of course, they should also propose how to deal with these risks.

Prime contracts and subcontracts should be considered for high-risk subsystems. If a prime contract is used, it adds workload to the Government, but can lower total program risks if effectively managed. Integration is a bigger issue with multiple prime contracts on one program. If the work is subcontracted, the Government should consider what type of the contract the prime will use, and realize they will have less control over development.

If most programs go over cost, then the system is probably too risky. It is better to predict the cost realistically, and commit the appropriate amount. Some budget people advocate squeezing a program a bit to encourage cost reduction efforts, but cutting back by 50% is not realistic. The 5th percentile of the probable cost is too low. Planners should try to target the 40th to 50th percentile of the probable cost. But even then, some programs will go over the contract price, and a program manager or his PEO could have a contingency fund. Starting with a reasonable contract price allows more realistic planning and earlier risk reduction efforts.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. Financial Management and Contract Types:

Study how contract types have changed over the years from 1980 to the present, and the policies for use of these contract types. Study how program financial management varies with contract type, and what affect this has on the program manager's ability to control various aspects of the program.

2. Prime and Subcontracts:

Study how some programs are run with only one prime contract, and a variety of subcontracts, and other have many prime contracts. Study ease of integration and management of development risks.

3. Study Program Risk Reduction Proposals in Contracts:

Study how various DoD contracts have proposed reducing risks, and how successful these programs have been in reducing risks.

VII. SIMULATION AND TESTING STRATEGY

A. PRIMARY RESEARCH QUESTION

This chapter answers the primary research question, "What was the simulation and testing strategy for the system, and did that strategy adequately evaluate the system for its ultimate operational use?" I will introduce the data, then analyze it, and finally draw conclusions.

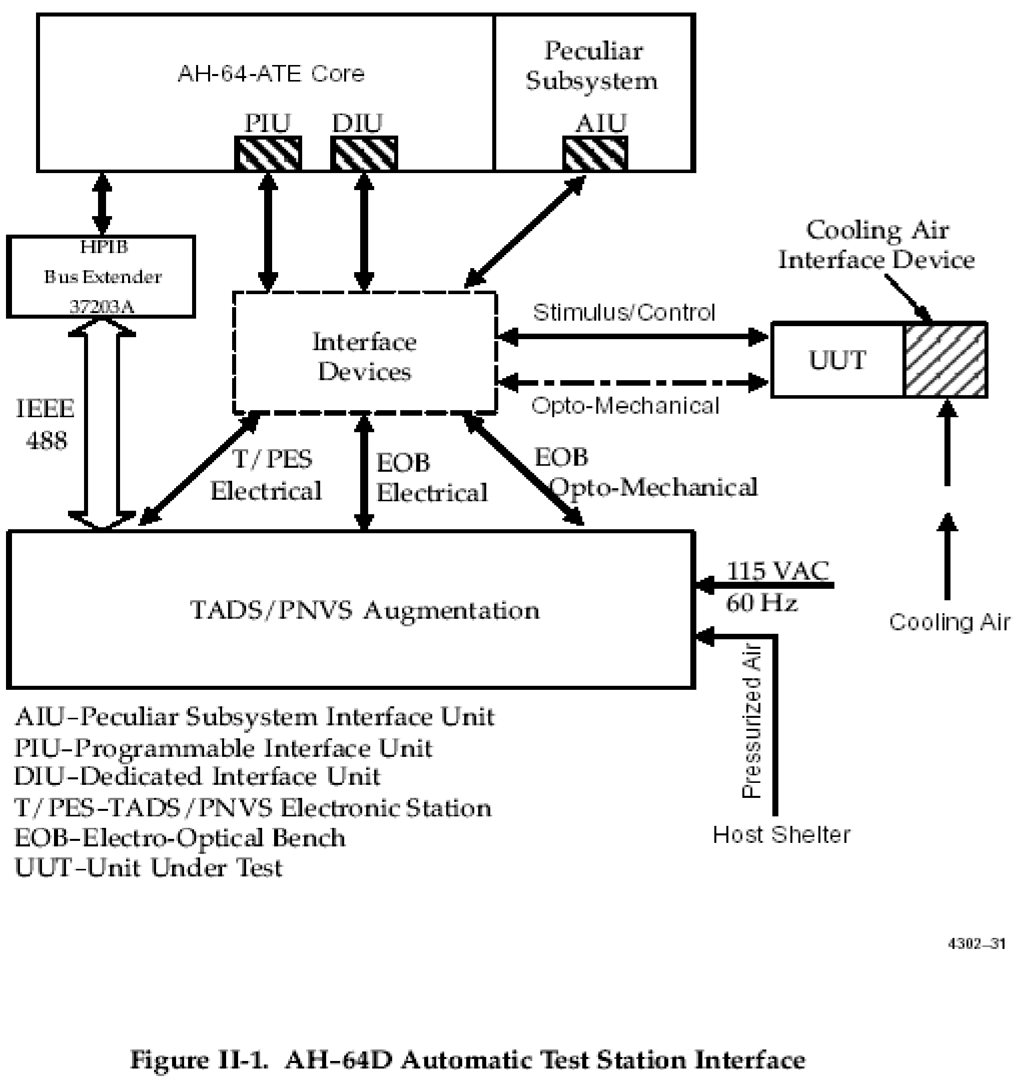

Figure 8. TADS Automatic Test Station Interface, from Interface Control Document for the Longbow Apache Target Acquisition Designation System PNVS (TADS PNVS), 26 April 1999

B. DATA

In addition to data from the combined survey, I included some related information from a General Accounting Office (GAO) study on the DoD testing process. This study contrasts the test processes during product development, between civilian company testing and DoD testing, and shows how DoD testing can be improved.

1. Test Approach Used?

This covers survey questions V1 through V15, Validation Activities.

Validation Activities: Testing and Simulation

V1. Was a failure modes and effects analysis done on the system? *Yes*

V1a. If yes, was it used to help establish the test plan? *Yes*

This analysis drove the test requirements for production test equipment and for fielded automatic test equipment.

This analysis drove the test requirements for production test equipment and for fielded automatic test equipment. The FMECA looks for things likely to break, and its results influenced qualification tests and simulation. Performance tests were run under extreme vibration conditions. Production planning was done during development, as a logistics effort to identify support requirements. They used the same test equipment in production as at the Aviation Intermediate Maintenance (AVIM) facility.

<u>For individual components</u>:

Questions V2 through V6 were answered using these possible answers. More than one answer is permitted.

1	2	3	4	5	9
Prime	Suppliers	Army center/lab	Other Government org.	Not done on project	Don't know

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

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

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

V4. Were **the components tested working together <u>in a controlled setting</u>**? What organization(s) did this testing? *Prime, Suppliers, and Other Government organization*

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

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? *Prime and Army center/lab*

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

V7a. To see **if the individual components of the system worked:** *Yes.*

V7b. To see if integrated components worked **in controlled setting:** *Yes.*

TADS/PNVS components were tested in the completed system using "aircraft simulator" test equipment. The TADS/PNVS itself was testing in the aircraft manufacturer's Systems Integration Laboratory.

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

15 % spent to see **if the individual components of the system worked**
5 % spent to see if integrated components worked **in controlled setting**
80 % spent to see if integrated components worked **in a realistic setting**
(0) % Spent on any other validation purpose
100 %

Questions V9 through V15 were answered using these possible answers:

1	2	3	4	5	9
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. *Strongly agree.*

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

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

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

V13. Most project validation events produced quality results. *Agree somewhat.*

V14. The project didn't recognize important lessons that validation work uncovered. *Strongly disagree.*

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

2. GAO Research:

This data is excerpts from: General Accounting Office (GAO) Report, Best Practices, A More Constructive Test Approach Is Key to Better Weapon System Outcomes, GAO/NSIAD-00-199, July 2000.

Report Abstract: This report examines (1) how the conduct of testing and evaluation affects commercial and Defense Department (DOD) program outcomes, (2) how best commercial testing and evaluation practices compare with DOD's, and (3) what factors account for the differences in these practices. GAO found that commercial firms use testing to expose problems earlier than the DOD programs GAO visited. Commercial firms' testing and evaluation validates products' maturity based on three levels at specific points in time, which works to preclude "late-cycle churn" or the scramble to fix a significant problem discovered late in development. Late-cycle churn has been a fairly common occurrence on DOD weapon systems, where tests of a full system identify problems that often could have been found earlier. DOD's response to such test results typically is to expend more time and money to solve the problems--only rarely are programs terminated. The differences in testing practices reflect the different demands commercial firms and DOD impose on program managers. Leading commercial firms insist that a product satisfy the customer and make a profit. Success is threatened if unknowns about a product are not resolved early when costs are low and more options are available. Testing is constructive and eliminates unknowns. Success for a weapons system is centered on providing a superior capability within perceived time and funding limits. Testing plays a less constructive role, because test results often become directly linked to funding and other key decisions and can jeopardize program support. Such a role creates a more adversarial relationship between testers and program managers.

Purpose Despite good intentions and some progress by the Department of Defense (DOD), weapon system programs still suffer from persistent problems associated with late or incomplete testing. Often, the fate of a program is jeopardized by unexpectedly poor test results. In such cases, testing becomes a watershed event that attracts unwanted attention from decision makers and critics. The discovery of problems in complex products is a normal part of any development process, and testing is perhaps the most effective tool for discovering such problems. However, why surprises in testing repeatedly occur and why such results polarize organizations into proponents and critics of programs have proven elusive questions to answer. Indeed, numerous solutions proposed over the years by different DOD leaders and distinguished outside panels have not had much effect.

Lessons learned by leading commercial firms in developing new products are applicable to the management and testing of weapon systems. These firms achieve the type of outcomes DOD seeks: they develop more sophisticated products faster and less expensively than their predecessors. Commercial firms have found constructive ways of conducting testing and evaluation that help them avoid being surprised by problems late in a product's development. In response to a request from the Chairman and the Ranking Minority Member, Subcommittee on Readiness and Management Support, Senate Committee on Armed Services, GAO examined (1) how the conduct of testing and evaluation affects commercial and DOD program outcomes, (2) how best commercial testing and evaluation practices compare with DOD's, and (3) what factors account for the differences in these practices.

Background The fundamental purpose of testing and evaluation does not differ for military and commercial products. Testing is the main instrument used to gauge the progress being made when an idea or concept is translated into an actual product.... In both DOD and commercial firms, product testing is conducted by organizations separate from those responsible for managing product development.

Results in Brief For the leading commercial firms GAO visited, the proof of testing and evaluation lies in whether a product experiences what one firm called "late-cycle churn," or the scramble to fix a significant problem discovered late in development….

On the weapon programs, system-level testing carried a greater share of the burden. Earlier tests were delayed, skipped, or not conducted in a way that advanced knowledge.... Leading commercial firms have learned to insist that a product satisfy the customer and make a profit. Success is threatened if managers are unduly optimistic or if unknowns about a product are not resolved early, when costs are low and more options are available. The role of testing under these circumstances is constructive, for it helps eliminate unknowns. Product managers view testers and realistic test plans as contributing to a product's success. Success for a weapon system program is different; it centers on attempting to provide a superior capability within perceived time and funding limits. Success is influenced by the competition for funding and the quest for top performance; delivering the product late and over cost does not necessarily threaten success. Testing plays a less constructive role in DOD because a failure in a key test can jeopardize program support. Specifically, test results often become directly linked to funding and other key decisions for programs. Such a role creates a more adversarial relationship between testers and program managers.

Principal Findings

Problems Found Late in Development Signal Weaknesses in Testing and Evaluation

Over the years, GAO found numerous examples of late-cycle churn in DOD programs, regardless of their size, complexity, or product type. More recent examples include the following:

• The DarkStar unmanned aerial vehicle crashed during initial flight tests. DOD spent twice the planned money and time to redesign and retest the aircraft, eventually terminating the program.

Testing Early to Validate Product Knowledge Is a Best Practice

Leading commercial firms GAO visited think in terms of validating that a product works as intended and use testing and evaluation as a means to that end. To limit the burden on the product's third maturity level (operating in a realistic environment), leading firms ensure that (1) the right validation events—tests, simulations, and other means for demonstrating product maturity—occur at the right times, (2) each validation event produces quality results, and (3) the knowledge gained from an event is used to improve the product. The firms hold challenging tests early to expose weaknesses in a product's design. AT&T refers to this as a **"break it big early"** philosophy….

Different Incentives Make Testing a More Constructive Factor in Commercial Programs Than in Weapon System Programs

… Test results tend to become scorecards that demonstrate whether the program is ready to proceed or to receive the next increment of funding. Whereas testing and evaluation of commercial products mainly benefits the product manager, in DOD, testing and evaluation is more for the benefit of the testers and decision makers above the program manager. Managers thus have incentives to postpone difficult tests and to limit open communication about test results. Managers in both the DarkStar unmanned aerial vehicle and the Standoff Land Attack Missile programs also overruled testers because of funding and schedule pressures.

Recommendations To lessen the dependence on testing late in development and to foster a more constructive relationship between program managers and testers, GAO recommends that the Secretary of Defense instruct acquisition managers to structure test plans around the attainment of increasing levels of product maturity, orchestrate the right mix of tools to validate these maturity levels, and build and resource acquisition strategies around this approach. GAO also recommends that validation of lower levels of product maturity not be deferred to the third level. Finally, GAO recommends that the Secretary require that weapon systems demonstrate a specified level of product maturity before major programmatic approvals."

Chapter 2. Problems Found Late in Development Signal Weaknesses in Testing and Evaluation

… Problems are most devastating when they delay product delivery, increase product cost, or "escape" to the customer.

Chapter4: Different Incentives Make Testing a More Constructive Factor in Commercial Programs Than in Weapon System Programs

The Under Secretary of Defense for Acquisition, Technology, and Logistics, before he took office, pinpointed the following differences in commercial and DOD testing:

In the commercial world, the reason for testing and evaluating a new item is to determine where it will not work and to continuously improve it . . . . Thus testing and evaluation is primarily for the purpose of making the best possible product, and making it as robust as possible . . . . By contrast, testing and evaluation in the Department of Defense has tended to be a final exam, or an audit, to see if a product works. Tests are not seen as a critical element in enhancing the development process; the assumption is that the product will work and it usually does. Under these conditions, the less testing the better—preferably none at all. This rather perverse use of testing causes huge cost and time increases on the defense side, since tests are postponed until the final exam and flaws are found late rather than early.1 (1 Defense Conversion: Transforming the Arsenal of Democracy; MIT Press, 1995.)

Commercial Incentives Foster Candor and Realism in Product Validation

Once a company decides to launch a product development, strong incentives, grounded in the business case, encourage a focus on product validation to keep the program on track. To meet market demands, leading commercial companies plan around comparatively short cycle times—often less than 2 years—to complete a product's development. These short time frames make customer acceptance and return on investment close at hand. Consequently, production looms as a near-term reality that continues to influence subsequent product decisions within the framework of the business case.

To deliver the product on time, commercial firms insist on validating the maturity of technologies before they are allowed onto a new product.

Testing Is Perceived as Impeding the Success of Weapon System Programs

The basic management goal for a weapon system program in DOD is similar to that of a commercial product: to develop and deliver a product that meets the customer's needs. However, the pressures of successfully competing for the funds to start and sustain a weapon system program create incentives for launching programs that embody more technical unknowns and less knowledge about the performance and production risks they entail. On the basis of our present and previous work, as well as our review of outside studies, such as those sponsored by DOD, we have identified several key factors that affect the business case for starting a new weapon system program.

Annual funding is approved →

User requirements exist →

Program promises best capability →

Program looks affordable →(back to beginning)

Testing Can Pose a Serious Threat to a DOD Program

Within the DOD business case for the programs we reviewed, test results tended to become scorecards that demonstrated to decision makers that the program was ready to proceed to the next acquisition phase or to receive the next increment of funding. As a result, testing operated under a penalty environment; if tests were not passed, the program might look less attractive and be vulnerable to funding cuts. Managers thus had incentives to postpone difficult tests and limit open communication about test results. Under these conditions, demonstrations that show enough progress to continue the program are preferred over actual tests against criteria, which can reveal shortfalls. Accordingly, DOD testers are often seen as adversaries to the program. In general, testers are often organizationally removed from the design and development effort and are viewed as outsiders. Unlike their commercial counterparts, they do not have a strong voice in early program planning decisions. As a result, their authority or influence is limited, and they are often overruled in decisions to proceed with programs despite testing weaknesses.

The role testing plays in DOD programs was analyzed in a September 1999 report from the Defense Science Board.3 The Board concluded that the "response to perceived test failures is often inappropriate and counterproductive." Instead of using testing, especially in the early stages, as a vital learning mechanism and an opportunity to expand product knowledge, testing is often used as a basis for withholding funding, costly rescheduling, or threats of cancellation.

DOD Testing Impaired by Optimism and Insufficient Resources

Although DOD does extensive test and resource planning, the planning on the weapon systems we reviewed was often undercut by unrealistic assumptions. DOD's acquisition regulation 5000.2R requires formal test plans and resource estimates for every weapon system program that must be reviewed and approved by numerous organizations. This formal process does not guarantee that the program will comply with the plan or receive the resources requested or that the plan itself is realistic. On the programs we reviewed, pressures to keep schedule and cost estimates as low as possible forced managers into optimistic plans that presume success instead of anticipating problems. Test resources and schedules were assigned accordingly. The resultant test plans eventually proved unexecutable because they underestimated the complexity and the resources necessary to validate the product's maturity. Typically, the time and money allocated to testing was more a by-product than a centerpiece of the product development estimate.

The DarkStar test approach had similar constraints. The contractor developed a test plan that accommodated cost and schedule limits, but did not address the range of technical parameters that needed to be investigated. Problems were noted during testing, but because of schedule and cost pressures, minimal attempts were made to correct them. The safety investigation board, which investigated after the vehicle crashed, reported that "scheduling was dictated by programmatic pressures rather than sound engineering processes" and "the overriding driver repeatedly appeared to be schedule and budget." The funding and schedule constraints were imposed without considering what resources were needed to adequately mature and integrate DarkStar components into a system. Ironically, the resources to redesign and retest the system—double the original estimate—were made available only after serious problems occurred under the original plan.

Conclusions

For testing and evaluation to become part of a constructive effort to validate the maturity of new weapon systems in DOD, the role it plays and the incentives under which it operates must change. Currently, testing and testers are not seen as helping the product succeed but as potential obstacles for moving forward. They become more closely linked with funding and program decisions and less likely to help the weapon system improve. Given the pressures on program managers to keep development cost and schedule estimates low, being optimistic and reluctant to report difficulties is more important to program success than planning a realistic validation effort to discover design and other problems. Attempts by decision makers to impose cost and schedule constraints on a program without full consideration of what is required to reach product maturity levels becomes a false discipline that can intensify pressures to defer or weaken testing, thereby increasing the potential for late cycle churn. If DOD is successful in taking actions that respond to our previous recommendations, especially those that will reduce the pressure to oversell programs at their start, the Department will have taken a significant step toward changing what constitutes success in weapon systems and making testing and evaluation a more constructive factor in achieving success.

Recommendations

To lessen the dependence on testing late in development and foster a more constructive relationship between program managers and testers, we recommend that the Secretary of Defense instruct the managers and testers of weapon system programs to work together to define levels of product maturity that need to be validated, structure test plans around reaching increasing levels of product maturity, and orchestrate the right mix of tools to validate these levels. Acquisition strategies should then be built and funded to carry out this approach. Such a focus on attaining knowledge, represented by product maturity levels, can guard against the pressures to forego valuable tests to stay on schedule or to hold tests that do not add value to the product. This approach, which creates common ground between testers and product managers in leading commercial firms without compromising independence, still demands that the product or weapon system being matured meet the needs of the customer.

We also recommend that Secretary of Defense not let the validation of lower levels of product maturity—individual components or systems in a controlled setting—be deferred to the higher level of system testing in a realistic setting. Although the mix of testing and evaluation tools may change and the acquisition strategy may be altered during the course of a development, the focus on attaining product maturity levels should not change. This discipline should also help guard against the practice of setting cost and schedule constraints for programs without considering the time and money it takes to sensibly validate maturity. Finally, we recommend that the Secretary of Defense require weapon systems to demonstrate a specified level of product maturity before major programmatic approvals. In doing so, the Secretary may also need to establish interim indicators of product maturity to inform budget requests, which are made well in advance of programmatic decisions. Testing and evaluation could then be cast in a more constructive role of helping a weapon system reach these levels and would ease some of the burden currently placed on program managers to rely on judgment, rather than demonstrated product maturity, in promising success at times when major funding commitments have to be made.

C. ANALYSIS OF SIMULATION AND TESTING STRATEGY

Primary Question: What was the simulation and testing strategy for the system, and did that strategy adequately evaluate the system for its ultimate operational use?

1. Test Approach Used?

Validation Activities: Testing and Simulation

In the early stages of the project, the contractor did a Failure Modes Effects and Criticality Analysis (FMECA) on the system. This analysis helped establish the test requirements and influenced simulation. This in turn, drove the design of test equipment and field automatic test equipment, and they also used the same test equipment at the Aviation Intermediate Maintenance (AVIM) facility. Another FMECA result was that performance tests were run under extreme vibration conditions. The production planning efforts during development focused on logistics in an effort to identify the full spectrum of support requirements.

Testing and simulation (T&S) were performed in a variety of settings: T&S of individual components, T&S of components in controlled settings, tests of components in realistic settings, and a hardware-in-the-loop type systems integration simulation laboratory.

The full test strategy included tests of sub-assemblies and of some individual components, performed by the Prime and suppliers as appropriate. They also verified some components with simulations.

The Prime, their suppliers, and Government organizations tested some integrated components in a controlled setting. The Prime and U.S. Army labs performed simulations of some components working together in a controlled setting. They also tested components working together in a realistic setting.

A hardware-in-the-loop type systems integration simulation laboratory was used to check individual components of the system, and to check integrated components in a controlled setting. TADS/PNVS used aircraft simulator test equipment in the aircraft manufacturer's Systems Integration Laboratory.

Summarizing the total amount spent on the testing and simulation discussed above, the contractor spent roughly 15% to see if the individual components of the system worked, 5% to see if integrated components worked in controlled setting, and 80% to see if integrated components worked in a realistic setting.

Validation work on component and system maturity was done in plenty of time to allow using that information to help the program. Validation knowledge was used consistently to improve components and thee system. However, the project didn't do all they could early on to get rid of project risk. The project's test philosophy was to "Break it big early," but sometimes caution prevented using rigorous testing.

Testers and project personnel on TADS/PNVS were in a good teaming relationship. The TADS/PNVS program used the best validation methods available, and they were quick to recognize important lessons learned from this work. The majority of the project validation work was of high quality.

2. GAO Research:

"Late Cycle Churn:"

According to the GAO, within the DoD, it is fairly common to have test failures late in the test cycle, which could (and should) have been discovered earlier in development. In industry, this is called "late-cycle churn," the scramble to fix a significant problem discovered late in development. The frequent result is spending a lot more money to fix problems. Discovering and fixing problems earlier in development costs far less money, and also saves time. Civilian companies that develop products have a different testing and evaluation philosophy, the "Break it Big Early" philosophy, which works to preclude "late-cycle churn."

Test Failure Consequences:

Rather than being viewed as constructive, some DoD organizations avoid difficult tests because test failures can increase the probability of funding reductions or program cancellation. Testing is often linked to funding and can jeopardize program support – a penalty environment. However, delivering late and over budget is not viewed as harshly. Of course, late cycle churn has even greater cost and schedule impacts, but because of the length of the normal developmental cycle, it is frequently years later and *under a new program manager, developer, or tester,* when faults are discovered.

Even if a program is somewhat protected by powerful ‘champions,’ other negative consequences are possible. These consequences or reactions from test failures, beside funding reductions and program cancellation, range from getting called ‘on the carpet’ and reprimanded unofficially, to getting fired – and possibly career ruination. The project may be protected, but that does not mean that the program manager and staff are similarly protected.

However, testing is perhaps the most effective tool for discovering design problems. Some development critics want you to fix everything before a particular test. But you have to find problems before you can fix them, and testing is a great way to find problems. Discovering problems in new products is a normal part of development and known as ‘test-fix, test-fix, test-fix….’ Eliminating problems, which can only be done after discovery, improves a product. Testing corrects latent problems that could delay product delivery, increase product cost, or be delivered to the customer. Field users usually view faulty delivered products as a blunder.

There is an apparently strong expectation in the military that test failures will cause strong negative reaction by somebody in their chain of command. Whether this belief is always justified, is not as important as that it is probably true often enough to cause the belief to be as widespread as it is. This expectation is a common part of military organizational culture, and as such, is very difficult to change.

On the other hand, cancellation of a program due to various risks should be minimized. Viewed pragmatically, if the risk due to test failures is a lot higher than due to schedule or cost problems, then you should not risk test failures. This has been the case for quite a while.

Less Testing:

There are many people at different levels who have reasons to delay or diminish tests. In many cases, the reason given is that the test article is not ready for the test as written, so modifying it is very logical.

Development personnel are normally divided between developers and developmental testers. This segregation helps keep the testers relatively independent, and therefore effective. But there has to be someone who is in charge of them all, namely the program manager. The PM is graded on how well the development goes. If the PM knows the system is not ready for a test, then it is quite easy to modify some tests so that the system passes. You still get some data, although it is arguable how valuable the data will be.

And of course, if the PM's next promotion ~~may~~ depend upon the system passing a test, then it is hard to resist some types of changes. Other changes include delaying tests, deferring difficult steps from tests, or lowering the test pass/fail criteria. It is much more difficult to affect the results of major tests. However, some programs go a long time between the major tests. When the system comes to a major test and fails, it is often a surprise to those outside of the program.

These test changes are often rationalized: if they know a system can not pass a test, they change the test to something the system can pass – what is the sense of running a test you know will fail? But, then the passed test's results are occasionally substituted for those of the originally programmed test. They have lowered the test criteria, while (in effect) presenting these results as proof that the system is on track, this does not mean that PMs are dishonest, but that there are routinely many testing modifications, delays, or de-scopings. The end result is that testing of a system is less rigorous than needed – not all the delays are due to one person, or one reason – and thus the system is more prone to "late-cycle-churn." Integrity requires listing test changes on test reports, to notify the chain of command, auditors, and other interested people.

This fear of performing tests to learn, engendered by the expectation of negative reactions by higher-level managers, causes the learning curve to be lower in DoD. Testers 'know' they *should not* risk test failures because of the potential reaction of the Program Manager; PMs 'know' they cannot risk high-visibility test failures because of the Program Executive Officer's reaction; PEOs 'know' they have to consider the Service Acquisition Executive’s reaction; and the SAE 'knows' they must consider the SecDef and Congressional reactions which could result in a significant loss of funds, or even program cancellation. Of course, this is despite an official policy to find flaws earlier. However, in some cases, there appears to be insufficient energy behind this newer policy to motivate certain echelons of the oversight chain to protect the PM's honest developmental testing efforts from the circling vultures eager to pounce upon a routine test failure (learning experience) as an excuse to seize his funds.

Break It Big Early – Testing to Learn:

There are basically two types of testing: there is testing to learn, and testing to confirm. The first type is done early in development, but it is frequently not used sufficiently by the DoD. In commercial development, the testing philosophy is to find flaws and to continuously improve the product, and make it as robust as possible. DoD sees testing as a "final exam" or an audit to evaluate a product. And the culture of the DoD often forces managers into optimistic plans that presume success, instead of anticipating problems. This success-oriented philosophy is somewhat understandable, given the reluctance to risk test failures.

Break It Big Early (BIBE) is a testing-to-learn strategy. It tells you about your system. If you use this early testing as a testing-to-confirm opportunity, you are going to affect the attitude of the author of the test procedure, the tester, and the program manager. You are adjusting their attitudes, during a preliminary stage of the design. It is all very well to tell the PM to reduce risk, but this 'catch-22' situation makes it very difficult.

Experimental Test Pilots try to 'break' equipment, that is they tend to test an aircraft on the ground very rigorously, especially new systems or new features, trying to do whatever they can to 'break' it, and then get those failures fixed. But when they are flying a prototype aircraft, they are more circumspect, and often will have a list of functions to avoid, and a list of corrective procedures in case something does malfunction or 'break.'

Commercial companies strive for short development cycles, usually less than two years, which improves their return on investment. Production is seen as a near-term event, so there is more impetus to test the product thoroughly and find all the hidden flaws.

Testing for the Scorecard:

Testing in DoD becomes a scorecard to rate system developmental progress. A major test is a decision point on whether or not to proceed with the program. Thus, program managers have incentives to avoid, or at least postpone, risky testing, and to limit open communications of results. Oversight organizations occasionally try to get access to lower level test data, although some program managers may be able to fend them off. Program success is frequently determined (especially by proponents in Congress with constituent jobs at risk) by how well you keep the money coming in, not if the product fulfills its requirements. 'Full funding' is not an end in itself; the system must fulfill its requirements, as verified by testing.

In both DoD and commercial companies, testing is conducted by separate organizations. The separation makes testers independent, and hopefully more candid. However, the negative side of the separation, is testers have less say in the design; testability is not designed in. Testers look at requirements from the point of view of how they will be tested, which is a useful perspective and a design tool that DoD often overlooks. Also, in the DoD there is often an adversarial relationship between developers and testers, particularly the Operational Testers.

GAO recommends increasing levels of maturity earlier in the development cycle, and proposes various methods to carry this out. However, the negative incentives surrounding rigorous early tests still remain in DoD. If acquisition managers are going pursue a higher level of maturity, they will have to decrease the risk of test failures resulting in funding losses. This will not be easy to do. The GAO study quotes a September 1999 report from the Defense Science Board: “The response to perceived test failures is often inappropriate and counterproductive.” The GAO continues:

> Instead of using testing, especially in the early stages, as a vital learning mechanism and an opportunity to expand product knowledge, testing is often used as a basis for withholding funding, costly rescheduling, or threats of cancellation.

D. CONCLUSIONS ON SIMULATION AND TESTING STRATEGY

Primary Question: What was the simulation and testing strategy for the system, and did that strategy adequately evaluate the system for its intended ultimate operational use?

1. Test Approach Used?

Validation Activities: Testing and Simulation

The contractor performed a Failure Modes Effects and Criticality Analysis (FMECA), and it strongly impacted design, testing, test equipment, and simulation. The testing and simulation (T&S) had considerable variety. Various organizations did tests of components, sub-assemblies, and the end system; some components were verified by simulations. They tested components and sub-assemblies in controlled settings (hardware-in-the-loop), and sub-assemblies in a realistic setting (aircraft simulator test equipment). The vast majority of the test money was spent on the last category, with a modest amount on testing in controlled settings.

Fairly high quality validation work helped the program in system maturity and improving components, but some early risks were not handled as well as they should have been. This is possibly an instance of avoiding testing that might fail and consequently threaten the program's continued funding. However, testers and project personnel usually worked well together.

2. GAO Research:

The Best Practices GAO Report shows that DoD programs routinely suffer from "Late Cycle Churn," a condition describing operational testing failures that discovered problems that should have been revealed in earlier developmental testing. Commercial developers use the "Break it Big Early" philosophy. It allows them to uncover system problems earlier, when they are less expensive to fix.

But DoD is reluctant to run a test that they might fail, even if it might highlight potential flaws. Test failure could cause the program to loose some of its funding or be cancelled – a harsh penalty. It also reflects poorly on the Program Managers, to the extent that they may never be promoted again. Late deliveries and cost overruns are more common and not so harshly punished. If DoD hopes to modify this balance, they need to also modify the probabilities (and severity) of rewards and punishments.

DoD does less testing early in development, which impacts the readiness of the system in late-cycle operational testing. The program manager, developers, and testers should not be judged solely on developmental success, but also on running a thorough developmental test program. Otherwise, there is a great incentive to run cursory tests.

Testing is a value-added activity, a necessity for successful development. The more rigorous the testing, the more you find out about the test article. You have to find flaws in order to fix them. But testing-to-learn should not be used for a 'final exam' or 'Scorecard' opportunity.

Simply ordering program managers to test more thoroughly will probably not be effective for DoD in the long run. Any programs that increase testing will undoubtedly uncover more problems; however, if those programs face the threat of being cancelled, then future program managers will get the message that more thorough testing will not save their programs. DoD must change the definition of what constitutes success in weapon systems and increase constructive testing and evaluation.

The testing philosophy of the TADS/PNVS program was not very different than those of other defense contractor companies at the time. The TADS/PNVS was a very important part of the AAH program, but very risky. It is likely that upper DoD managers would have balked at the contract if it had presented a realistic cost estimate (based upon "20-20 hindsight.") But the lower cost caused some risky behavior – you cannot allocate money to risk reduction testing if funds are not available.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. Test Strategies:

Study how the merging of Developmental Testing with Operational Testing has affected the openness of the program management offices and development contractors to the "break it big early" philosophy.

2. NASA Development Test Strategies:

Study how the NASA compares with the DoD and commercial developers in their testing strategy. Do these developers compare more to the commercial model, or the military model. What are the effects of large Government bureaucracy on test strategies? Also, what are the political factors affecting testing strategy? Does NASA have more control of its funding, or is it just as subject to cancellation if a system has poor test results?

3. Independent Research and Development (IR&D):

Some programs have taken the route of off-loading more and more of their high-risk work to separate IR&D projects. This reduces overall program risk, and test 'failures' can be disassociated from the program. These strategies may help programs lower their risk of losing funding, while reducing developmental risk. Study how programs do this, what percentage of work is off-loaded, and their various strategies for integrating results back into the system.

4. Commercial Versus DoD Developmental Programs:

Study commercial and DoD developmental programs and compare them on the basis of program size, program development time period and program complexity. This will supplement the overall comparison of all programs. Are the DoD programs of similar size / complexity / development time as efficient as commercial programs? Compare how well each has adopted lean engineering and lean manufacturing techniques.

LIST OF ACRONYMS AND ABBREVIATIONS

AAH	AH-64 Apache Attack Helicopter
ACAT	Acquisition Category
AMC	U.S. Army Material Command
AMCOM	U.S. Army Aviation and Missile Command
ANSI	American National Standards Institute
ASH	Advanced Scout Helicopter – cancelled in the 1970s
ATCOM	U.S. Army Aviation and Troup Command (ATCOM and MICOM are now merged into AMCOM)
D	Development (Question on the Survey)
DoD	Department of Defense
DOS	Disk Operating System
DPM	Deputy Program Manager
DSMC	Defense System Management College
FLIR	Forward-Looking Infra-Red
FTA	FLIR Target Acquisition
G&C	Guidance and Controls Laboratory
GAO	General Accounting Office
IPT	Integrated Product Team
IBM	International Business Machines
IR&D	Independent Research and Development
LOS	Line-of-Sight
LOSS	Line-of-Sight Stabilization
LSBS	Laser to sensor bore-sight
MICOM	U.S. Army Missile Command(ATCOM and MICOM are now merged into AMCOM)
MIT	Massachusetts Institute of Technology
NPS	Naval Postgraduate School
NVL	Night Vision Laboratory
OS	Operating System
ODS	Operation Desert Storm
PM	Program Manager
PMO	Program Manager's Office
PNVS	Pilot Night Vision System
S&T	Science and Technology Group within system Prime Contractor responsible for doing IR&D and developing new technology and concepts.
SP	Start of Program (Question on the Survey)
TADS	Target Acquisition Designation System
Technology A	Line-of-Sight Stabilization
Technology B	FLIR target acquisition
Technology C	Laser to sensor bore-sight
TP	Transition to Production (Question on the Survey)

TRADOC	U.S. Army Training & Doctrine Command (and/or other appropriate user representatives)
TRL	Technology Readiness Level
UAH	University of Alabama in Huntsville

LIST OF REFERENCES

1. From Hot Air to Hellfire - James W. Bradin, © 1994

2. Selected Acquisition Report (SAR), 30 Sep 1992

3. GAO Report, Best Practices - A More Constructive Test Approach Is Key to Better Weapon System Outcomes, GAO / NSIAD-00-199, July 2000. Click on website http://www.gao.gov/ then "GAO Reports", "Find GAO Reports", type in the report number in the blank, and enter.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A: COMBINED QUESTIONNAIRE RESPONSE:

The combined survey was created by combining the answers from Government and contractor responses.

THIS PAGE INTENTIONALLY LEFT BLANK

Combined Survey

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.

<u>This is not a traditional questionnaire</u>. 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 page 8), 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**): _____/1976 (mo/yr) [TRL2 at system level]

In what organization was the primary work leading up to this point accomplished? **There were really three important organizations that contributed. The ASH PM (Advanced Scout Helicopter) prior to being cancelled and the AAH PM were the driving force for establishing and planning the program. The technology work was being led by the MICOM G&C lab and The Night Vision Lab (NVL). Contractor S&T organizations were doing their own work in response to the anticipated requirement for the ASH and AAH programs.**

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	X Active support	___Involved	___Kept informed	___Not involved	___DK
Other prime org.	___ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Supplier S&T org.	___ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Other supplier org.	___ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Army Lab/Center	___ Lead/co-lead	X Active support	___Involved	___Kept informed	___Not involved	___DK
Other DoD/S&T org.	___ Lead/co-lead	___Active support	___Involved	_ X Kept informed	___Not involved	___DK

What was the nature of the Army Lab/Center's involvement? (Simulation? Concept formulation? Integration? Requirements development?) **The MICOM G&C lab was the developer of the Hellfire missile for which the TADS acquires and designates targets. Major systems requirements such as Total Pointing Error (TPE) for the laser designator were defined by the G&C lab based on testing and simulations. They also did early work on the laser hardware that does the designation. NVL was the developer of FLIR technology which was used in the TADS night side and the PNVS. They were responsible for the development and eventually production of the FLIR common modules which are used in the TADS Night Side. Significant support was given by these labs and Frankfort Arsenal (fire control, optics) in formulating requirements, evaluating proposals and monitoring development progress.**

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**): _____/1977 (mo/yr)

What was the Technology Readiness Level (refer to page 8) for the SYSTEM on this date?_ **Level 3**

What was the Production Readiness Level (refer to page 8) for the SYSTEM on this date? **Level 1**

In what organization was the primary work in the period from **SP** to **D** accomplished? **Supplier**

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	_X Active support	___Involved	___Kept informed	___Not involved	___DK
Other prime org	___ Lead/co-lead	___Active support	_X Involved	___Kept informed	___Not involved	___DK
Supplier S&T	_X Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Other supplier org	___ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Army Lab/Center	___ Lead/co-lead	X Active support	___Involved	___Kept informed	___Not involved	___DK
Other DoD/S&T 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?) **G&C Lab, NVL, and Frankfort Arsenal provided engineering support, simulation, and 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**:** _____/1980 (mo/yr) (TRL 7 at system level)

What was the Production Readiness Level for the SYSTEM on this date? **Level 2**

In what organization was the primary work in the period from D to TP accomplished? **Martin Marietta, Orlando, the prime contractor. This work was done under a project management (PM) 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	___ Lead/co-lead	_X Active support	___Involved	___Kept informed	___Not involved	___DK
Other prime org	___ Lead/co-lead	___Active support	_X Involved	___Kept informed	___Not involved	___DK
Supplier S&T	_X_ Lead/co-lead	___Active support	___Involved	___Kept informed	___Not involved	___DK
Other supplier org	___ Lead/co-lead	_ X Active support	___Involved	___Kept informed	___Not involved	___DK
Army Lab/Center	___ Lead/co-lead	_X Active support	___Involved	___Kept informed	___Not involved	___DK
Other DoD/S&T org.	___ Lead/co-lead	___Active support	___Involved	_X Kept informed	___Not involved	___DK

What was the nature of the Army Lab/Center's involvement? (Engineering support? Simulation or testing? Integration? Requirements interpretation?) **MICOM G&C, NVL, and Frankfort Arsenal continued to provide engineering support, simulation, test witnessing and requirements interpretation.**

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 **Line of Sight Stabilization**

Technology B **FLIR target acquisition**

Technology C **Laser to sensor bore sight**

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
New and unproven for the prime contractor?	1. _X_	1. ___	1. _X_
Technology had been used by prime contractor but it was **new to to this kind of application?**	2. ___	2. _X_	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
Technology forced deep and serious production process change?	1. X _	1. X _	1. ____
Technology caused significant production process change?	2. ____	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
This system was the Prime's only planned application of the technology.	1. ___	1. ___	1. ___
Prime was planning or had started follow-on uses of the technology.	2. _ X _	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**

T5. When **System** planning and pre-development began, technology TRL was:	# __4___	# __4___	# __3___
T6. When **System** went into Development, technology TRL was:	# __5___	# __5___	# __4__
T7. When **System** reached Transition to Production, technology TRL was:	# __9___	# __9___	# __8___

When SP started stabilization technology was not new and had had many applications but none to this difficult an application in a helicopter flight envioronment. Likewise, due to the work on FLIR technology by NVL there was a significant technology base to draw on; however, meeting target detection and recognition requirements was a very difficult goal and integration of a FLIR meeting these requirements into the stabilized turret was a real challenge. The boresight problem was recognized as critical from the very beginning but achieving a boresight which met accuracy requirements and remained stable over environmental extremes proved very difficult and tenuous. Since boresight stability is impacted by many factors in all sensors, boresighting components and the stabilized turret, it was not possible to address boresight shortcomings until the entire TADS system was designed, built, and tested for other areas of performance.

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

	Technology A	**Technology B**	**Technology C**
T8. Yes, it contributed to Readiness at start of Planning/Pre-development.	8a ____	8b. _ X _	8c. ____
T9. Yes, it contributed to Readiness for Development.	9a. _ X __	9b. __ X _	9c. _ X __
T10. Yes, it contributed to Readiness for Transition to Production.	10a . _ X __	10b. __ X _	10c. _ X __
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: ___ 1. Slowed down? ___ 2. Stopped and restarted? X _ 3. Neither

TADS/PNVS program was originally part of the ASH (Advanced Scout Helicopter) program, which was cancelled. This happened prior to 1977, the start of SP phase.

AAH (Apache AH 64 PMO) was already involved when ASH left the program, as was MICOM. AAH and MICOM support of TADS/PNVS continued on, when ASH left the program.

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? _ X Yes ___ No

If YES, was it: _ X 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.

FROM INTERVIEW: This concept of an integrated product team (IPT), really came more into vogue about or after the time we first went into production. At that time there was a big emphasis to bring in production people, logistics, and, so forth in the very early stages of the design program. In the early stages of the TADS PNVS program, we did have those people involved and that is when I would say we did it. We did not call it IPT and they didn't organize it that much, but there were reliability, logistics, maintenance, and production requirements. In the beginning of the program in 1977 when they did this initial primary design with 7 different contractors and then the fly off, there was much heavier emphasis, of course, on the performance aspects of TADS/PNVS because it is something that no one had ever done before, so the rest of it doesn't matter if you cannot do the performance part.

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? _ X No. ___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
___ 6. Other. Please specify ________________

The design chief could draft people from other groups. It was as good as "DX brick bat" priority, which same individual had later on, at least within the company in Orlando. However, they didn't have the microwave electronics hybrids design group, nor the printed circuit layout design people on the project. Those were both functional groups, and the TADS/PNVS group didn't have enough work to justify keeping them on their team. But they had as good of a priority with these groups as any other project in the company in Orlando.

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 _ X 2. Most (2/3rds or more) ___3. Some (over a third) ___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 ___X2. Most (2/3rds or more) ___3. Some (over a third) ___4. Few ____5. None ____DK/can't say

Most were in the same building, about 90%, and the rest were in another building in the same city.

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

___1. All X _2. Most (2/3rds or more) ___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?

X _1. Prime contractor's facilities ___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

This analysis drove the test requirements for production test equipment and for fielded automatic test equipment. The FMECA looks for things likely to break, and its results influenced qualification tests and simulation. Performance tests were run under extreme vibration conditions. Production planning was done during development, as a logistics effort to identify support requirements. They used the same test equipment in production as at Aviation Intermediate Maintenance (AVIM) facility.

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 ___ 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 ___ 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 ___ Army center/lab _ X __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?
___ Prime ___ Suppliers _ X 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?
___ Prime ___ Suppliers _ X Army center/lab ___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
TADS/PNVS components were tested in the completed system using "aircraft simulator" test equipment. The TADS/PNVS itself was testing in the aircraft manufacturer's Systems Integration Laboratory.

V8. Recalling the total effort (100%) spent on testing and simulations, please allocate the percent of that total that were:
_15___ % spent to see **if the individual components of the system worked**
_5___ % spent to see if integrated components worked **in controlled setting**
_80___ % spent to see if integrated components worked **in a realistic setting**
____ % 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	4	X	9
V10. Project test philosophy was to "Break it big early."	1	2	3	X	5	9
V11. Component and system maturity were validated at the right times in the program.	1	2	3	4	X	9
V12. The project and the testing community had an adversarial relationship.	X	2	3	4	5	9
V13. Most project validation events produced quality results.	1	2	3	X	5	9
V14. The project didn't recognize important lessons that validation work uncovered.	X	2	3	4	5	9
V15. Sometimes the project settled for less than the best validation method.	X	2	3	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	4	5 X	9
D2. The team leader was good at getting necessary resources.	1	2	3	4 X	5	9

D3. There was a lot of turn-over in team membership.	1	2 X	3	4	5	9
D4. The team leader had both design & production experience.	1	2	X	4	5	9

Developer team leader had **excellent** design experience; but production experience was associated with smaller systems.

D5. The team leader had very high technical competence.	1	2	3	4	5 X	9
D6. Some key technical skills were not represented on the team itself.	1	2 X	3	4	5	9
D7. Team meetings were sometimes frustrating and non-productive.	1	2	3 X	4	5	9
D8. Professionals were split across too many different tasks & teams.	1	2	3 X	4	5	9
D9. Project results did not take advantage of the team's best ideas.	1	2 X	3	4	5	9
D10. Key members continued through pre-production planning and testing.	1	2	3	4 X	5	9
D11. There was often uncertainty about the future of project funding.	1	2	3	4	5 X	9
D12. The team was reluctant to share concerns with gov't PM	. 1 X	2	3	4	5	9
D13. Management project reviews were constructive & helpful.	1	2	3	4 X	5	9
D14. Formal reviews were conducted at key decision points.	1	2	3	4	5 X	9
D15. At the prime contractor, the project was a management priority.	1	2	3	4	5 X	9
D16. Usually team knew right away where to get necessary outside help.	1	2	3	4 X	5	9
D17. Project had a visible & supportive champion in the Prime's management.	1	2	3	4	5 X	9
D18.There was a lot of contact with TRADOC* during the project.	1	2	3	4	5 X	9
D19. The gov't PM was reluctant to share problems with Army leaders	X	2	3	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__	____	____	____	(__)

The Manufacturing engineers reviewed prints all throughout the project, but they didn't use computational models or analytic tools. Computer tools didn't exist at the time, and they didn't have any manufacturing analytical tools – 1970s and early 1980s.

	Never	Once or twice	Several times	Many times	Don't know, Not appl.
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__	(__)

Design engineers and suppliers worked closely together. This was a very unique design so the suppliers were designing/tailoring their hardware for this specific job in many cases.

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	Development – Middle	Development – Later	TP: Transition	(Never)	(DK/ 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_)

The TRADOC Systems Manager and other military personnel changed about every three years as I remember, but I don't know exactly when these changes occurred. However, I don't think this was ever a problem.

	SP: Selection	D: Development – Early	Development – Middle	Development – Later	TP: Transition	(Never)	(DK/ NA)
W5. When did TRADOC/other users show strong support?	_X_	_X_	_X_	_X_	_X_	(__)	(__)
W6. When was there change in the system requirements?	____	____	____	____	_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: Selection	D: Development – Early	Development – Middle	Development – Later	TP: Transition	(Never)	(DK/ NA)
W16. When did the team & technical professionals from **Production** have unscheduled & informal **joint** conversations about the project?	____	_X_	_X_	_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_	_X_	(__)	(__)

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

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

	SP: Selection	D: Development – Early	Development – Middle	Development – Later	TP: Transition	(Never)	(DK/ NA)
W26. When did the team & technical professionals from **Suppliers** have unscheduled & informal **joint** conversations about the project?	_X	_X	_X_X	_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__ __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	2	3	4X	5
B2. Cut-backs in project resources forced changes/compromises.	0	1X	2	3	4	5
B3. Changes in company strategies and goals hurt the project.	0X	1	2	3	4	5
B4. A critical production issue was uncovered very late in the process.	0	1	2X	3	4	5
B5. Management pressure pushed technology prematurely into production.	0	1	2X	3	4	5
B6. There was a lack of acceptance standards for the new technology.	0	1X	2	3	4	5
B7. The technology was hard to scale up from lab & pilot tests.	0	1	2	3X	4	5
B8. Testing, quality control and/or acceptance took longer than planned.	0	1	2	3X	4	5
B9. Departments at the prime resisted project ideas & approaches.	0	1	2X	3	4	5
B10. One or more suppliers did not meet their commitments.	0	1	2	3X	4	5
B11. Army Labs/Centers resisted project ideas or approaches.	X	1	2	3	4	5
B12. Army program offices resisted project ideas or approaches.	0	1X	2	3	4	5
B13. Threat definition or other requirements changed during the project.	0X	1	2	3	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**?

_X__ 1. Many serious changes ___ 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

There was a large amount of work. TADS pointing angle accuracy was a big problem. They had to work on getting a noise-free FLIR. And they needed to work on consistency of Line-of-Sight (LOS) Stabilization – they made repeated changes to meet this specification requirement. The delivery rate of 10, and then 12 per month exacerbated the problem.

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. ____

After the early stages of development LOS stabilization never really became an issue any more. FLIR acquisition ranges were met in the later stages of development and were not a problem in the production hardware. Boresight performance continued to be an issue into the early stages of production. The cost of the fixes were not major but took a lot of time to work out. All three technologies were essential to the performance of the TADS and thus had to be successfully used in the final system.

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

There were some schedule changes from earlier schedules but I can't remember all of the reasons or exactly how much change and from what baseline schedule the changes occurred.

O6. **After the SYSTEM was actually in Production**, how many additional changes in designs and processes were required?
___ 1. Many serious changes ___ 2. Significant changes _X__3. Minor changes ___4. No or almost no changes
___ 7. System did not reach production ___ 8. Not Applicable ___ 9. Don't know

Again, the contractor was incentivised to make reliability improvement changes and under the warranty program could make changes to improve reliability and thereby save the contractor (and ultimately the government) money. Producability changes were also made mostly because of parts that were no longer available.

O7. Did the SYSTEM as it was implemented meet the program's cost goals?
_X__ 1. The results met or exceeded cost goals ___ 7. System did not reach production.
___ 2. The results came close to achieving cost goals ___ 8. Not applicable.
___ 3. The results fell far short of achieving cost goals ___ 9. Don't know.

O8. Did the System Development program, as implemented, come in on budget?
___ 1. The project met or under-ran budget. ___ 9. Don't know.
___ 2. The project slightly exceeded budget.
_X__ 3. The project significantly exceeded budget.

As stated above there were significant overruns to the development contracts. The "Maturity phase contract with Martin Marietta started off at about $45M and ended up at about twice that. However, TADS/PNVS was not a separate line item in the budget but was just part of the AH-64 budget and this overrun was covered within the AH-64 budget.

O9. Did the System as it was implemented meet the project's technical goals and functional requirements?
___ 1. The results met or exceeded technical goals ___ 7. Did not reach production, was not implemented.
X__ 2. The results came close to achieving technical goals ___ 8. Not applicable.
___ 3. The results fell far short of achieving technical goals ___ 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.
___ 2. Yes, problems in the field caused minor problems in the system's effectiveness.
_X_ 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. ___ 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.

Except for those items I checked as "don't know" and taking into account my added notes, I feel confident that I've given a good picture of what happened.

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?

The biggest problem was the cost overruns and the underlying reasons for these over-runs in development. The source of these cost overruns was due to a couple of factors. The primary problem was probably associated with the acquisition approach. After the fly-off there was a down-select to the winning contractor. That down-select was made in the form of the contract award for the maturity phase of the development program. Each contractor submitted a proposal for the maturity phase as part of the down-select competition. It certainly was not in the contractors' best interest at that stage to cost the program in their proposals to fully cover all risk areas. First, the contractor would not go out of his way to highlight areas of risk that the government team had not identified and secondly, for those areas of risk that were identified the contractors did not want to indicate the full cost upside of the risk thereby putting themselves at a substantial competitive disadvantage for the down-select (both by proposing a higher cost than their competitor and by highlighting greater technical risk with their designs that required greater funding in the maturity phase to correct). Having said all of this, I do not feel that the acquisition approach was necessarily the wrong one because the approach with the competitive fly-off and a subsequent maturity phase is designed to significantly reduce the risk that the developed systems will not meet performance goals. Since the TADS/PNVS was the number one riskiest technology in the AAH program this was an appropriate approach, and one that was ultimately successful. Having said that, I think that both the government team and the contractor underestimated the effort it would take to implement the maturity phase design changes, meet all performance goals, develop test equipment, and transition to production. The project manager, therefore, had to deal with all the issues that came up because there was more effort required to get the job done in the required time frame than had been planned for. The solutions to almost all problems resulted in increased cost.

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.

Production Readiness 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.

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. Fredrick Reed
   USA AMCOM
   Redstone Arsenal, AL

4. Dr. Willie J. Fitzpatrick
   USA AMCOM
   Redstone Arsenal, AL

5. Bill Craig
   USA AMCOM
   Redstone Arsenal, AL

6. Dr. Richard Rhoades
   University of Alabama at Huntsville
   Huntsville, AL

7. Professor David F. Matthews
   Naval Postgraduate School
   Monterey, CA

8. Professor Brad R. Naegle
   Naval Postgraduate School
   Monterey, CA

9. Dr. David Lamm
   Naval Postgraduate School
   Monterey, CA

THIS PAGE INTENTIONALLY LEFT BLANK