EMPIRICAL RELATIONSHIPS BETWEEN RELIABILITY INVESTMENTS AND LIFE-CYCLE SUPPORT COSTS

REPORT SA701T1

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Executive Summary

The military services need confidence that their systems will not fail during mission execution and, if they do, that they can be quickly and easily returned to service. However, test results since 2001 show that roughly 50 percent of DoD's programs are unsuitable at the time of initial operational test and evaluation, because they do not achieve reliability goals. This represents a significant and alarming change in the number of programs found unsuitable, as compared to historical levels. Because reliability is a prime determinant of long-term support costs, delivered reliability so far off the mark has serious consequences for both operational suitability and affordability. To better understand the consequences, the Director of Operational Test and Evaluation asked LMI to study the cost of not achieving adequate levels of operational suitability by investigating the empirical relationships between reliability investment and life-cycle support costs.

LMI approached the problem by initially developing two overarching constructs, illustrated in Figure ES-1, to guide our analysis. The first asserts that achieved reliability is a function of reliability goal setting, the maturity of the technology, and investment in reliability effort. The second asserts that support cost is a function of utilization, primarily density and operational tempo (OPTEMPO); product design, for example, reliability and maintainability; and support process design, particularly repair cycle time.

Figure ES-1. Achieved Reliability and Support Cost Constructs

Achieved Reliability =

f (goal setting,
technology readiness,
reliability effort)

Support Cost =

f [usage (density, OPTEMPO),
product design (e.g., reliability, maintainability)
support process design (e.g., cycle times)]

We used the two constructs to organize data from six case studies: Predator Unmanned Aerial Vehicle (UAV), Global Hawk UAV, MH-60S Fleet Combat Support Helicopter, CH-47F Improved Cargo Helicopter, Force XXI Battle Command, Brigade-and-Below (FBCB2) system, and a complex vehicle electronics system (which we developed by analogy to designs not yet in production). In our analysis of the five cases that have been produced and fielded, we identified a number of trends:

- Reliability goals, although established and articulated in operational requirements documents, do not appear to be driving either management or engineering effort.
- Availability of mature technology was not an issue in any of the cases.
- Generally, the programs significantly improved system reliability. For the five fielded case studies, reliability improvement ranged from 23.6 percent to 674.5 percent. The reliability improvements were partially the result of design enhancements pursued for reasons such as the introduction of better technology to resolve performance limitations. In four of the cases, the programs made a deliberate effort to improve reliability in its own right. In two of these four cases, however, the improvement was not evident until after operational test or initial operational capability.
- Under-investment in reliability may be large.

The cases were instructive not only individually but also when taken together. Using data from the cases, we were able to develop a preliminary relationship between investment in reliability (normalized by average production unit cost) and achieved reliability improvement. Figure ES-2 shows the relationship.

To establish a relationship between achieved reliability improvement and reduction in support cost, we used the Cost Analysis Strategy Assessment (CASA) model. Combining the two relationships—investment in reliability to reliability improvement and reliability improvement to support cost reduction—yields a curve such as that shown in Figure ES-3. This figure, which reflects data from the complex electronics case, should be interpreted to indicate that an investment in reliability equal to twice the average production unit cost would yield an approximate 25 percent reduction in support cost.

Figure ES-2. Relationship between Investment in Reliability and Achieved Improvement (Excluding Complex Ground Vehicle Electronics System)

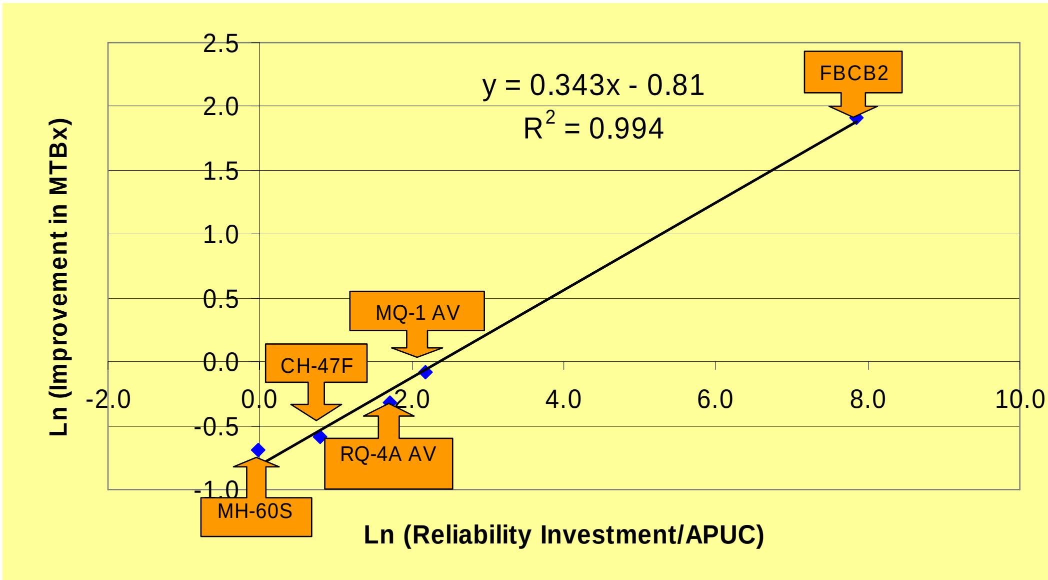
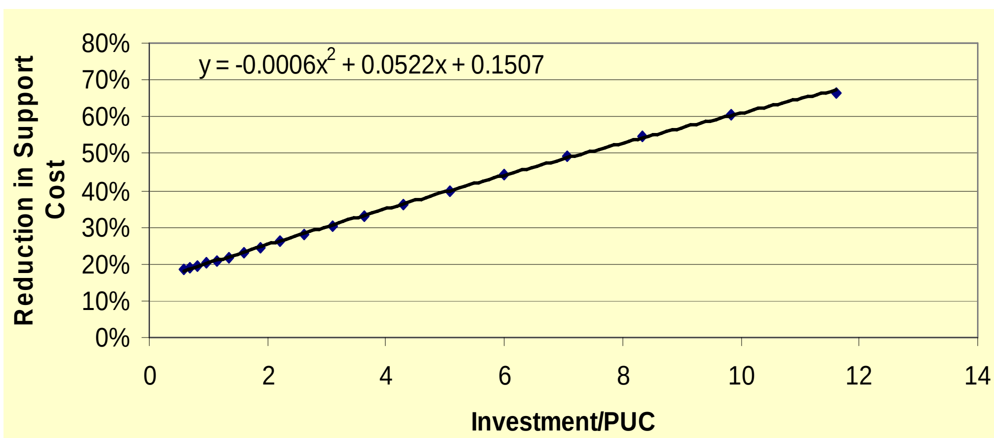


Figure ES-3. Relationship of Reliability Investment to Support Cost Reduction (Complex Ground Vehicle Electronics System)



Estimating the relationship between achieved reliability and support cost is a straightforward exercise once the data are available. The CASA model even automates the process. Thus, the more important relationship, and the primary contribution of this study effort, is an *empirical link* between investment in reliability and amount of reliability improvement. We have not found a similar result in the literature.

We emphasize that what we developed is a preliminary relationship between investment in reliability improvement and support cost reduction. We consider this relationship preliminary for three reasons:

- The empirical relationship between investment and reliability is built on eight data points (the five from this study are on Figure ES-2). Additional data are warranted to strengthen this relationship and make sure that it can be replicated.
- The curve in Figure ES-3 reflects the data from one case study. For that case, it shows a nearly linear relationship between investment in reliability and support cost reduction. Although the relationship between investment and reliability improvement appears to be system independent, that is not true for the relationship between reliability improvement and support cost reduction. Hence, relationships such as shown on the figure will almost certainly be technology and system dependent and may, or may not, all be linear. We observed a wide range in returns on investment among the cases studied. Thus, further work will be needed to determine if it is possible to develop a set of systematic relationships (e.g., a family of curves) or if the better alternative is a repeatable process.
- Finally, there were significant problems with data, a situation that appears to have become more serious in the last decade.

While recognizing the limitations flowing from a limited sample and the less-than-ideal data, the preliminary results indicate that it is possible to estimate the reduction in support cost as a function of reliability investment.

DoD has periodically placed emphasis on reliability in the past. Approximately 20 years ago, for instance, DoD launched a major effort—often called the “IDA/OSD Reliability and Maintainability Study”—to understand and address underinvestment in reliability. Almost immediately on the heels of that effort, the Air Force launched R&M 2000—a major corporate push to place more emphasis on reliability. Reliability also figures heavily in DoD’s attention to total ownership cost. Yet underinvestment in reliability, if the cases in this study are indicators, continues. We suggest that addressing the issue requires another look at the incentives that are operating within DoD, because it is arguably through incentives that behavior can be affected. In this context, it will be important to understand why reliability goals do not seem to be driving management and engineering attention.

Considering our conclusions, we recommend that DoD take the following actions:

- Replicate and further strengthen the relationship between investment and reliability improvement. When further validated, such metrics will enable program managers to make evidence-based tradeoffs between investment in reliability and other necessary investments.

- Develop and validate a set of systematic relationships between investment in reliability and support cost reduction or, if that is not practicable, develop and validate a repeatable estimating method.
- Determine root causes of data issues and address them. Without reasonably complete and reliable data, any analytic results are going to be compromised.
- Examine incentives that lead to underinvestment in reliability (including inattention to goals) and how to reshape the incentives.

Contents

Figures

Tables

Acknowledgements

Since the inception of this study in late 2006, many people and organizations have contributed to the research described in this report. Throughout our study, the authors received continued assistance from the following organizations:

- 303rd Aeronautical Systems Group/Engineering, Wright-Patterson Air Force Base, OH
- 303rd Aeronautical Systems Wing, 658th Aeronautical Systems Squadron/Logistics, Wright-Patterson Air Force Base, OH
- Air Combat Command/MQ-1 Branch, Langley Air Force Base, VA
- Air Combat Command/RQ-4A Branch, Langley Air Force Base, VA
- Avion, Inc., Integrated Logistics, Huntsville, AL
- Institute for Defense Analysis, Operational Evaluation Division, Alexandria, VA
- Land Warfare, Director Operational Test and Evaluation, Alexandria, VA
- Naval Air Systems Command, MH-60S Fleet Support Team, Cherry Point, NC
- Northrop Grumman Corporation, Global Hawk Reliability Program, Product Support–Reliability Engineering, Palmdale, CA
- Program Executive Office, Command Control and Communications Tactical, Program Manager, FBCB2, Fort Monmouth, NJ
- U.S. Navy, Multi-Mission Helicopter Program Office (PMA-299), H-60 Director of Logistics, Patuxent River, MD.

This research could not have been conducted without the gracious cooperation of these organizations. We also need to acknowledge that any misunderstanding or misrepresentation of data or opinion is our responsibility alone.

We also appreciate the support, guidance, and encouragement from the Director of Operational Test and Evaluation and from our colleagues at SAIC.

Chapter 1
Introduction

The military services need confidence that their systems will not fail during mission execution and, if they do, that they can be quickly and easily returned to service. However, test results since 2001 show that roughly 50 percent of DoD's programs are unsuitable at the time of initial operational test and evaluation, because they do not achieve reliability goals. This represents a significant and alarming change in the number of programs found unsuitable, as compared to historical levels.

Because reliability is a prime determinant of long-term support costs, delivered reliability so far off the mark has serious consequences for both operational suitability and affordability. To better understand the consequences, the Director of Operational Test and Evaluation asked LMI to study the cost of not achieving adequate levels of operational suitability by investigating the empirical relationships between reliability investment and life-cycle support costs. Specific study objectives were as follows:

- Using empirical data, investigate the relationships between reliability investment and life cycle support costs.
- Analyze the root causes of not meeting R&M requirements.

STUDY APPROACH

The importance of reliability to ownership cost is well understood, and many models are available that quantify the change in life-cycle ownership cost caused by a change in reliability. However, what has not been readily available is a model that quantifies the amount that must be invested in reliability to achieve a given degree of reliability improvement.[1]

To address this issue and guide the study effort, LMI developed two overarching constructs, illustrated in Figure 1-1. The first asserts that achieved reliability is a function of reliability goal setting, technology, and investment in reliability effort.

[1] In our literature search for such a cost estimating relationship, we found only two related studies: James K. Seger, "Reliability Investment and Life-Cycle Cost," *IEEE Transactions on Reliability*, Vol. R-32, No. 3, August 1983, and James A. Forbes et al., *Using Technology to Reduce Cost of Ownership, Volume 2: Business Case Analysis*, LMI Report LG404RD4, April 1996. Seger's study, which was mostly theoretical, focused on design cost, and it adopted a 1973 Rome Air Development Center study result that asserted investments in reliability during engineering design typically range from 2 percent to 8 percent of design engineering costs. The Forbes' et al. study looked at the returns on technology investments to improve R&M and reduce the cost of ownership; that study contained empirical data, some of which we used in this study.

The second asserts that support cost is a function of utilization, primarily density and operational tempo (OPTEMPO); product design, for example, reliability and maintainability; and support process design, particularly repair cycle time.

Figure 1-1. Achieved Reliability and Support Cost Constructs

Achieved Reliability =

**f (goal setting,
technology readiness,
reliability effort)**

Support Cost =

**f [usage (density, OPTEMPO),
product design (e.g., reliability, maintainability)
support process design (e.g., cycle times)]**

We used the two constructs to organize data from six case studies and then to highlight overall trends. The six cases were as follows:

- Predator Unmanned Aerial Vehicle (UAV)
- Global Hawk UAV
- MH-60S Fleet Combat Support Helicopter
- CH-47F Improved Cargo Helicopter (ICH)
- Force XXI Battle Command, Brigade-and-Below (FBCB2) system
- Complex vehicle electronics system.

The study approach was a form of gap analysis. For each case study, we estimated life-cycle support costs for reliability demonstrated early in the program, typically during developmental tests (DTs) and operational tests (OTs). We then estimated support costs using the most current reliability values available.

To estimate life-cycle support costs and to establish a relationship between achieved reliability improvement and reduction in support cost, LMI used the Cost Analysis Strategy Assessment (CASA) model. A general-purpose life-cycle cost (LCC) model, CASA is maintained by the U.S. Army Logistics Support Activity. The model covers the entire life of the system, from its initial research costs to those associated with yearly maintenance, as well as spares, training costs, and other expenses. (Appendix A describes the model.)

To perform an abbreviated root cause analysis, LMI collected data on the R&M programs. Example data are R&M techniques employed—failure modes and effects analysis, reliability demonstration tests, and accelerated life testing—and the relative intensity of these efforts. In addition, during our study, we developed an empirical relationship between investment in reliability and achieved improvement. Combining the two relationships—investment in reliability to reliability improvement and reliability improvement to support cost reduction—provides a link between the dollarized investment in reliability and the dollarized return on investment (ROI). We believe this may be the first time such an empirical relationship has been available. In short, our assessment enabled us to answer two key questions:

- What is the impact of reliability investments on reduction in failure rates?
- Does an improvement in reliability lead to a reduction in LCC?

LIMITATIONS

Although obtaining data is always a challenge, we found problems with incomplete, corrupted, inconsistent, and missing data to be surprisingly pervasive. In no case, for instance, were we able to obtain consistent OPTEMPO or failure data from standard service data systems. For example, compared to what program offices believed to be correct, OPTEMPO data in standard systems were in all cases disparate—in some cases, by a full order of magnitude. To work around this problem, we sought and obtained what are essentially ad hoc data from program offices and their contractors and then filled in voids by reverse engineering or application of estimating relationships. We emphasize the quality of the data not only because it is a limitation on the study but because the data issue is a problem in its own right that deserves attention. If anything, it has gotten worse in the last decade. (Appendix B discusses the issues with data.)

The following are other limitations of the study:

- Our sample size was small. Empirical data were limited to six case studies.
- We used LCCs as estimated by the CASA model, not actual LCCs.
- We assumed that reliability investments were the cause for reductions in support costs.
- When line replaceable unit (LRU)-level costs were not available, we allocated subsystem level costs to the LRU level.

REPORT ORGANIZATION

This report is organized as follows:

- Chapter 2 describes the case studies and presents our data and findings. Using the cases, it looks at the relationship between reliability and support cost. In addition, using the data from the cases in aggregate, it looks at the relationships between investment in reliability and reliability improvement and between reliability improvement and support cost reduction.
- Chapter 3 presents our conclusions and recommendations

The appendixes contain supporting detail.

Chapter 2
Evaluation of Case Studies

In this chapter, we look at the relationship between reliability and support cost for six cases, which span all three military services and include fixed- and rotary-wing aircraft, network-enabled systems, and a complex ground vehicle electronics system. For five cases—Predator UAV, Global Hawk UAV, MH-60S Fleet Combat Support Helicopter, CH-47F ICH, and FBCB2 system—we do the following:

- Provide a summary description of the platform or system.
- Use the achieved reliability construct to show how and why reliability improved over time. To determine reliability, we look at requirements, technology, and investment.
- Use the support cost construct to relate the improvement in reliability to the projected reduction in support cost, which we define as the investment in pipeline spares plus the "maintenance" part of operations and maintenance. (We do not account for fuel usage or similar costs that are generally unrelated to reliability.) To determine support cost, we look at utilization, system design, and support process design.

For the sixth case—a complex ground vehicle electronics system that is still in design—we show the relationship between reliability improvement and support cost reduction.

Appendix C contains product, usage, process, and investment data for each case. Appendix D contains general, summary-level assumptions used for CASA modeling.

PREDATOR UAV

Description

The Predator design evolved from the Defense Advanced Research Projects Agency (DARPA)/Leading Systems Amber program (FY84–FY90). The Predator is a system, not just an aircraft. A fully operational system consists of four aircraft (with sensors), a ground control station, and primary satellite link. We analyzed only the aircraft portion of the Predator system.

The Predator aircraft is a single-engine, propeller-driven, remotely piloted aircraft designed to operate at medium altitude for long-endurance sorties. It receives control commands from its control station and provides sensor and telemetry data in return.

In January 1994, the Army awarded General Atomics Aeronautical Systems a contract to develop the Predator system. The initial advanced concept technology demonstration (ACTD) phase lasted from January 1994 to June 1996. During the initial ACTD phase, the Army led the evaluation program, but in April 1996, the Air Force replaced the Army as the operating service for the initial ACTD aircraft (RQ-1) (the "R" designates reconnaissance role).

The Predator was designed to provide persistent intelligence, surveillance, and reconnaissance (ISR) coverage of a specified target area. As an ISR platform, the Predator carried either an electro-optics/infrared (EO/IR) sensor package or a synthetic aperture radar (SAR) package. In FY02, the RQ-1 migrated into MQ-1 (the "M" designates multirole) with the addition of a weapon-carrying capability. The MQ-1 aircraft can simultaneously carry EO/IR sensors and two Hellfire missiles.

Since initial operational capability (IOC) in FY05, the 11th, 15th, and 17th Reconnaissance Squadrons, Creech Air Force Base, NV, operate the Predator. In FY06, the 15th Reconnaissance Squadron flew 2,777 sorties for more than 57,800 flying hours.[1]

Reliability

Reliability Determinants

Requirements

Since the Predator started as an ACTD, the program had no formal reliability requirements. Development of the operational requirements document (ORD), usually produced early in a program to guide system design, did not begin until after the ACTD ended. The threshold ORD requirement—mean time between system failure (MTBSF) of 40 hours—was achieved soon after ACTD.[2] Thus, the reliability requirement is a reflection of what *had* been achieved rather than what *should* be achieved through design. Thus, although understandable for this type of acquisition, reliability requirements were not driving engineering or management efforts.

Although the system performed remarkably well when compared to requirements outlined in the ORD, reliability issues surfaced during Operation Enduring Freedom (OEF). Performance and vehicle losses drove the need to improve reliability. Moreover, the ORD reliability metric was not the metric used for the initial

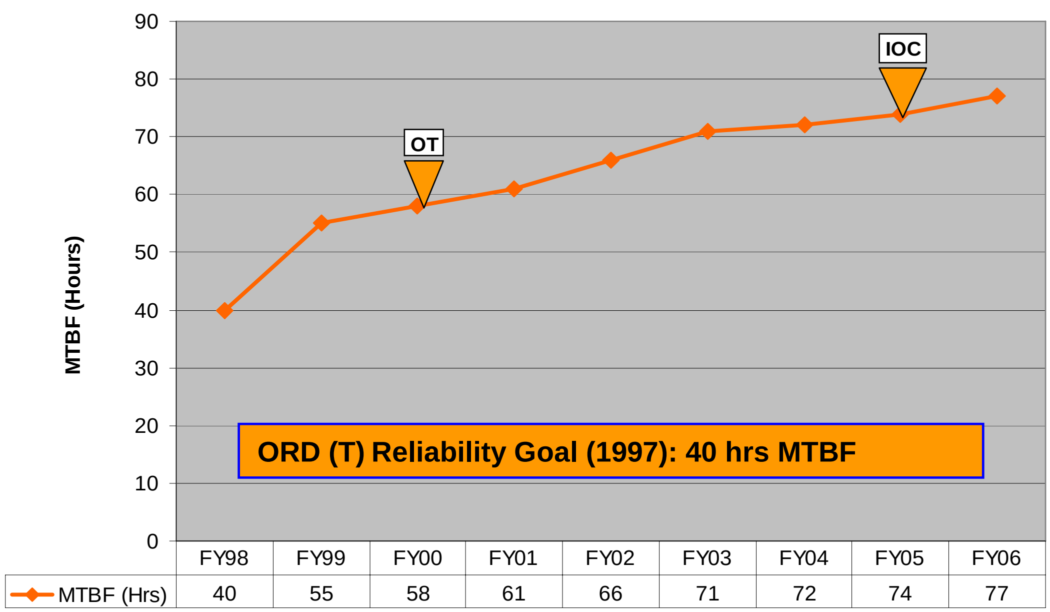
[1] Maj Michael Lock, ACC, MQ-1 Branch Chief, e-mail to Andy Long, February 8, 2007.

[2] OSD DOT&E, DOT&E Report on IOT&E, pp. 27–28, September 2001.

operational test and evaluation (IOT&E), nor was it the reliability metric that the system program office uses. The requirement, as noted above, is stated in terms of MTBSF, but DOT&E used a requirement of mean time between mission affecting failure (MTBMAF) of 40 hours. DOT&E argued that MTBMAF suffices for the intent of the ORD.[3] (We were unable to determine DOT&E's rationale for using a different metric.) Further, the using command and system program office use a third metric, MTBF.

Because MTBF is the value tracked over time, we used MTBF values provided by the 303rd Aeronautical Systems Wing, 658th Aeronautical Systems Squadron, for FY03–FY06 and MTBF values reported by the Office of the Secretary of Defense (OSD) and vetted by the 658th squadron for FY98–FY02 to estimate support costs.[4,5] Figure 2-1 shows the values.

Figure 2-1. Predator Reliability History, FY98–FY06



Technology

After initial fielding, the Air Force upgraded the ACTD Predator with a better performing and more reliable engine, communications, flight controls, and sensor payloads.[6]

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[3] OSD DOT&E, DOT&E Report on IOT&E, pp. 27–28, September 2001.

[4] OSD, *UAV Reliability Study*, February 2003, Figure 3-4, p. 25.

[5] Capt Douglas Warren, 303rd Aeronautical Systems Wing, 658th Aeronautical Systems Squadron (MQ-1), e-mail to Andy Long, February 2007.

[6] OSD, *UAV Reliability Study*, February 2003, Figure 3-4, p. 25.

Investment

Research, development, test, and evaluation (RDT&E) budget item justification sheets from FY98 to FY06 show clear evidence that Air Force management placed concerted emphasis on improving overall system reliability as part of improving performance (Table 2-1). For example, in FY99, 1-year before IOT&E, the budget justification called for $588,000 to "improve system R&M to meet ORD requirements." Further, in FY05, 5 years after IOT&E, the budget justification states, "this program will continue to evolve and upgrade Predator capabilities to meet emerging requirements and address R&M issues."[7] This was also evidenced in OSD reports during this time. OSD estimated an MTBF of 36 hours in FY97; in FY00, its estimate increased to an MTBF of 58 hours.[8,9]

Table 2-1. Predator Reliability Investment by Year (FY03 $ thousand)

Investment	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
R&M	11,430	2,289	2,671	2,218	960	950	7,860	5,627	5,123
Cumulative	11,430	13,719	16,390	18,608	19,568	20,518	28,377	34,004	39,127

The cumulative reliability investment for FY98–FY06 is $39.1 million, or approximately $4.3 million per year. To provide perspective, the average production unit cost (APUC) taken from the Selected Acquisition Report is $4.2 million (FY03 $).[10] Thus, the annual investment in reliability was just about the same magnitude as the Predator APUC.

ACHIEVED RELIABILITY

The overall failure rate was reduced by 48.1 percent, resulting in an overall improvement in MTBF from 40 hours in FY98 to 77 hours in FY06, or 92.5 percent.[11,12]

[7] RDT&E Budget Item Justification Sheet, Exhibit R-2A (PE 0305205F), Endurance Unmanned Aerial Vehicles, Project 4755 Predator, February 1998 to 2006.

[8] OSD, *UAV Reliability Study*, February 2003, Figure 3-4, p. 25.

[9] OSD, *UAV Reliability Study*, February 2003, Table 2-3, pp. 7–8.

[10] Under Secretary of Defense for Acquisition and Technology, *Selected Acquisition Reports, Washington D.C.*, December reports, 1996–2004.

[11] OSD, *UAV Reliability Study*, February 2003, Figure 3-4, p. 25.

[12] Capt Douglas Warren, 303rd Aeronautical Systems Wing, 658th Aeronautical Systems Squadron (MQ-1), e-mail to Andy Long, February 2007.

Support Cost

SUPPORT COST DETERMINANTS

Utilization

Table 2-2 shows the density and OPTEMPO for Predator for FY98–FY06. The number of aircraft represents the active inventory as of September in each fiscal year.[13] The sharp increase in sorties and flying hours beginning in FY02 coincides with the increased use of Predator in OEF and Operation Iraqi Freedom (OIF).

Table 2-2. Predator OPTEMPO Data, FY98–FY06

Item	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Flying hours	3,185	5,134	6,364	7,344	19,228	20,487	31,297	40,958	57,833
Aircraft	30	40	51	53	51	45	60	69	87
Sorties			862	875	1,557	1,387	1,985	2,636	2,777

Predator Design

Table 2-3 provides a breakout of the Predator components used in CASA modeling. Failure of these components typically results in the loss of the aircraft or, in the case of sensors, an unsuccessful mission.[14,15] (Reliability data in Figure 2-1 include trends from the RQ-1 to the current MQ-1 aircraft.)

Table 2-3. Breakout of Predator Aircraft Components

System	Component	Vendor	Model	Quantity
Airframe		Northrop Grumman		1
Propulsion	Engines	Rotax	914	1
	Propeller			
	Generators			
	Fuel tray			
Flight Controls	FCS computers	GA-ASI	PCM	1
	Actuators	MPC		
	Navigation system	Litton	LN-100G	1
	Air data system			

[13] Maj Michael Lock, ACC, MQ-1 Branch Chief, e-mail to Andy Long, February 8, 2007.

[14] Capt Douglas Warren, 303rd Aeronautical Systems Wing, 658th Aeronautical Systems Squadron (MQ-1), e-mail to Andy Long, February 2007.

[15] OSD, *UAV Reliability Study*, February 2003, Table 2-2, p. 7.

Table 2-3. Breakout of Predator Aircraft Components

System	Component	Vendor	Model	Quantity
Communications	LOS data link		L3 Comm.	1
	BLOS data link	Magnavox	UHF Satcomm	1
		L3 Comm.	RQ-1U	1
Payload	Sensors	Raytheon	MTS	1
		Northrop Grumman	AN/ZPQ-1	1
	EO/IR cameras			
	Tactical Endurance Synthetic Aperture Radar			

The ORD requires a three-level maintenance concept. On-equipment maintenance, which involves removing and replacing LRUs, is done by organic resources; off-equipment repairs (to LRUs) are done at either the shop level or the depot level.

Currently, a mix of both contractor and Air Force organic personnel perform maintenance at each level, while off-equipment repairs (LRUs) are performed at the shop and depot levels in CONUS and OCONUS. Technical data and other documentation needed to support organic maintenance at either level have only partially been developed, and very few of the standard logistics planning documents exist. The ORD also established a mean repair time (MRT) of 1.9 hours for the aircraft. During dedicated IOT&E, the MRT was 2.4 hours.[16,17]

Support Process Design

LMI had limited information on contractor support processes, so we created a set of nominal values and then vetted them for reasonableness with representatives of the 303rd Aeronautical Systems Wing, 658th Aeronautical Systems Squadron (MQ-1).

SUPPORT COST RESULTS

To estimate support cost benefits, we made two simplifying assumptions:

- All aircraft are produced and fielded in a single year. Because we use constant dollars, inflation has no impact. However, the payback stream is compressed, increasing the discounted payback amount.
- MTBF stands in for mean time between demand, because mean time between demand was not available.

[16] OSD DOT&E, DOT&E Report on IOT&E, pp. 27–28, September 2001.

[17] Tom Pember, ACC/A8AU1, MQ-1 Branch, e-mail to Andy Long, May 17, 2007.

As estimated using the CASA model, the improvement in MTBF from 40 to 77 hours reduces life-cycle support cost by approximately 61 percent (see Table 2-4). The ROI based on the CASA 20-year support cost is approximately 23 to 1.

Table 2-4. Predator Reliability Investment and Support Cost Reduction

MTBF hours			CASA 20-year support cost (FY03 $ million, discounted 7% annually)			Economics (FY 03 $ million)	
1998	2006	Percent change	1998	2006	Percent change	Reliability investment	ROI
40	77	92.5%	$1463.9	$576.7	60.6%	$39.1	22.7:1

GLOBAL HAWK UAV

Description

Like the Predator, Global Hawk is the offspring of the DARPA effort to develop a high-altitude, long-endurance UAV, and it is also a system consisting of aircraft and ground elements. As was true with Predator, we focused only on the aircraft portion of the Global Hawk system.

ACTD began in FY95 under DARPA and transitioned to the Air Force in FY98. In February 2001, DOT&E provided an early operational assessment (EOA) in support of the Milestone II decision; it found the Global Hawk system to be potentially effective and potentially suitable, based on performance from June 1999 to June 2000. Therefore, DOT&E approved the system for transition to the engineering and manufacturing development (EMD) phase and low-rate initial production (LRIP). However, improvements were required in a number of areas. Among them, the EOA noted the need for improvement in reliability to better accommodate stressing OPTEMPO. They also noted a need for maturation of training plans, the logistics infrastructure, and the maintenance concept to provide an operationally suitable system.[18,19]

Global Hawk completed the first trans-Pacific flight by a UAV in April 2001 during a deployment to Australia, returning to the United States 2 months later. The air vehicle completed 13 of 14 planned sorties over 46 days, totaling 287 flight hours. LMI used data collected during that demonstration.[20]

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[18] OSD DOT&E, *FY 2001 Annual Report, RQ-4A GLOBAL HAWK Unmanned Aerial Vehicle (UAV) Systems,* February 2002, pp. V-105–V-106.

[19] Institute for Defense Analyses, *Unmanned Aerial Vehicle Operational Test and Evaluation Lessons Learned* Paper P-3821, December 2003, pp. C-13–C-14, Table C-7 and Figure C-3.

[20] OSD DOT&E, *FY 2001 Annual Report, RQ-4A GLOBAL HAWK Unmanned Aerial Vehicle (UAV) Systems,* February 2002, pp. V-105–V-106.

The Air Force plans to enhance Global Hawk capabilities and address reliability issues in a spiral development effort continuing into FY10. Table 2-5 shows the reliability-related enhancements included in these spirals.[21] For consistency, we used longitudinal data from the Block 10 aircraft only.

Table 2-5. Global Hawk Reliability Planned Enhancements

Spirals	Year	Reliability enhancements
Block 0 (ACTD)	FY95–FY00	Airframe reliability and maintainability improvements
Block 10	FY01–FY06	Internal Mission Management Computer improvement Communication (data link) improvements Spoiler actuator replacement
Block 20	FY03–FY07	Engine upgrade Electrical power upgrade
Block 30	FY05–FY09	Simultaneous imagery recorder Enhanced operational reliability Corrosion control Rain intrusion fixes Inertial measurement unit integration into the flight control system Battery replacement Replacement of the radar's pump with a nitrogen bottle (improved reliability through simplification) Environmental control system enhancements Enhanced fault detection/fault isolation
Block 40	FY04–FY10	In flight engine restart capability

As of April 2006, Block 0 and Block 10 aircraft had flown more than 600 sorties totaling more than 9,000 flying hours. Two of seven Block 10 aircraft are supporting OIF operations and have logged more than 600 combat flying hours.[22] The remaining five and one Block 20 aircraft are based at Edwards Air Force Base and are flying test and training missions. Since August 2003, Block 10 aircraft based at Beale Air Force Base and Edwards Air Force Base have accumulated nearly 4,700 flying hours.[23,24] The current Air Force production schedule indicates a total of 19 Global Hawks by the beginning of Block 40: seven Block 10, six Block 20, five Block 30, and one Block 40. When fielding is complete, the inventory will total 51.[25]

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[21] OSD, *UAV Reliability Study*, February 2003, p. 18.

[22] Maj Ron Jobo, Global Hawk Systems Group, OSD R-TOC Conference, Block 10 Aircraft Combat Status as of 14 April 06, For Official Use Only, May 2006.

[23] Joe Miller, Northrop Grumman, RQ-4A UAV R&M Performance Metrics (UAV Block 10), Total BAFB Fleet FH from August 2003 through August 28, 2006.

[24] LtCol Kathleen Callahan, ACC/A4UD (A8UD), e-mail to Andy Long, February 2007.

[25] LtCol Kathleen Callahan, ACC/A4UD (A8UD), e-mail to Andy Long, February 2007.

Reliability

RELIABILITY DETERMINANTS

Requirements

Global Hawk had a reliability goal during ACTD of less than one loss per 200 missions (defined as 24-hour missions, or 4,800 hours). When ACTD ended in FY01, three aircraft had been lost in approximately 6,300 flying hours—well short of the goal. As a result, reliability improvements were planned for Block 10 aircraft (Table 2-5).[26] Like the Predator, because the Global Hawk uses an ACTD acquisition strategy, reliability requirements were not driving engineering or management efforts.

Like the ACTD requirement, the Block 10 ORD reliability requirement is also stated in performance terms. It requires an effective time on-station of greater than 85 percent when applied to

- three air vehicles,
- one mission control element/launch recovery element,
- one maintenance crew,
- 4 hours' egress and 4 hours' ingress,
- 20 hours on-station,
- 28 hours' endurance, and
- MTTR of 4 hours and mean logistics downtime of 9.5 hours.[27]

However, the Global Hawk system specification requires Global Hawk to provide sufficient reliability to result in a mean time between critical failure (MTBCF) of 100 flight hours or more (a critical failure affects the mission). Figure 2-2 shows the MTBCF values we used. FY01–FY03 values are from operational assessments and demonstrations,[28] and FY04–FY06 values were provided by the system program office.[29]

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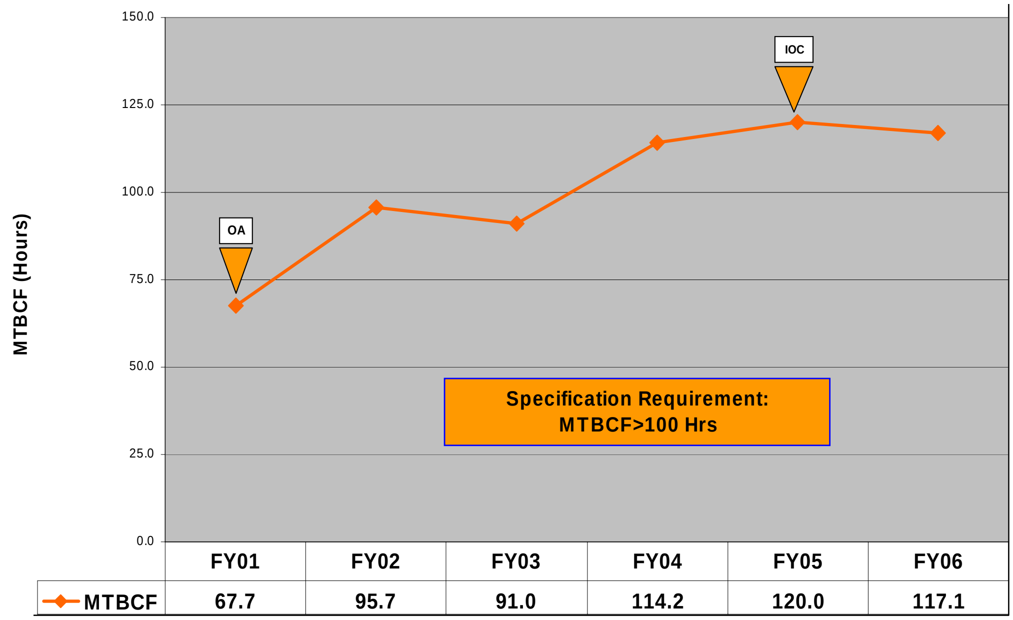
[26] OSD, *UAV Reliability Study*, February 2003, p. 19.

[27] Frank Berger, *Reliability and Maintainability (RAM) Program Overview*, February 2007, p. 11.

[28] Institute for Defense Analyses, *Unmanned Aerial Vehicle Operational Test and Evaluation Lessons Learned*, 1999, pp. C-13–C-14, Table C-7 and Figure C-3.

[29] Frank Berger, *Reliability and Maintainability (RAM) Program Overview*, February 2007, p. 11.

Figure 2-2. Global Hawk Block 10 Reliability History, FY01–FY06



Technology

After ACTD, the Air Force upgraded the Block 10 Global Hawk with a better performing and more reliable internal mission management computer, data links, primary aircraft navigator, environmental control system, fuel balance system, and spoiler actuators.

Investment

RDT&E budget item justification sheets from FY99 to FY06 show that the Air Force placed concerted emphasis on improving overall system reliability as part of improving performance. For example, in FY99, the budget justification called for $5,210,000 to improve airframe reliability and maintainability.[30] Further, in FY03, the budget justification states, "continue spiral development and related tasks, including…lithium batteries…to satisfy ORD requirements."[31] The emphasis on reliability improvements is also noted in OSD and program office reports during this time. OSD estimated the MTBCF at 96 hours in FY97, and in FY06, the program office estimated the MTBCF at 117 hours.[32,33]

[30] RDT&E Budget Item Justification Sheet, Exhibit R-2A (PE 0305205F), Endurance Unmanned Aerial Vehicles, Project 4799 Global Hawk, February 1999, p. 8.

[31] RDT&E Budget Item Justification Sheet, Exhibit R-2A (PE 0305205F), Endurance Unmanned Aerial Vehicles, Project 4799 Global Hawk, February 2003, p. 11.

[32] Frank Berger, *Reliability and Maintainability (RAM) Program Overview*, February 2007, p. 11.

[33] OSD DOT&E, DOT&E Report on IOT&E, September 2001, p. V-105.

As shown in Table 2-6, the cumulative reliability investment for FY99 to FY06 is $121.9 million, or approximately $15.2 million per year. To provide a sense of proportion, the APUC, provided by the program manager (PM), is $31.2 million (FY03 $).[34] Thus, the annual investment in reliability was about 50 percent of the APUC for a single aircraft.

Table 2-6. Global Hawk Reliability Investment by Year (FY03 $ thousand)

Investment	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
R&M	14,723	0	5,090	197	7,936	59,804	16,118	18,062
Cumulative	14,723	14,723	19,814	20,011	27,947	87,751	103,869	121,931

ACHIEVED RELIABILITY

The overall failure rate for Block 10 aircraft was reduced by 42.2 percent, resulting in an overall improvement in MTBCF from 67.7 hours in FY01 to 117.1 hours in FY06, or 73 percent.[35,36]

Support Cost

SUPPORT COST DETERMINANTS

Utilization

Table 2-7 shows the density and OPTEMPO for Global Hawk for FY99–FY06. The sharp increase in Block 10 sorties and flying hours beginning in FY05 coincides with the increased use of Global Hawk in OIF. For this analysis, we used Block 10 OPTEMPO data for CASA modeling.

Table 2-7. Global Hawk OPTEMPO Data

Item	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Spiral block	Block 0				Block 10			
Flying hours	6,261.6				318.3	468.1	1,203.9	1,024.7
Aircraft	7				5	5	7	7
Sorties	313				34	50	166	71

[34] Maj Martin J. O'Grady, 303 AESG/PM, e-mail to Andy Long, May 9, 2007.

[35] Institute for Defense Analysis, *Unmanned Aerial Vehicle Operational Test and Evaluation Lessons Learned*, 1999, pp. C-13–C-14, Table C and Figure C-3.

[36] George Robles, Global Hawk Reliability Program, Product Support–Reliability Engineering Northrop Grumman Corporation, Block 10 Reliability & Requirement Verification Status–Predicted, March 26, 2007, p. 11.

Table 2-8 provides a breakout of Global Hawk Block 10 components used in CASA modeling. Reliability data include trends from the initial ACTD aircraft (Block 0) to the current Block 10 aircraft.

Table 2-8. Breakout of Global Hawk Aircraft Components

System	Component/s	Vendor	Model	Quantity
Airframe		Northrop Grumman		1
Propulsion	Turbo fan engines	Rolls Royce	AE3007H	1
	Generators	Smiths Aerospace		
	Fuel pump			
Flight controls	FCS computers	Vista Controls		2
	Actuators (spoilers)	MPC		4
	Actuators (ruddervators)	Northrop Grumman		8
	Air data system	Rosemount	1281	2
	Navigation system	Northrop Grumman/Litton	LN-211G	2
Communications	LOS data link: X (CDL), UHF	L3 Comm.		1 (X band) 1 (UHF)
	BLOS data link: Ku, UHF	L3 Comm.		1 (Ku) 1 (UHF)
	LOS data link: X (CDL), UHF	L3 Comm.		1 (X band) 1 (UHF)
Payload	EO/IR cameras	Raytheon		1
	SAR/MTI	Raytheon	ERU HISAR	1

The ORD requires a three-level maintenance concept. On-equipment maintenance, which involves removing and replacing LRUs, is done by organic resources, while off-equipment repairs (LRUs) are done at either the shop level or depot level.

Currently, a mix of both contractor and Air Force organic personnel perform maintenance at each level, while off-equipment repairs of LRUs are performed at the shop and depot levels in CONUS and OCONUS. Technical data and other documentation needed to support organic maintenance at either level have only partially been developed, and very few of the standard logistics planning documents exist. Rapid acquisition processes do not allow sufficient time for developing technical data and fully integrating training requirements.

No ORD requirements or specifications exist for Global Hawk maintainability. From January to October 2006, MTTR was 1.09 hours for Block 10 aircraft operating in OIF.[37]

Support Process Design

Because we had limited information about contractor support processes, we created a set of nominal values for Block 10 aircraft and then vetted them for reasonableness with the 303d Aeronautical Systems Group (Global Hawk Systems Group), Wright-Patterson Air Force Base, OH.

SUPPORT COST RESULTS

In the case of Global Hawk, removal data at the component level were available, so we used mean time between removal as equivalent to mean time between demand. We also modeled the planned buy schedule. Because the change in removal rate over time was not available, we assumed that the change in mean time between removal is proportional to the change in MTBCF.

As estimated using the CASA model, the improvement in MTBCF from 67.1 to 120 hours reduces life-cycle support cost by approximately 23.1 percent (see Table 2-9). The ROI based on CASA 20-year support cost is approximately 5 to 1.

Table 2-9. Global Hawk Reliability Investment and Support Cost Reduction

MTBCF hours			CASA 20-year support cost (FY03 $ million, discounted 7% annually)			Economics (FY03 $ million)	
2001	2006	Percent change	2001	2006	Percent change	Reliability investment	ROI
67.1	120	78.8%	$2,547.4	$1,958.8	23.1%	$121.9	5:1

MH-60S FLEET COMBAT SUPPORT HELICOPTER

Description

Operational in FY02, the MH-60S Fleet Combat Support Helicopter, a remanufacture of the HH-60H, is the replacement for the current CH-46D, UH-3H, and HH-1N, all of which have exceeded their original service lives. The primary mission of the baseline MH-60S configuration is to provide the Navy's Combat Logistics Force with responsive vertical replenishment, vertical onboard delivery, ship-to-shore airhead support, and Amphibious Task Force search and rescue. Secondary missions include special warfare support (over water), medical evacuation, and noncombatant evacuation. A second MH-60S configuration planned for

[37] Joe Miller, Northrop Grumman, RQ-4A UAV R&M Performance Metrics (UAV Block 10), Total BAFB Fleet FH, January 2006 to October 2006.

FY07, the Armed Helicopter, will support three missions: combat search and rescue, anti-surface warfare, and aircraft carrier plane guard. A third MH-60S configuration planned for FY07 will support the organic airborne mine countermeasure mission.[38]

The MH-60S is an Army UH-60L Black Hawk airframe incorporating the Navy Seahawk GE T700-401C engines, transmission/drive train, stabilator, flight controls, and a folding rotor head and tail pylon. It uses the common cockpit design that consists of multifunctional displays and a tactical data processing system based on an open architecture client-server. MH-60S avionics include dual UHF/VHF transceivers, dual embedded global positioning system (GPS)/inertial navigation systems, and night vision device-compatible heads-up displays. The armed helicopter configuration will also include tactical moving maps, a forward-looking infrared sensor with a laser range finder/target designator, crew-served side-suppression weapons, Hellfire missiles, forward-firing guns/rockets, and an integrated self-defense system. The airborne mine countermeasure configuration will incorporate a tactical common data link, a sensor workstation, a winch-and-tether towing system, and one of five mine detection sensors or destructors under development.[39]

As of December 2006, 94 MH-60S aircraft were in service, with an additional 267 planned by the end of FY10. These 94 aircraft accumulated nearly 119,000 flying hours performing ship-to-shore airhead support and Amphibious Task Force search and rescue.[40,41]

Reliability

Reliability Determinants

Requirements

The operational evaluation of the MH-60S Fleet Combat Support Helicopter was conducted from October 24, 2001, through March 7, 2002. The aircraft was reliable during the OT&E. The ORD threshold requirement—mean time between operational mission failure (MTBOMF) of 20.3 hours—was exceeded by 3.7 hours (for an MTBOMF of 23.96 hours).[42] The ORD requirement for maintainability was a mean corrective maintenance time (MCMT) of less than 3.6 hours. During

[38] CAPT Paul Grosklags USN, Multi-Mission Helicopter Program Office (PMA-299), OSD IDA Conference, November 8, 2006.

[39] DOT&E, *Combined Operational Test and Development and Live Fire Test and Evaluation on MH-60S Fleet Combat Support Helicopter*, August 2002.

[40] Russell Wilson, NAVAIR, MH-60S Fleet Support Team, MH-60S Reporting Period: January 2001–December 2006, e-mail to Andy Long, February 2007.

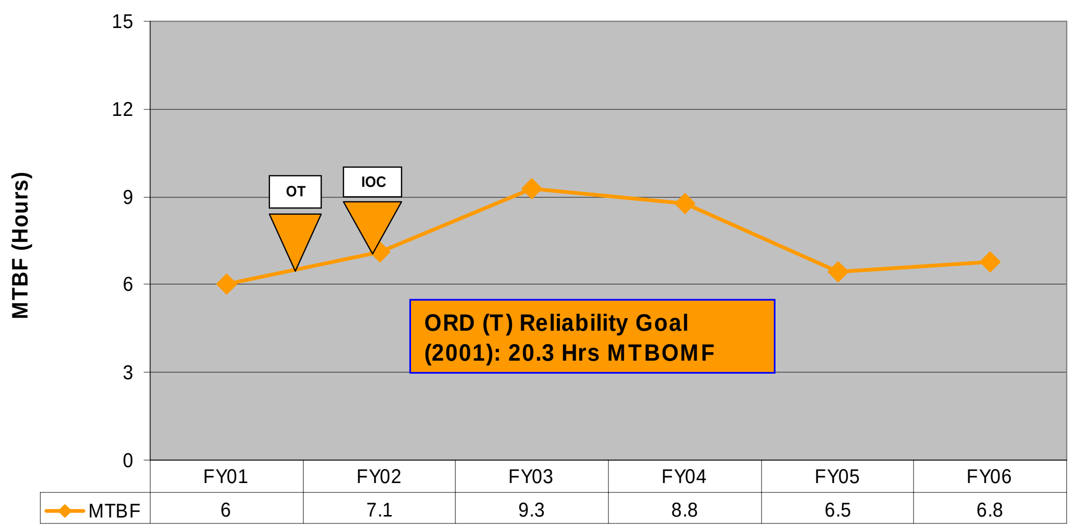
[41] CAPT Paul Grosklags USN, Multi-Mission Helicopter Program Office (PMA-299), OSD IDA Conference, November 8, 2006.

[42] DOT&E, *Combined Operational Test and Development and Live Fire Test and Evaluation on MH-60S Fleet Combat Support Helicopter*, August 2002, p. 19.

OT&E, the achieved MCMT was 2.72 hours. Interviews with PMA-299 program managers did not reveal direct evidence that reliability requirements drove engineering or management efforts.

Since FY02, the reliability data parameter measured in the field has been MTBF rather than the ORD metric of MTBOMF. Therefore, LMI used MTBF to assess reliability improvement and the reliability input parameter for CASA modeling. Figure 2-3 shows the MTBF values provided by the PMA-299 program office.[43]

Figure 2-3. MH-60S Reliability History, FY01–FY06



Technology

PMA-299 is pursuing technology to improve the performance and reliability of the MH-60S. For example, PMA-299 is partnering with the Army to improve life limits of dynamic components. Moreover, PMA 299 is participating in programs addressing reduction in total ownership cost (RTOC) and in Product Enterprise Team initiatives to improve reliability and performance of bearings, gaskets, and retaining bolts.

The overall improvement in reliability due to the insertion of technology has been modest, but when compared to the older HH-60H platform, the reliability improvement is dramatic. For example, in FY06, the MTBF of the MH-60S was a factor of 9 better that its predecessor.

[43] Russell Wilson, NAVAIR, MH-60S Fleet Support Team, MH-60S Reporting Period: January 200–December 2006, e-mail to Andy Long, February 2007.

Investment

Because the MH-60S is a remanufacture of the HH-60 variant, we were unable to find reliability investment dollars (specifically targeted toward the support helicopter) in RDT&E budget justification exhibits prior to IOC. However, PMA-299 provided us with investment data for reliability investments after IOC.[44] These investments were funded by RTOC and other like sources, so we have only a partial estimate of the total reliability investment, provided in Table 2-10. As the table shows, the cumulative reliability investment for FY04–FY06 is $13.1 million, or approximately $2.62 million per year. To provide perspective, the APUC taken from Selected Acquisition Reports is $22.8 million (FY03 $).[45] Thus, the annual investment in reliability was about 12 percent of the APUC for a single MH-60S. Assuming that we captured only 50 percent of the actual reliability investment, the resulting percentage (23 percent of APUC per year) would still be less than many of the other programs in this study.

Table 2-10. MH-60S Reliability Investment by Year (FY03 $ thousand)

Investment	FY04	FY05	FY06
R&M	490	11,752	870
Cumulative	490	12,242	13,112

ACHIEVED RELIABILITY

The overall failure rate for the MH-60S as compared to its predecessor, HH-60H, was reduced by 89 percent. The MTBF went from 0.79 hour in FY06 for the HH-60H to 6.8 hours in FY06 for the MH-60S—an improvement by a factor of 8.6:1.[46] However, when this comparison is made at the component level (listed below in Table 2-12), the MTBF went from 2.4 hours in FY06 for the HH-60H to 3.6 hours in FY06 for the MH-60S—a 50 percent improvement.

[44] CAPT Paul Grosklags USN, OSD IDA Conference, November 8, 2006.

[45] Under Secretary of Defense for Acquisition and Technology, *Selected Acquisition Reports, Washington D.C.*, December reports, 1996–2004.

[46] Gina Kleinkauf, PMA-299 Senior Analyst, HH-60H NALDA LMDSS Aircraft Verified Failure and BCM Report, e-mail to Andy Long, June 2007.

Support Cost

SUPPORT COST DETERMINANTS

Utilization

Table 2-11 shows the density and OPTEMPO of MH-60S for FY02–FY06. For this analysis, we used MH-60S Fleet Combat Support Helicopter OPTEMPO data for CASA modeling.

Table 2-11. MH-60S OPTEMPO Data

Item	FY02	FY03	FY04	FY05	FY06
Flying hours	334	22,729	31,460	31,752	32,245
Aircraft	1	7	10	93	94

MH-60S Design

As previously stated, the MH-60S is a remanufacture of the HH-60 variant. Due to the complexity of the MH-60S, we limited our study design to those components unique to the MH-60S Fleet Combat Support Helicopter. Table 2-12 lists the MH-60S components, along with the like HH-60 components.[47] Interestingly, many of the newer technology components in the MH-60S are not only more reliable than their predecessor HH-60 components, but also are less expensive to purchase. For example, the MH-60S CPU has an APUC that is approximately 50 percent that of the older HH-60 CPU, and it improved reliability by 230 percent.

[47] Joon S. Park, H-60 Director of Logistics, NALDA Phase II, Detailed Database and NALDA 79 Flight Hour Data, December 2006.

Table 2-12. Breakout of MH-60S Components (APUC in FY07 $ thousand)

HH-60H Reporting period: Jan. 1999–Dec. 2006			MH-60S Reporting period: Jan. 2001–Dec. 2006		
Component	MFHBR	APUC	Component	MFHBR	APUC
CPU159/A AFCS computer	582	$180	CPU133/A digital computer	1,944	$86
Auxiliary power systems	2,160	$86	Aircraft power unit	10,000	$80
Sections 2/3/4 drive shaft assembly	6,480	$4	Sections 2/3/4 drive shaft assembly	10,000	$4
CP1820/ASN150 navigational computer	434	$99	CP-2428/A digital data computer	2,236	$84
Stabilator amplifier installation	549	$34	Stabilator amplifier installation	1,351	$43
MLG drag beam/axle assembly	>10,000	$24	Beam-axle assembly	>10,000	$26
Floor assembly	>10,000	$10	Aircraft floor	>10,000	$20
T1360/ALQ144(V) transmitter	582	$52	Light, infrared transmitter	>10,000	$5

Note: MFHBR = mean flying hours between removal.

Support Process Design

PMA-299 Director of Logistics provided usable repair cycle times and weight data for CASA modeling.

SUPPORT COST RESULTS

We obtained before and after reliability and production unit cost data on the sample of MH-60S components identified in Table 2-12 from PMA-299. This is not an exhaustive list of components addressed by the MH-60S program. Rather, it is a list of functionally equivalent HH-60H and MH-60S components. As estimated using the CASA model, the life-cycle support cost was reduced by approximately 83.2 percent. The ROI based on CASA's 20-year support cost is approximately 49 to 1, assuming conservatively that 50 percent of the total reliability investments in the MH-60S apply directly to the sampled components. (See Table 2-13.)

Table 2-13. MH-60S Reliability Investment and Support Cost Reduction

MTBF hours			CASA 20-year support cost (FY03 $ million, discounted 7% annually)			Economics (FY03 $ million)	
HH-60H 2006	MH-60S 2006	Percent change[a]	2006	2006	Percent change	Reliability investment	ROI
2.4	3.6	50%	$384.6	$64.7	83.2%	$6.6	49:1

[a] Improvement over HH-60 for like components.

CH-47F IMPROVED CARGO HELICOPTER

Description

The CH-47F ICH is a remanufactured version of the CH-47D Chinook cargo helicopter with the new T55-GA-714A engines. The ICH program was initiated to extend the service life of the CH-47 airframe, while reducing operations and support costs. The current CH-47D cargo helicopter fleet is unable to support the requirements of a primarily CONUS-based contingency force. The operational capability that is critical to support this wide range of contingencies is not provided by current cargo helicopter systems without improvements. The first CH-47D aircraft reached their service life goal of 20 years in FY02. Continually increasing maintenance rates (measured as man-hours per flight hour), resulting from years of high use, are adversely impacting units' ability to maintain the fleet to Army standards. Increases in operations and support costs, cargo weight, range requirements, and OPTEMPO, as well as emphasis on rapid self-deployability and threat anti-aircraft capabilities, have reduced the effectiveness of the CH-47D fleet. In addition, the CH-47D cannot communicate in the Army Force XXI digital battlefield network without new equipment.

The improved cockpit of the CH-47F ICH retains the current CH-47D air vehicle monitoring suite and incorporates a Military Standard 1553 data bus to handle a tactical data link, communications, and navigation data. The new cockpit will make the Chinook a cost-effective and capable digitized tactical platform by providing modern technology controls and displays and a data transfer system that allows for loading and storing of preflight data, mission data, and maintainer data. In addition, the upgrade will cut operations and support costs, because reliable solid-state systems with built-in diagnostics will replace the CH-47D's analog avionics. The upgrade also provides an open architecture system to allow for insertions of technology such as advanced aircraft survivability equipment. Coupled with head-up displays projected in night vision goggles, the avionics upgrade will greatly improve flight safety at night, especially for external load operations.

Approval for entry into the EMD phase came in FY98 based on a perceived low technical risk, and milestone decision authority was delegated to the Army Acquisition Executive. The CH-47F ICH completed its first operational test (OT) flight at the Boeing Philadelphia manufacturing facility in June 2001. In FY02, the program underwent significant restructuring, due to delays, changes to the ORD, and cost overruns resulting in a Nunn-McCurdy breach. Nonetheless, the Army Acquisition Executive approved the purchase of up to 30 LRIP aircraft in that same year.

Current production and fielding plans call for full-rate production to begin sometime after FY08 with a total of 337 CH-47F aircraft by FY18.

Reliability

RELIABILITY DETERMINANTS

Requirements

IOT&E Phase 1 was conducted in May 2004. Results of the evaluation indicated that the mean time between mission abort (MTBMA) was 19.7 hours, significantly lower than the ORD threshold requirement of 44 hours.[48] Later in the same year, Boeing conducted the 1,000-hour flight test program, which achieved an MTBMA of 31.4 hours.[49] In FY06, the ORD requirement for MTBMA was decreased from 44 hours to 30 hours.[50] The ORD requirement for maintainability was mean time between essential maintenance action (MTBEMA) of 3.3 flight hours (3.5 flight hours objective). For OT, the achieved MTBEMA = 3.5 hours.[51]

LMI used the Boeing MTBMA value, because Boeing's analysis included pre-IOT&E and post-IOT&E data as one large block of 1,100 flying hours as compared to 100 flying hours for IOT&E. In January 2007, the Chinook Scoring Conference reported an MTBMA of 46.7 hours.[52]

Figure 2-4 shows the reliability history of these aircraft. The figure includes an FY02 MTBMA of 22 hours, which was based on a sampling of CH-47Ds by Avion.[53] We show this estimate to illustrate reliability growth from the CH-47D to CH-47F. The first purely CH-47F estimate was done by Avion in FY03, which found an MTBMA of 30.1 hours.[54] Interviews with engineers on this program indicate that due to budgeting constraints, reliability requirements had little or no impact on engineering or management efforts. LMI used the FY03 estimate as the lower bound value for assessing reliability growth. Data for FY05 and FY06 were taken from scoring conferences conducted by PM Cargo Helicopters.[55]

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[48] Director, Operational Test and Evaluation, *FY 2004 Annual Report, CH-47F Improved Cargo Helicopter (ICH)*, 2004, pp. 61–63.

[49] Boeing, *CH-47F 1000 Hour Flight Test Program Report*, June 25, 2004, Figure 2.

[50] Operational Requirements Document for the CH-47F Cargo Helicopter, June 2006, Paragraph 4.4.2, Change 4.

[51] Boeing, *CH-47F 1000 Hour Flight Test Program Report*, June 25, 2004, Figure 2.

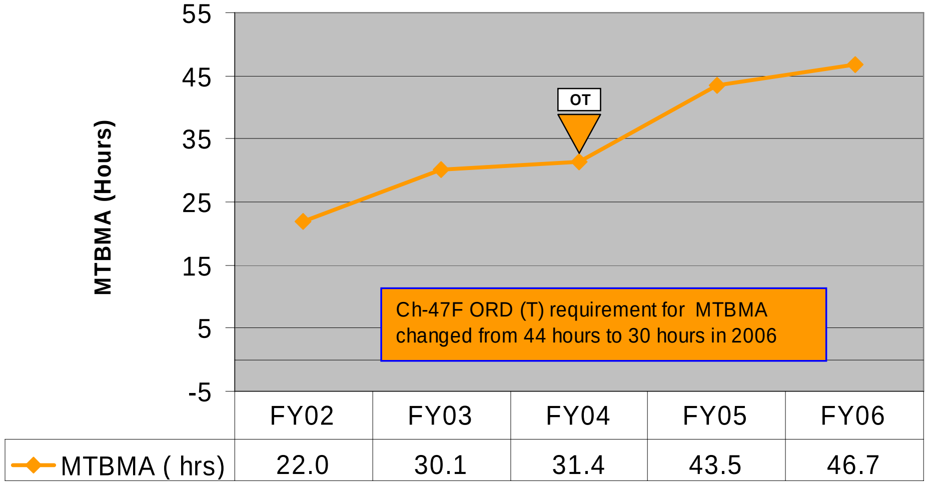
[52] Tom Snow, Avion, R&M Scoring Conference Minutes, February 2007, Section 2.

[53] Avion, Inc., *Final Report, CH-47D Direct Maintenance Total Ownership Cost Baseline in Support of the Fielding of the Improved Cargo Helicopter (ICH)*, December 2002, p. 14.

[54] Tom Snow, Avion, R&M Scoring Conference Minutes, February 2007, Section 2.

[55] Tom Snow, Avion, R&M Scoring Conference Minutes, February 2007, Section 2.

Figure 2-4. CH-47F Reliability History, FY02–FY06



Production of the first unit equipped, scheduled for FY07, has slipped by at least 2 years due to budgeting constraints imposed by Congress.[56]

Technology

The CH-47F aircraft include the following technologies to improve performance and overall reliability:[57]

- New platform airframe to reduce vibration
- Common avionics architecture system to improve avionics
- Upgraded 714b engine with enhanced lift capability and reliability
- Engine air particle separator to improve engine reliability
- Reliable electrical power supply and distribution systems.

Investment

RDT&E budget item justification sheets from FY02 to FY06 show clear evidence that Army management placed concerted emphasis on improving overall system reliability as part of improving performance (Table 2-14). For example, in FY02, the budget justification called for nearly $13.9 million (FY03 $) for a contract for EMD that includes “decreasing operation and support costs through vibration reduction/airframe stiffening, incorporating a new electronics/architecture system

[56] LTC Hume, HQDA, U.S. Army, Part IIA and IIB CH-47F Acquisition Strategy, 2004, Figure 2-1.

[57] Army RDT&E Budget Item Justification (R-2A Exhibit), 0203744A, Aircraft Modifications/Product Improvement Program, 0203744A (430) and Exhibit R-2A IMPR CARGO HELICOPTER, Continue Engineering Manufacture Development (EMD), 2003–2007.

for compatibility with the digital battlefield and structural modifications as necessary to extend the life of the airframe."[58] To provide perspective, the APUC taken from the Selected Acquisition Report is $23.1 million (FY03 $).[59] Thus, the annual investment in reliability from FY02 to FY06 was about 43 percent of the APUC for a single CH-47F.

Table 2-14. CH-47F Reliability Investment by Year (FY03 $ thousand)

Investment	FY02	FY03	FY04	FY05	FY06
R&M	13,859	0	4,666	11,501	9,568
Cumulative	13,859	13,859	18,525	30,026	39,595

ACHIEVED RELIABILITY

The overall failure rate for the CH-47F was reduced by 35.8 percent, resulting in a 55.5 percent improvement in MTBMA, from 30.1 hours in FY03 to 46.7 hours in FY06.[60]

Support Cost

LMI did not analyze support costs for the CH-47F. To date, only five CH-47F aircraft have been produced and these systems are still in test. Moreover, a support process for in-service CH-47F aircraft has not been instituted, and data such as component unit costs and repair cycle times are not yet available.

FORCE XXI BATTLE COMMAND, BRIGADE-AND-BELOW SYSTEM

Description

The FBCB2 system is the principal network-enabled command and control (C2) system providing Army components at brigade level and below a seamless battle command capability. The computer, along with associated communication and GPS equipment, allows each platform user in the network to send and receive information across the depth and breadth of the battlefield. The system facilitates the flow of battle command information and supports lower echelon battle C2 and other sensor systems on the battlefield, resulting in vertical and horizontal infor-

[58] Army RDT&E Budget Item Justification (R-2A Exhibit), 0203744A–Aircraft Modifications/Product Improvement Program, 0203744A (430) Item No. 161 Page 10 of 20 Exhibit R-2A IMPR CARGO HELICOPTER, Continue Engineering Manufacture Development (EMD), February 2003.

[59] Under Secretary of Defense for Acquisition and Technology, *Selected Acquisition Reports, Washington D.C.*, December reports, 1996–2004.

[60] Tom Snow, Avion, R&M Scoring Conference Minutes, February 2007, Section 2.

mation integration. This shared common battlefield picture displays near-real-time information that contributes to situational awareness, provides graphics and overlays, and allows the exchange of C2 messages.

The primary development contractor is Northrop Grumman Mission Systems; acquisition services are provided by the FBCB2 program office. The FBCB2 system began its life in FY94 as a prototype. From FY00 to FY02, the system matured through a series of reliability demonstration tests, field demonstrations, and limited user tests. Fielding of the FBCB2 system began in FY02, with 1,722 systems going to the 4th Infantry Division. IOT&E was a combination of events including LUT-2A in FY01, OEF in FY04, and DT/OT in FY04.[61] In FY04, the Army decided to go to full-rate production amid a disagreement with DOT&E over whether or not to include government-furnished equipment (GFE) in the DT/OT.

To date, the Army has fielded more than 15,000 systems and plans to field a total of nearly 57,000 systems through FY15. In support of OIF alone, the Army has expedited delivery of more than 8,800 systems.[62]

Reliability

Reliability Determinants

Requirements

The FBCB2 ORD specified reliability threshold requirements for three blocks of mean time between essential function failure (MTBEFF): for Block 1, an MTBEFF of 500 hours; for Block 2, an MTBEFF of 710 hours; and for Block 3, an MTBEFF of 910 hours). For our reliability growth assessments and CASA modeling, LMI used only the Block 1 requirement.

During IOT&E, the U.S. Army Training and Doctrine Command (TRADOC) and DOT&E interpreted the requirement differently. The difference concerned whether or not GFE failures should be included in the assessed system MTBEFF. TRADOC's position, based on its Failure Definition Scoring Criteria (FDSC), was that only the FBCB2 system hardware and software should be evaluated, because the PM had no control over the reliability of communications links.[63] DOT&E took the user's perspective, advocating the inclusion of GFE because the user does not care why the system failed but only that it failed.[64]

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[61] FY 2004 DOTE Report, Force XXI Battle Command, Brigade and Below/Blue Force Tracker (FBCB2/BFT) Block I, Summary, p. 70.

[62] COL Brett Weaver, TSM Force XXI (FBCB2), Force XXI Battle Command Brigade and Below (FBCB2), Computer Set, Digital, January 25, 2005.

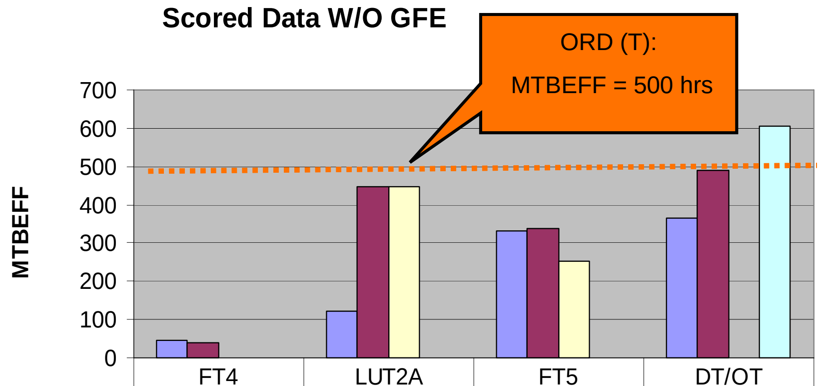
[63] TRADOC, Combat Development Engineering, FDSC for FBCB2 BFT System, December 2003, p. 13.

[64] Interoffice Memo, IDA, Operational Evaluation Division, Fbcb2 BLRIP Suitability Submission, June 15, 2004, p. 6, Figure 1.

Although perfectly reasonable, the DOT&E interpretation meant that the FBCB2 system would never be able to meet the Block 1 threshold requirement in the ORD. Given the DOT&E assessed reliability for GFE (MTBEFF of 149 hours), the FBCB2 system with 100 percent reliability of FBCB2 hardware and software still would fail to meet the requirement.[65]

Figure 2-5 shows scoring results for several test events, including DT/OT. Each set of contiguous bars shows the results from one test event; the colored bars within that set represent computed scores under the different scoring schemas discussed above. The abbreviations FT-4, LUT-2A, FT-5, and OT/DT refer to testing events. The FBCB2 system met or nearly met the ORD Block 1 threshold requirement in two of three cases based on TRADOC's FDSC.[66] For our study, LMI used the lowest scoring result: MTBEFF = 364 hours. Based on the discussion above, it is not clear the degree to which reliability requirements drove engineering or management efforts.

Figure 2-5. FBCB2 Scored Data without GFE



	FT4	LUT2A	FT5	DT/OT
IDA/DOT&E (BLRIP)	47	121	333	364
AEC FBCB2 SER	40	447	338	490
DAU Chart Data		447	253	
DT/OT FDSC Consensus				604.2

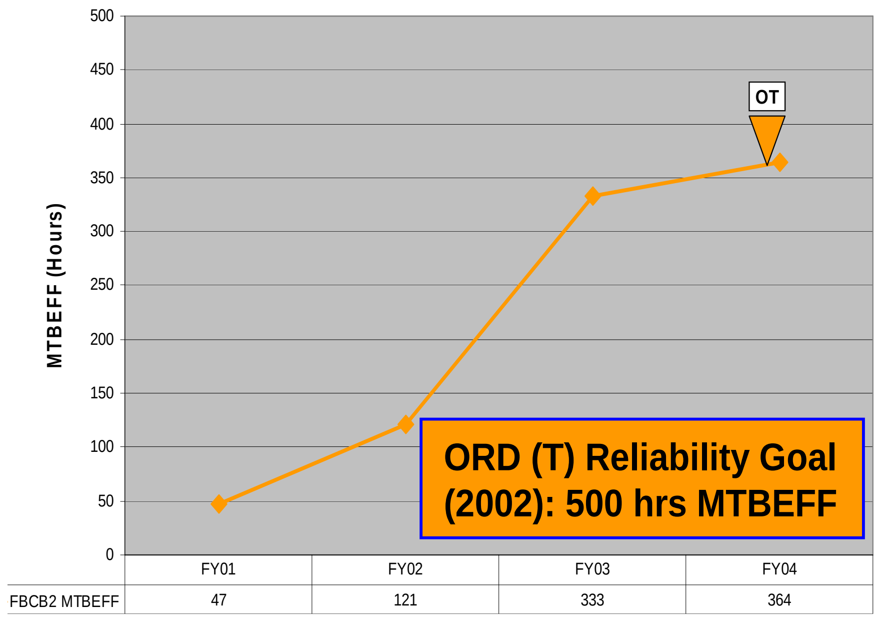
Figure 2-6 shows the FBCB2 reliability history from FY01 to FY04.[67] Since DT/OT in FY04, no additional tests of the FBCB2 system have been done.

[65] Interoffice Memo, IDA, Operational Evaluation Division, FBCB2 BLRIP Suitability Submission, June 15, 2004, p. 6, Figure 1.

[66] ATEC and EPG, *Abbreviated Test Report for the Reliability Data of the Units Participating in the FBCB2 BFT DT/OT Appliqué+ (Hardware Version 4)*, For Official Use Only Proprietary, April 2004, p. 2-14.

[67] FBCB2,BLRIP Suitability Submission, Operational Evaluation Division, Interoffice Memo, IDA Task BD-9-2299(86), June 15, 2004.

Figure 2-6. FBCB2 Reliability History (without GFE), FY01–FY06



The FBCB2 system must achieve an MTTR of less than 30 minutes. The PM conducted three logistics/maintenance demonstrations to evaluate MTTR, and MTTR was collect at FT5 and the DT/OT. In all reliability events and maintenance demonstrations, the system achieved an MTTR of less than 30 minutes.

Technology

Since prototype demonstrations began in FY94, the Army has consistently sought and obtained better technology to improve FBCB2 performance and reliability. The following are examples:

- Components ruggedized for operating environments
- Cables designed to prevent bent connecting pins
- Removable hard drives
- Improved power supply
- Removable dust filters.

Investment

RDT&E budget item justification sheets for FY99–FY04 provide evidence that Army management placed emphasis on improving overall system reliability as part of improving performance (Table 2-15). For example, in FY99, the budget justification called for about $3 million (FY03 $) for hardware development.[68] Further, in FY03, the budget justification showed a line entry for nearly $5 million to “conduct Development Test/Operational Test for Block I Capability of FBCB2-Blue Force Tracker (BFT) at the U.S. Army Electronic Proving Ground and at Fort Irwin, CA.”[69] To provide perspective, the APUC taken from the Selected Acquisition Report is $38.7K (FY03 $).[70] From FY99 to FY04, 10,225 FBCB2 systems were fielded.[71] Thus, the annual investment in reliability per unit fielded was approximately $8,600, or about 22 percent of the APUC for a single FBCB2 system.

Table 2-15. FBCB2 Reliability Investment by Year (FY03 $ thousand)

Investment	FY99	FY00	FY01	FY02	FY03	FY04
R&M	3,048	0	29,600	17,607	18,295	18,838
Cumulative	3,048	3,048	32,647	50,255	68,550	87,388

ACHIEVED RELIABILITY

The overall failure rate for the FBCB2 system was reduced by 87.1 percent, resulting in a 674.5 percent improvement in MTBEFF, from 47 hours in FY01 to 364 hours in FY04.[72]

Support Cost

SUPPORT COST DETERMINANTS

Utilization

Table 2-16 shows the density and OPTEMPO of the FBCB2 system for FY02 to February 14, 2007.[73] The PM for the system provided data that includes a bump in operating hours and units due to OEF and OIF.

[68] Army RDT&E Budget Item Justification, PE Number 0203759A, Project D120, Page 4 of 5, Exhibit R-3, Cost Analysis, Force XXI Battle Command, Brigade and Below (FBCB2) 228 Budget Item Justification, February 1999.

[69] Army RDT&E Budget Item Justification, PE Number 0203759A, Item No. 164 Page 5 of 7, Exhibit R-3, Cost Analysis, Force XXI Battle Command, Brigade and Below (FBCB2) 228 Budget Item Justification, February 2003.

[70] Under Secretary of Defense for Acquisition and Technology, *Selected Acquisition Reports, Washington D.C.*, December reports, 1996–2004.

[71] COL Brett Weaver, TSM Force XXI (FBCB2), Force XXI Battle Command Brigade and Below (FBCB2), Computer Set, Digital, January 25, 2005.

[72] FBCB2, BLRIP, Suitability Submission, Operational Evaluation Division, Interoffice Memo, IDA Task BD-9-2299(86), June 15, 2004.

[73] Terry Elzin, PM FBCB2 Test Manager, Turn Ins between Mar06 through Feb07.xls, e-mail to Andy Long, April 25, 2007.

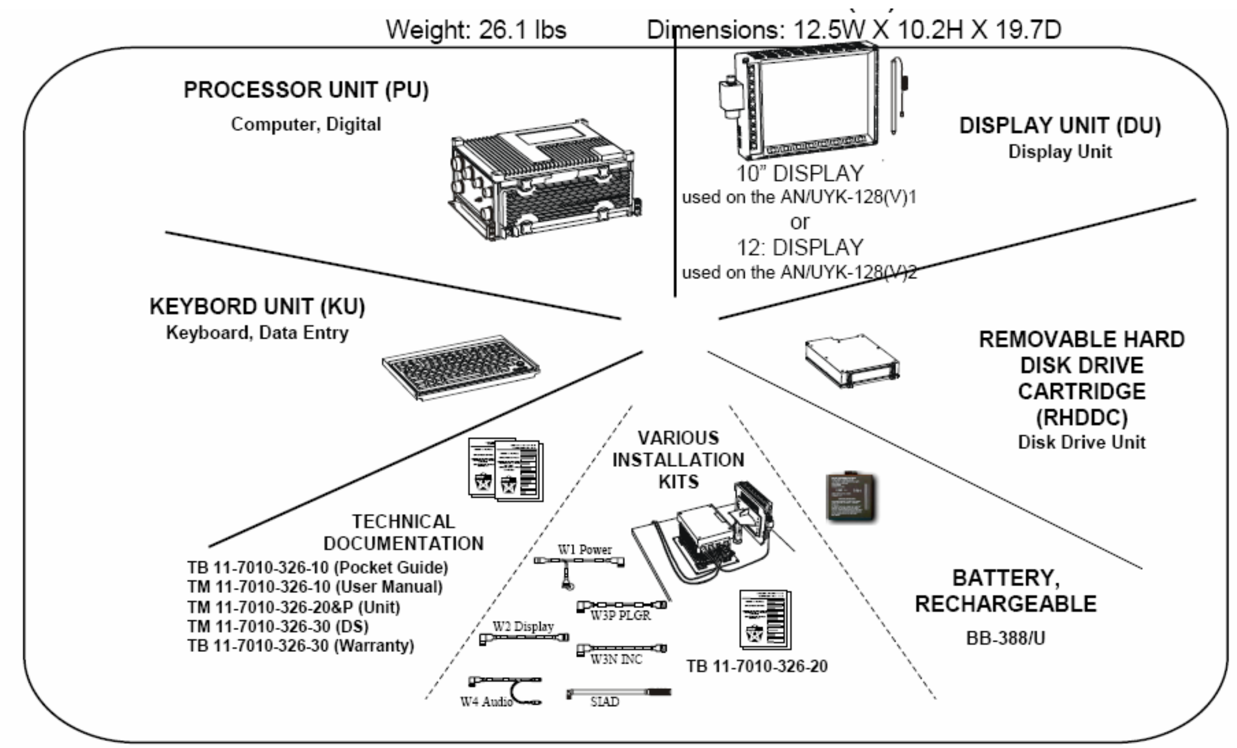
Table 2-16. FBCB2 OPTEMPO Data

Item	FY02	FY03	FY04	FY05	FY06	2/14/2007
Hours	13,457,826	19,812,095	27,291,628	32,693,957	40,626,794	74,662,000
Fielded FBCB2 units	5,047	7,430	10,235	12,261	15,236	28,000

FBCB2 Design

Figure 2-7 provides a breakout of the FBCB2 system components. The FBCB2 system consists of commercial off-the-shelf computer hardware ruggedized for military use (CPU and screen), system operating software, FBCB2 software, GPS device, installation-kit hardware, and communications network devices. It provides capabilities to warfighters in multiple configurations. Among the vehicles on which FBCB2 systems reside are the M1A1 Abrams Main Battle Tank, M2A2/M3A2 Bradley Fighting Vehicle, M113 Armored Personal Carrier, M981 Fire Support Team Vehicle, and various configurations of the High-Mobility Multipurpose Wheeled Vehicle. The FBCB2 system is also installed in Tactical Operations Centers and runs in personal digital assistants (PDAs) as a dismounted system. It is also used in Army aviation systems and logistics support.

Figure 2-7. Breakout of FBCB2 System Components



The whole system is interconnected through a terrestrial communications infrastructure called the Tactical Internet, which is based on commercial Internet protocols and made up of existing Enhanced Position Location Reporting System and Single Channel Ground and Airborne Radio System radios and an Inter-network Controller (router). Alternatively, systems can be connected using celestial satellite communications via an L-Band transceiver and operations center; this is more commonly referred to as FBCB2 Blue Force Tracking. Both terrestrial and celestial-based systems can exchange information with each other. (We did not differentiate between FBCB2 terrestrial and BFT for our reliability assessment or CASA modeling; the only difference between them is the GFE communications links.)

Support Process Design

The PM for the FBCB2 system provided manufacturing unit cost (MUC), MTTR, and weight data for CASA modeling (see Table 2-17).[74] As the table shows software was responsible for 67 percent of the assessed failures and 80 percent of the APUC.

Table 2-17. FBCB2 Design

Data	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs.)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost/ repair ($K)
Hardware									
Processor unit	3,636.7	0.00027	30.0%	$4.22		0.5	17%	7.7	$1.382
Removable hard disk drive	3,306.1	0.00030	33.0%	$0.23		0.5	9%	NA	NA
Keyboard unit	9,091.7	0.00011	12.0%	$0.52		0.5	0%	0.5	$0.100
Display unit	4,364.0	0.00023	25.0%	$1.83		0.5	13%	4.9	$0.427
Subtotal	1,091.0	0.0009166	33.4%	$6.8	26.1				
Software	546.0	0.00183150	66.7%	$27.2					
GFE communications	149.0	0.00671141							
Total	364.0	0.00274725	100%	$34.0	26.1	< 0.5			

Notes: RTOK = retest okay.

SUPPORT COST RESULTS

As estimated using the CASA model, the improvement in MTBF from 47 to 364 hours reduced life-cycle support cost by approximately 86 percent. The ROI based on the CASA 20-year support cost is about 128 to 1. (See Table 2-18.)

[74] Terry Elzin, PM FBCB2 Test Manager, Turn Ins between Mar06 through Feb07.xls, e-mail to Andy Long, April 25, 2007.

Table 2-18. FBCB2 Reliability Investment and Support Cost Reduction

MTBEFF hours			CASA 20-year support cost (FY03 $ million, discounted 7% annually)			Economics (FY03 $ million)	
2001	2004	Percent change	2001	2004	Percent change	Reliability investment	ROI
47	364	674.5%	$13,060.4	$1,880.8	85.6%	$87.4	128:1

COMPLEX VEHICLE ELECTRONICS SYSTEM

Description

The systems discussed thus far are either in use or at least through operational test. That begs the question, then, what results would look like for a new system, not yet fielded. To address that question, we created, by analogy, subsystem- and component-level data for a new, notional complex electronic system. The analogous system on which this case is based is real and in design. We created a similar, notional system to avoid potential issues with proprietary data.

Reliability

RELIABILITY DETERMINANTS

Requirements

The reliability values are provided below under the topic of system design. These values should be considered to be allocated rather than estimated or actual. That being the case, the value for field reliability is likely to be less optimistic.

Technology

The technology is a liquid-cooled multiprocessor computer.

Investment

No information on investment in reliability is available.

ACHIEVED RELIABILITY

Since the system has not yet been fielded, achieved reliability is not yet known.

Support Cost

Support Cost Determinants

Utilization

Eventually, DoD will field a total of 3,645 systems, each of which will operate 141 hours per month for 20 years.

System Design

The system comprises two types of LRUs, which we call LRU-A and LRU-B.

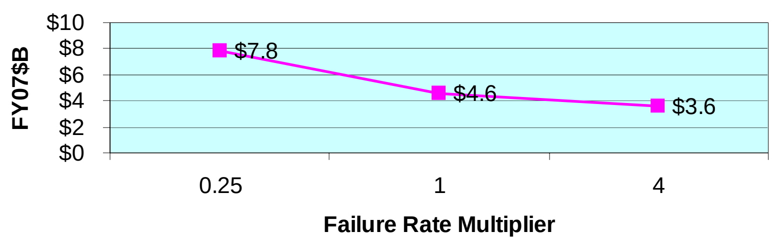
The system has five LRU-As costing $81,000 each. The MTBF of an LRU-A is 4,000 hours. Each LRU-A comprises seven types of shop repairable units (SRUs).

The system has two LRU-Bs costing $70,000 each. The LRU-B MTBF is 4,650 hours. LRU-B comprises nine types of SRUs.

Support Cost Results

Because the system is in design, precluding us from comparing two different experience points, we show how support cost would vary as a function of overall system reliability. To create the results, shown in Figure 2-8, we varied overall system reliability over a range of 8:1, from reliability one-fourth that allocated to one that is four times that allocated. In this instance, the 8:1 change in reliability yields approximately a 2:1 change in support cost (pipelines spares plus operations and maintenance). Although the specifics are not reported here, reliability will have a stronger influence on support cost than will such factors as mean time to repair, pipeline length, and degree of commonality.

Figure 2-8. Support Cost



RELATING INVESTMENT IN RELIABILITY TO REDUCTION IN SUPPORT COST

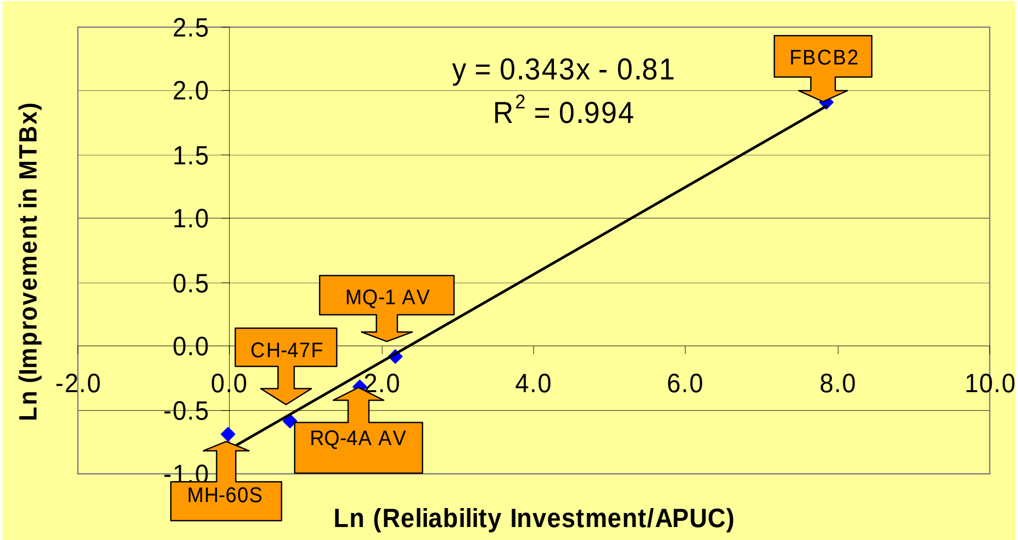
Thus far in this chapter, we have provided data for six individual cases. In this section, we pull some of these data together to create two relationships:

- Relationship between investment in reliability and reliability improvement
- Relationship between reliability improvement and support cost reduction.

Relationship between Investment in Reliability and Reliability Improvement

We are aware that there is a long history of attempts to determine a relationship between investment in reliability and reliability improvement. An example is James Seger's 1983 article, "Reliability Investment and Life-Cycle Cost," in the August 1983 *IEEE Transactions on Reliability*. Generally (and this was the case with Seger), the interest has been in determining a relationship between reliability benefits and investment in reliability design during initial system design. Research typically focused on the development of a hypothetical mathematical relationship. We have not seen any previous efforts that, in the end, did not founder on the same shoals: absence of empirical data. In our study, forced more by circumstances than anything else, LMI primarily looked at systems that were already in service. The unanticipated advantage of looking at these systems is that investment in reliability is visible in the services' budget data. We then realized that dividing investment in reliability improvement by APUC could provide a way of normalizing the data from large systems and smaller systems. (We obtained APUC data from SARs.) When the ratio of reliability investment to APUC is plotted against the percentage improvement in reliability on a log-log scale, the result is a straight line. Figure 2-9 shows the results for cases in this study.

Figure 2-9. Relationship between Reliability Investment and Reliability Improvement, Log-Log Scale (Excluding Complex Ground Vehicle Electronics System)



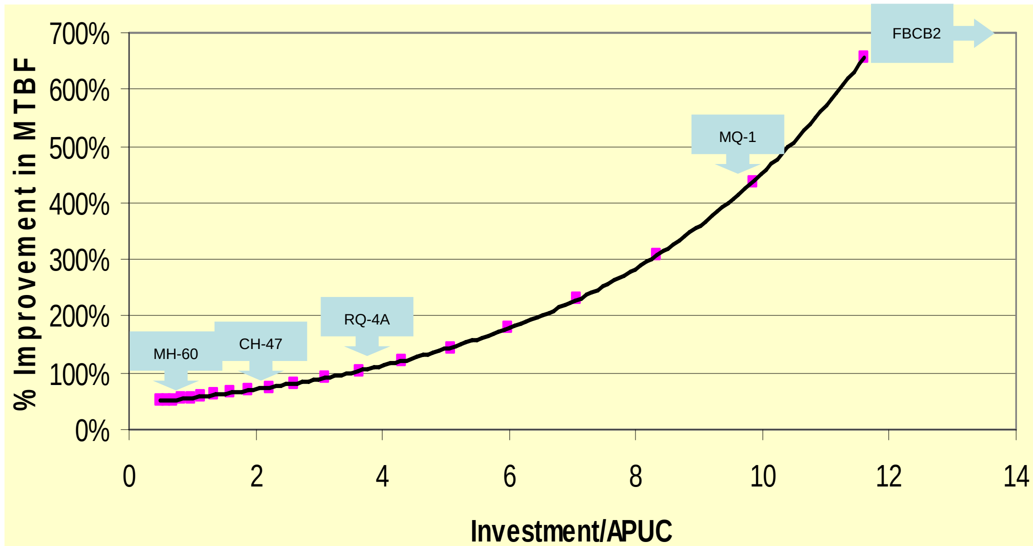
To test the stability of the relationship, we added data from three cases reported in a previous LMI study.[75] The equation was relatively stable at y = 0.363 × −0.794, although the R^2 statistic dropped to 0.59 (this was expected because the data were not of the same quality). Further research will be needed to corroborate our findings, but we suggest that the relationship is sufficiently intriguing to make such additional research worthwhile. We believe that because our data were from a disparate sampling of systems, these results are likely to be system and technology independent.

Relationship between Reliability Investment and Support Cost Reduction

We have already provided a number of case examples showing how reliability improvement reduces support cost. We have also provided ROI information. Here we would like to connect investment in reliability improvement to support cost reduction. To aid in interpreting results, we first replotted the data from Figure 2-9 on linear scales; Figure 2-10 shows the result. The FBCB2 system would be off the graph and is not plotted.

[75] LMI, *Using Technology to Reduce Cost of Ownership*, Report LG404D4, James A. Forbes, Donald W. Hutcheson, and Beirn Staples, April 1996.

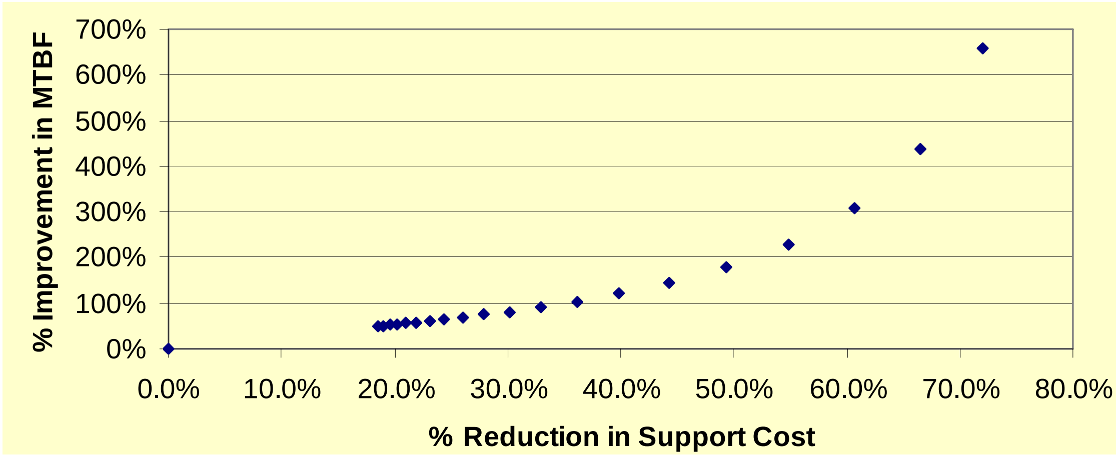
Figure 2-10. Relationship between Reliability Investment and Reliability Improvement, Linear Scales



Generally, as investment gets larger, one expects the rate of return to level off: more investment yields proportionally smaller marginal return. At some point, this has to be true for investments in reliability. Figure 2-10, however, shows not just the absolute magnitude of improvement but also the rate of improvement increasing with larger investments in reliability. This behavior is consistent with what is sometimes called a technology s-curve.[76] The idea is that when introducing new technologies, management practices, and the like, the rate of return initially increases, generally slowly at first because of the large fixed costs to get started. This period of increasing returns is then followed by a (potentially lengthy) period of essentially linear returns and then an eventual flattening out. For at least the cases studied, given the increasing returns to scale, the programs appear to be underinvested in reliability; more investment would have yielded increasingly larger reliability improvement. If a larger sample would show similar behavior, then the statement could be true for DoD as a whole. Next, using the notional complex system described in the last case, we plot percentage reduction in support cost versus percentage improvement in MTBF (Figure 2-11). These are the same results reported earlier but over a wider range of reliability. We have intentionally reversed the scales on this figure with the "x" scale on the vertical axis to make it easy to compare to the graph of investment versus reliability improvement. Results like these will almost certainly be technology and system dependent.

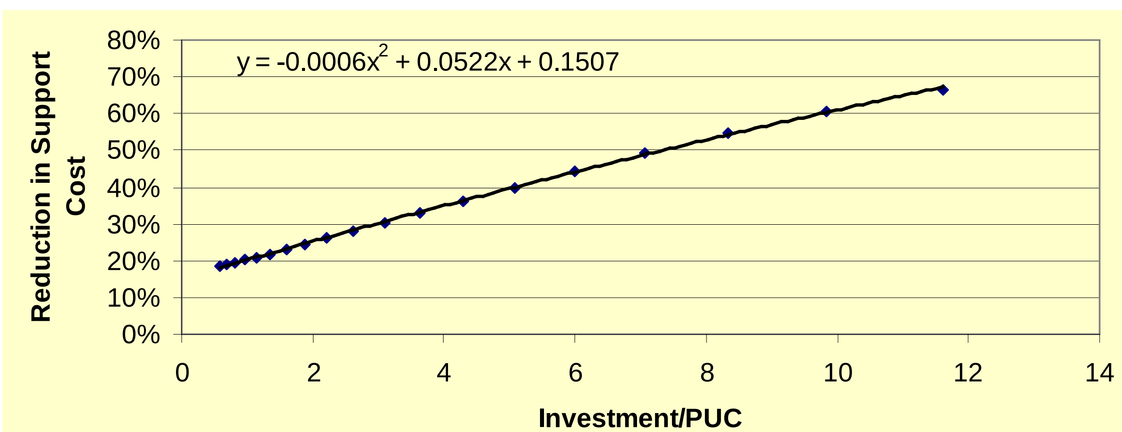
[76] Richard N. Foster, *Innovation: The Attacker's Advantage.* 1986.

Figure 2-11. Support Cost Reduction vs. Reliability Investment (Notional Complex Ground Electronics System)



Finally, in Figure 2-12, we plot investment in reliability versus support cost reduction for the case of the complex system. This figure indicates that an investment in reliability improvement of twice the APUC will produce a reduction in support cost of about 25 percent, an investment of four times the APUC will produce a reduction of about 35 percent, and so on.

Figure 2-12. Investment in Reliability vs. Support Cost Reduction (Notional Complex Ground Electronics System)



We note two caveats about this statement:

- Unlike the relationship between reliability investment normalized by APUC and improvement, the relationship between investment in reliability and support cost reduction is almost certainly system and technology dependent. Therefore, the results are illustrative and should not be generalized.

- The results in Figures 2-9 and 2-10 are based on our empirical analysis of systems already in service. There is a belief (albeit based more on experience rather than empirical data) that $1 invested early in the design stage will have twice the impact on reliability as the same dollar invested after testing. Said another way, investing in reliability early in design is twice as cost-efficient as investing after testing. To the extent that this belief is valid, a relationship such as that in Figure 2-12 would underestimate the return on investments made during design.

Chapter 3
Conclusions and Recommendations

This study examined six systems. In our analysis of the five systems that have been produced and fielded—Predator UAV, Global Hawk UAV, MH-60S, CH-47F, and FBCB2—we identified a number of trends:

- Reliability goals, although established and articulated in operational requirements documents, do not appear to be driving either management or engineering effort.
- Availability of mature technology was not issue in any of the cases.
- Generally, the programs significantly improved system reliability. For the five fielded case studies, reliability improvement ranged from 23.6 percent to 674.5 percent. The reliability improvements were partially the result of design enhancements pursued for reasons such as the introduction of better technology to resolve performance limitations. In four of the cases, the programs made a deliberate effort to improve reliability in its own right. In two of these four cases, however, the improvement was not evident until after operational test or initial operational capability.
- Under-investment in reliability may be large.

The cases were instructive not only individually but also when taken together. Using data from the cases, we were able to develop a preliminary relationship between investment in reliability (normalized by average production unit cost) and achieved reliability improvement. Figure 3-1 shows the relationship.

To establish a relationship between achieved reliability improvement and reduction in support cost, we used the CASA model. Combining the two relationships—investment in reliability to reliability improvement and reliability improvement to support cost reduction—yields a curve such as that shown in Figure 3-2.

Figure 3-1. Relationship between Investment in Reliability and Achieved Improvement (Excluding Complex Ground Vehicle Electronics System)

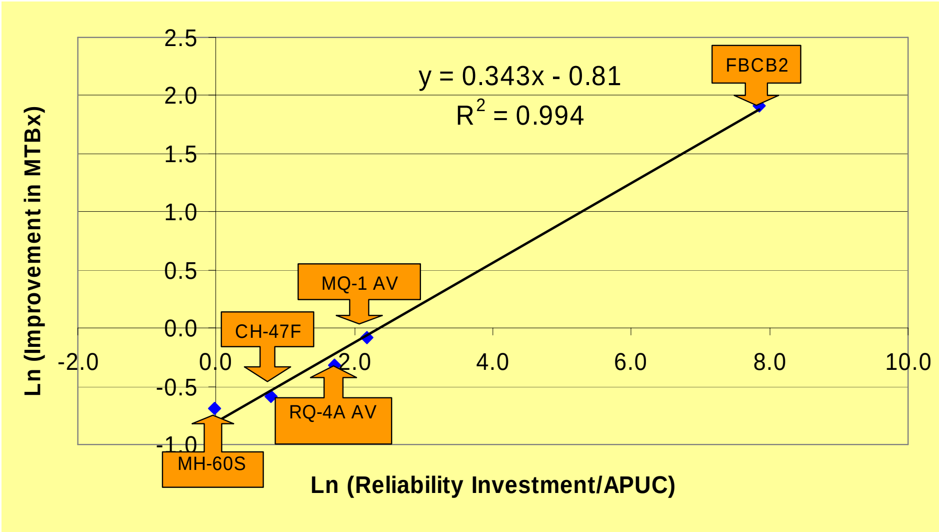
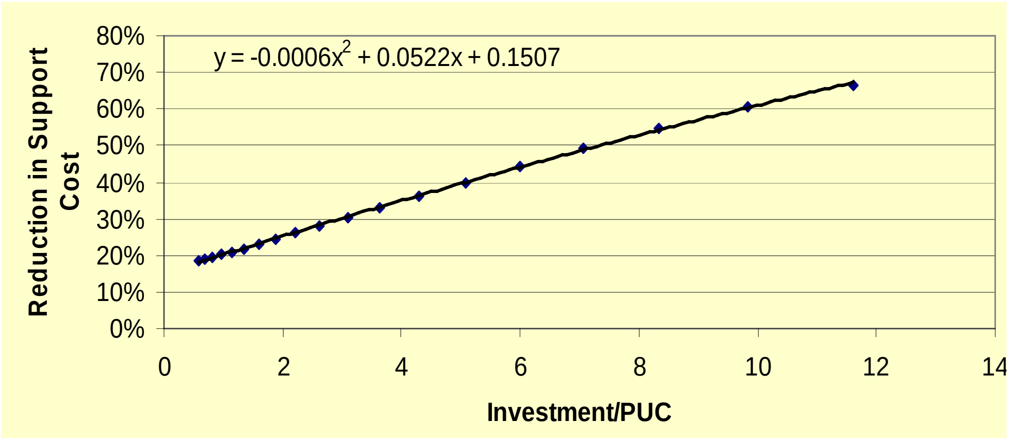


Figure 3-2. Relationship of Reliability Investment to Support Cost Reduction (Complex Ground Vehicle Electronics System)



Estimating the relationship between achieved reliability and support cost is a straightforward exercise once the data are available. The CASA model even automates the process. Thus, the more important relationship, and the primary contribution of this study effort, is an empirical link between investment in reliability and amount of reliability improvement. We have not found a similar result in the literature despite a reasonably concerted effort to search for it. If others have reported results that we missed, then we would welcome learning of them, because they would provide the opportunity to cross-check and replicate our results.

We emphasize that what we developed is *a preliminary relationship* between investment in reliability improvement and support cost reduction. We consider this relationship preliminary for three reasons:

- The empirical relationship between investment and reliability is built on eight data points (the five from this study are shown on Figure 3-1). Additional data are warranted to strengthen this relationship and make sure that it can be replicated.
- The curve in Figure 3-2 reflects the data from one case study. For that case, it shows a nearly linear relationship between investment in reliability and support cost reduction. Relationships such as shown on the figure will almost certainly be technology and system dependent and may, or may not, all be linear.
- There were significant problems with data, a situation that appears to have become more serious in the last decade. (Appendix B discusses the issues with data and likely causes.)

Even in the small sample of cases we examined, the range of discounted returns on investment was extraordinarily wide, with the smallest being about 5:1 and the largest being about 134:1. We suspect that there is going to be no substitute for case-by-case analysis.

While recognizing the limitations flowing from a limited sample and the less-than-ideal data, the preliminary results indicate that it is possible to estimate the reduction in support cost as a function of reliability investment.

The authors of this report recognize that DoD has periodically placed emphasis on reliability in the past. Approximately 20 years ago, for instance, DoD launched a major effort—often called the "IDA/OSD Reliability and Maintainability Study"—to understand and address underinvestment in reliability. Almost immediately on the heels of that effort, the Air Force launched R&M 2000—a major corporate push to place more emphasis on reliability. Reliability also figures heavily in DoD's attention to total ownership cost. Yet underinvestment in reliability, if the cases in this study are indicators, continues. We suggest that addressing the issue requires another look at the incentives that are operating within DoD, because it is arguably through incentives that behavior can be affected. In this context, it will be important to understand why reliability goals do not seem to be driving management and engineering attention.

Considering our conclusions, we recommend that DoD take the following actions:

- Replicate and further strengthen the relationship between investment and reliability improvement. When further validated, such metrics will enable program managers to make evidence-based tradeoffs between investment in reliability and other necessary investments.

- Develop and validate a set of systematic relationships (e.g., family of curves) between investment in reliability and support cost reduction or, if that is not practicable, develop and validate a repeatable estimating method. As noted above, the wide range of returns on investment we observed in the cases suggests that the more likely path is the development of a repeatable method.

- Determine root causes of data issues and address them. We cannot understate the need for attention in this area. Without reasonably complete and reliable data, any analytic results are going to be compromised. Two of the authors of the report (Forbes and Long) have been involved in DoD reliability and support cost efforts for more than two decades. Although obtaining usable data has never been easy, it came as a surprise to find that data in Visibility and Management of Operations and Support Cost (VAMOSC) databases were unusable. Such has not been the case historically.

- Examine incentives that lead to underinvestment in reliability (including inattention to goals) and how to reshape the incentives. Although the various analytic and data considerations are important, understanding and mitigating underinvestment in reliability are of greater importance.

Appendix A
Cost Analysis Strategy Assessment Model

To estimate life-cycle support costs and to establish a relationship between achieved reliability improvement and reduction in support cost, LMI used the CASA model. This appendix summarizes the characteristics of a government-approved model and then describes the CASA model relative to them.

BACKGROUND

The CASA model was developed by the Defense Systems Management College in cooperation with Honeywell Avionics Division's Logistics Technical Staff in response to a broad range of requirements gathered by the military services' acquisition program offices. Over the past several years, the model has been validated and used successfully by all of the DoD services, industry contractors, and other government agencies. The CASA program has 1,030 users:

- Air Force (government and industry)—141
- Army (government and industry)—459
- Navy (government and industry)—170
- Marines (government and industry)—19
- Other DoD components (Coast Guard, OSD, etc.)—150
- Other entities (NASA; Federal Aviation Administration; Energy, Transportation, and Commerce departments; U.S. Senate; colleges; and state and local agencies)—81.

The model is not service or equipment specific and can handle a wide variety of "relevant costs." The model is comprehensive but highly tailorable. As user requirements have evolved, the model has evolved to the current 9.0 version. LMI used version 8.0 for this study.[1]

[1] Interview with Phillip Paschel, Program Manager, CASA, May 22, 2007.

CHARACTERISTICS OF A GOVERNMENT-APPROVED LCC MODEL

Research shows that a wide variety of both general-purpose and special-purpose LCC models have been developed. The government has regularly required that studies use the "government-approved" models when estimating the cost of ownership of alternative solutions. This requirement ensures that all of the contractors and government LCC estimates are comparable, repeatable, and understandable. Many of these models are cataloged in the DoD Acquisition Logistics Guide distributed by the Logistics Support Activity (LOGSA), an agency of the Army Material Command that serves all of DoD in the area of logistics supportability assessment and related tools.

Interviews and surveys of many industry representatives have resulted in a finding that many government models were considered unnecessarily complex and "input data hungry." Both industry and government program managers need a flexible model that can operate effectively with tailored levels of input detail, from simple to complex, depending on the decision being considered. The next section will show that the CASA model fits all of these requirements.[2]

DESCRIPTION OF THE CASA MODEL

The CASA model is basically a management decision aid based on LCC. In actuality, CASA is a set of analysis tools formulated into one functioning unit. It collects, manipulates, and presents as much of the total cost of ownership as the user desires. It contains a number of programs and submodels that allow the user to perform several tasks, such as the following:

- Generate program data files
- Perform life-cycle costing
- Perform sensitivity analysis
- Perform LCC risk analysis
- Perform LCC comparisons and summations on up to 2,000 repairable candidates.

The model also includes a wide variety of preprogrammed output report formats designed to support the analysis process. The CASA model covers the entire life of the system, from its initial research costs to those associated with yearly

[2] Defense Systems Management College, *Acquisition Logistics Guide*, Part 3, Logistics Resources and Tools, Chapter 16: Cost Analysis Strategy Assessment Model (CASA), Third Edition December 1997.

maintenance, as well as spares, training costs, and other expenses incurred once the system is delivered. Currently, RDT&E and production costs are "throughput" costs, meaning they are not derived by the model. They are input and reported in some report outputs depending on their relevance to the analysis. The model calculates and projects the operations and support costs over the 20 to 30 years of operating the system. Currently, RDT&E and production cost estimating modules are being considered in response to numerous users' requests.

The CASA model employs some 82 algorithms with 190 variables. Only a small number of the inputs are mandatory. Most of the inputs are optional and are subject to tailoring to the analysts' needs. Inputs include the following:[3]

- General information (study life, operating hours, etc.)
- Maintenance-level information (1 to 10 levels)
- System production and cost data
- System deployment data
- System hardware data (MTBF, MTTR, unit cost, etc.)
- Support equipment data
- Transportation data
- Training data
- Failure data
- Warranty data
- Inflation and discounting factors.

The CASA model, therefore, is a relatively "compact" model designed to facilitate well-informed decisions while holding model input data gathering to a moderate level. CASA works by taking the data entered, calculating the projected costs, and determining the probabilities of meeting, exceeding, or falling short of any LCC target value. Offering a variety of strategy options, CASA allows the user to alter original parameters to observe the effects of such changes on strategy options. At any number of program junctions, inputs may be saved and calculations may be made to that point for later evaluation. Furthermore, CASA will accept only correct inputs. It checks every entry as it is input; incorrect data will cause the cursor to refrain from movement and/or alert the user.

[3] U.S. Army Materiel Command, Logistics Support Activity, Logistics Information Warehouse (LIW) version 1.00, https://liw.logsa.army.mil/index.cfm?fuseaction=login.main (1 of 2), accessed May 22, 2007.

The CASA model can be used for a wide range of analytical tasks:[4]

- LCC estimates (system and subsystem)
- Item tradeoff analysis
- Support concept analysis
- Production rate and quantity analysis
- Warranty analysis
- Spares provisioning
- Reliability growth analysis
- Operational availability analysis
- Software project cost estimation.

OBTAINING CASA

Version 9.0 is the latest version of the CASA model. This version has new improved system wizards and reporting capabilities and new data implementation. Major enhancements enable the user to do the following, among other things:

- Map program cost requirements within the acquisition life cycle
- Use reports as resource documentation for business case analysis, decision support, and Integrated Product Team meetings
- Connect data sources directly to the CASA model
- Eliminate data entry
- Create a reusable cost modeling capability.

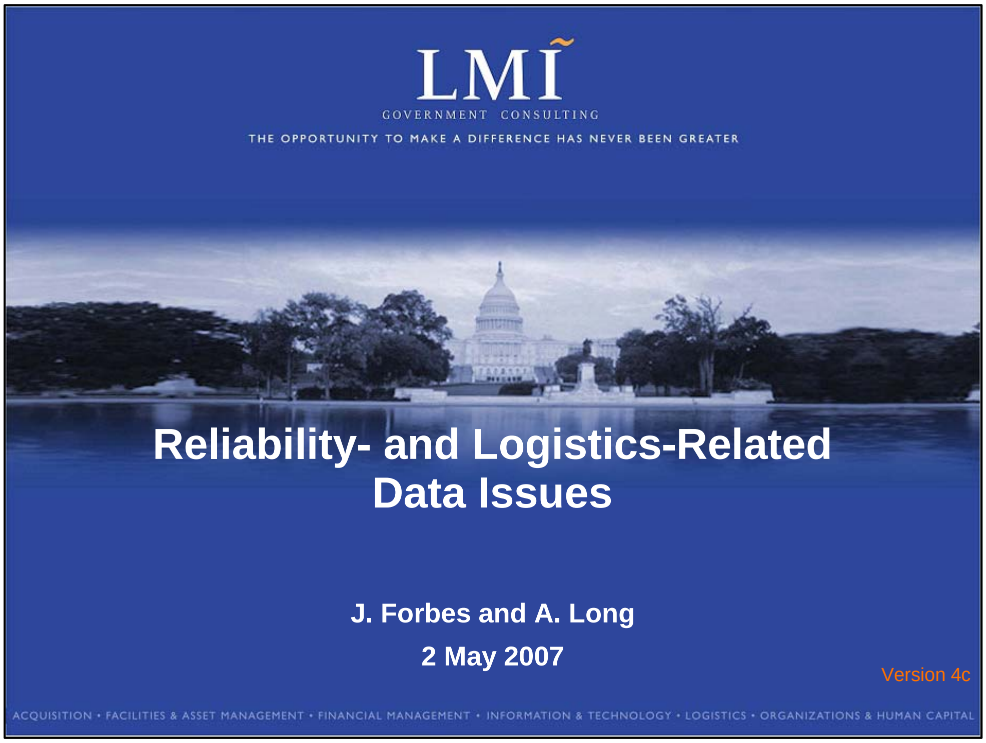
The CASA model runs on any Windows-based operating systems (Windows 95 or later versions) and is downloadable directly from the LOGSA Logistics Information Warehouse: https://www.logsa.army.mil/alc/casa/.[5]

[4] Phillip Paschel, U.S. Army Materiel Command, Cost Analysis Strategy Assessment (CASA), April 9, 2007.

[5] Interview with Phillip Paschel, Program Manager, CASA, May 22, 2007.

Appendix B
Issues Related to Reliability and Logistics Data

The quality of the reliability and logistics data was a limitation on our study. Moreover, the data issue is a problem in its own right that deserves attention. (If anything, it has gotten worse in the last decade.) Therefore, this appendix contains a briefing, with notes, about specific data issues that LMI encountered. The briefing also addresses the impacts and root causes of data problems and provides potential solutions for identified root causes.



This briefing addresses the following topics:

- Examples of data problems encountered
- Impacts of lack of or invalid data
- Potential root causes
- Potential paths forward.

Data Availability by Platform/System

Platform	Usage Data Density, OPTEMPO	Product Data Failure rate, MTBF, MTTR, MR	Support Process Data CWT, Cycle Times, NRTs
MQ-1 Predator	Gaps in flying hours data in AFTOC. Useable data provided by MAJCOM.	Usable data available from OSD Studies, PM, and other sources	Limited visibility into contractor support processes. Used default values.
RQ-4A Global Hawk	Gaps in data. Flying hour counting rules vary by operational unit. (Beale reports pre and post flight operations in FH data; Edwards does not.)	Reliability data parameter measured in the field (MTBF) not consistent with the parameters used to establish ORD requirement (ETOS>100 hrs)	Limited visibility into contractor support processes. Used default values.
FBCB2 Appliques	OT Other than for OT, unable to locate usage data. Does not appear to be captured.	Used DT/OT data available from AEC and IDA. Data differs by source for same test events.	Limited visibility into contractor support processes. Used default values.
MH-60S	Usable data available from PMA 299	Reliability data parameter measured in the field (MTBF) not consistent with the parameters used to establish ORD requirement (MTBOMF)	Usable data available from PMA 299
Stryker	FY 2002 to FY 2005 CLS data unavailable. CLS Data for FY 2005.5 to FY 2006.5 for two Stryker brigades.	Limited data available, pedigree suspect or unknown	Limited visibility into contractor support processes. Because of other missing data did not model.
CH-47F	OT data available for 5 aircraft: 2-EMD Aircraft 2-zero time CH-47F Aircraft 1-Hybrid Aircraft, CH-47D outfitted with a CAAS cockpit	Reliability data parameter measured in the field (MTBF) and ORD requirement (MTBMA) are used interchangeably. Unclear whether data contain all failures or only those causing mission abort.	Data appear to be unavailable

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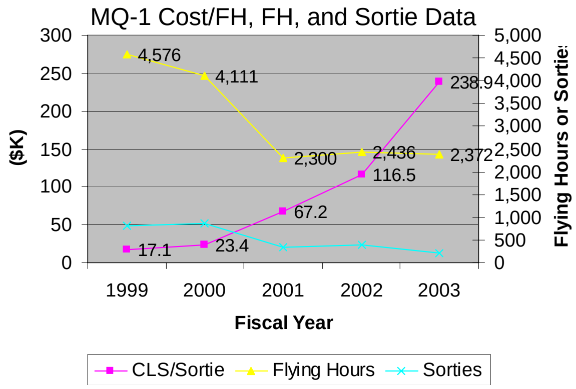
Usable data available from standard source
Usable data available from PM or other sources
Data problematic: incomplete, inconsistent, pedigree suspect or unknown
Data appear to not be available

PAGE 2

Examples of data problems by case study and data type are shown above. Problems with incomplete, corrupted, inconsistent, and missing data are pervasive. In no case were we able to obtain consistent OPTEMPO or failure data from the services' standard data systems. To work around this problem, we sought and obtained what are essentially ad hoc data from program offices and their contractors and then filled in voids by reverse engineering and application of various estimating relationships.

Example: apparent loss of MQ-1 flying hours and sorties



- **4:1 reduction in sorties**
- **2:1 reduction in flying hours**
- **Unexplained 14:1 increase in CLS cost/Sortie**
- **Discussion with SMEs indicates disconnect likely due to missing FH**

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PAGE 3

Gaps in flying hours and sortie data are an example of a data issue that we encountered. Shown here are ABIDES and AFTOC data for flying hours and sorties for the MQ-1 Predator. These data indicate that the Predator OPTEMPO in flying hours and sorties flown were decreasing from FY99 to FY03, yet the CLS cost per sortie was increasing. Discussions with Major Command subject matter experts indicate the disconnect is likely due to missing flying hours in OCONUS operations.

Global Hawk Program FHs and Sorties: ABIDES vs Other Sources

Data: ABIDES AFCAP

Data	Block 10	Total Program
FHs	2574	3025.3
Sorties	52	52

AFCAP hours & sorties data is populated from A3's Cost Center Report.

Source/s:

ABIDES AFCAP (Air Force Cost & Performance) Data for UAVs, April 2007

Data: OEM and SPO

Data	Block 10 (1)	Total Program (2)
FHs	3015	9276.2
Sorties	322	635

Block 10 data normalized to adjust for differences in counting rules for FHs data between Edwards AFB and Beale AFB (AOR aircraft, 2011 and 2012)

Source/s:

1. Northrop Grumman, Joe Miller, RQ-4A UAV R&M Performance Metrics (UAV Block 10), Total Fleet FH from Aug 2003 through Aug 28, 2006
2. Global Hawk Systems Group, LTC Ron Jobo, OSD R-TOC Conference, BLOCK 10 Aircraft Combat Status as of 14 April 06, 3 May 2006

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PAGE 10

Gaps in data and flying-hour counting rules vary by operational unit. Two problems are illustrated here:

- As was the case with Predator, flying hour and sortie data in ABIDES and AFTOC for Global Hawk vary significantly compared to like data from OEM and SPO.
- The counting rules for flying hours differ by unit, and the differences are not made clear in the data. In this example, one unit counts pre-flight prep as flight hours, while the other does not.

MH-60S Reliability Metric: ORD vs Depot

ORD Reliability Metric:

Table IV-1. Measures of Operational Suitability and Test Results

Category	Measures of Operational Suitability (MOS)	Threshold	Results	Sat/Unsat
Reliability	Mean Time Between Operational Mission Failure ($MTBOMF_{sys}$)	>20.3 hr	23.96 hr	Sat
Maintainability	Mean Corrective Maintenance Time between	<3.6 hr	2.72 hr	Sat

Source: DOT&E, Combined Operational Test and Development and Live Fire Test and Evaluation on MH-60S Fleet Combat Support Helicopter, Table IV-1. Measures of Operational Suitability and Test Results, pg.19, August 2002

NAVAIR Reliability Metric:

Year	TMS	Failures	Flt Hrs	MTBF
2002	MH-60S	47	334	7.1
2003	MH-60S	2,454	22,729	9.3
2004	MH-60S	3,581	31,460	8.8
2005	MH-60S	4,921	31,752	6.5
2006	MH-60S	4,754	32,245	6.8
MH-60S Totals		15710	118,186	7.5

Source: NAVAIRDEPOT, MH-60S R&M Analysis, March 2007

NAVAIR Response to Request for ORD Reliability Metric:

From: [redacted]
Sent: Thu 3/8/2007 1:16 PM
To: LONG, Andy
Cc:
Subject: RE: MH-60S Data

I am a bearer of bad news, but we do not track the MTBOMF. I would recommend in your report that you explain your acronyms to people receiving it. Majority of us here had no clue. It may help out in dealing with NAVAIR. I was an Aircraft Anaylst in the Marine Corps, and I never heard of your metric.

Well, I wish you luck in your endeavors.

[redacted]

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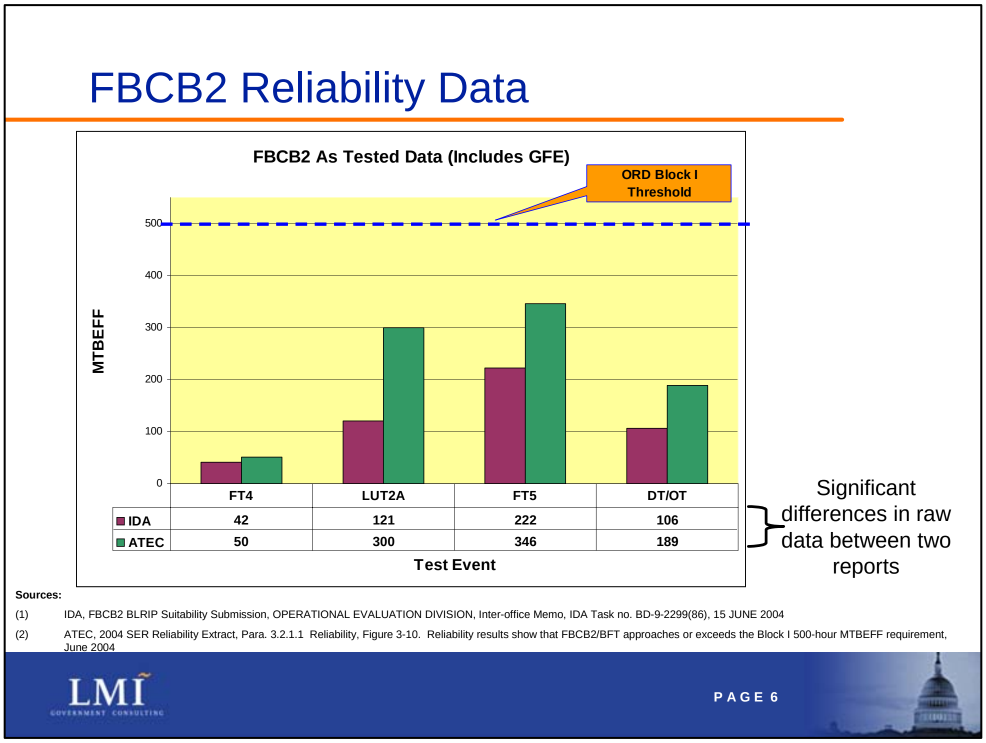
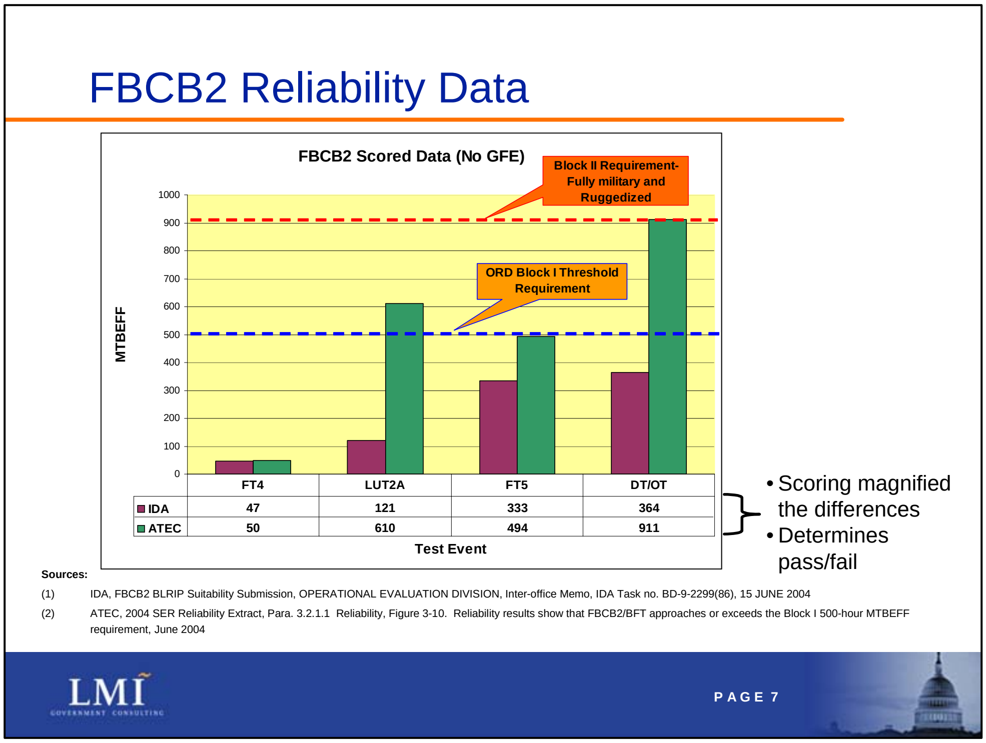
PAGE 5

Reliability data parameters measured in the field are not consistent with the parameters used to establish the ORD requirement. Shown here is an example of the difficulty sometimes encountered in determining reliability improvement as compared to the ORD requirement. In this case, the MH-60S ORD requirement is MTBOMF, while the metric collected by NAVAIR is MTBF. NAVAIR representatives with whom we communicated were not aware of the ORD metric.



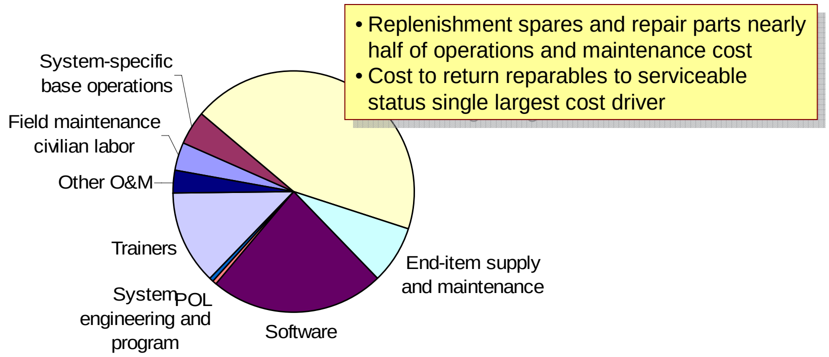
Large differences exist between sources for the same test events. This example comes from the FBCB2 program. As shown, there were significant differences in raw data taken from the same test events. The problem becomes determining why differences exist and how best to characterize the reliability achievement.



Large differences exist between sources for same test events. As one might expect, if the raw data vary by event, so too will the interpetation of the data. Scoring magnifies the differences and can significantly affect the pass/fail decision.

…and a support process problem of long standing – component repair costs

Distribution of Operations and Maintenance Cost for Representative Weapon System



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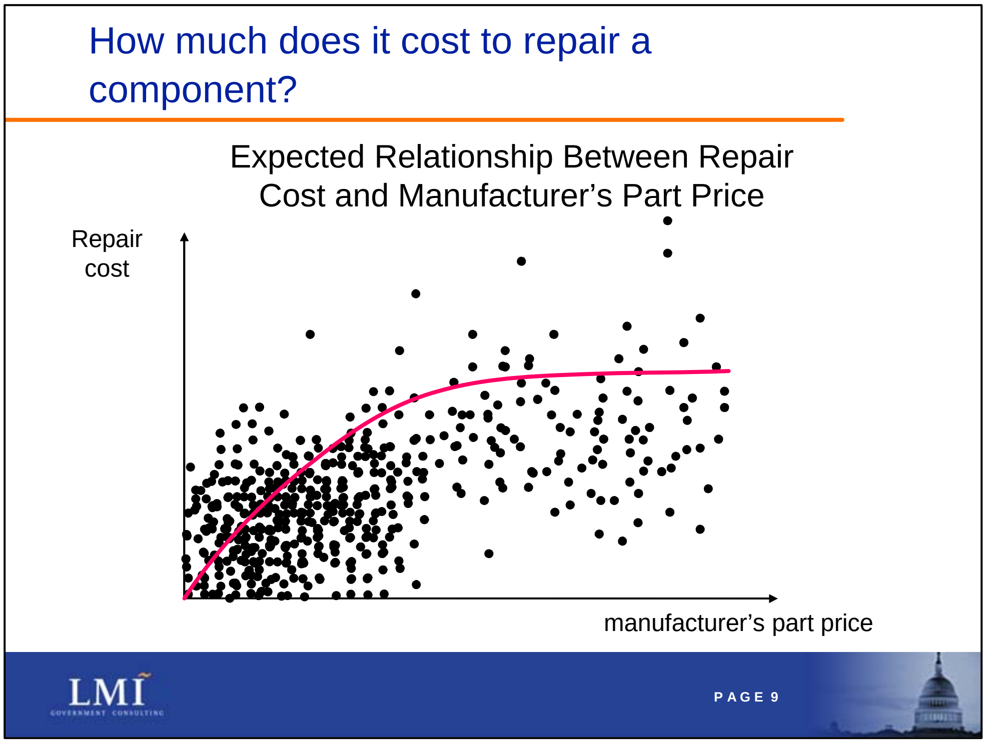
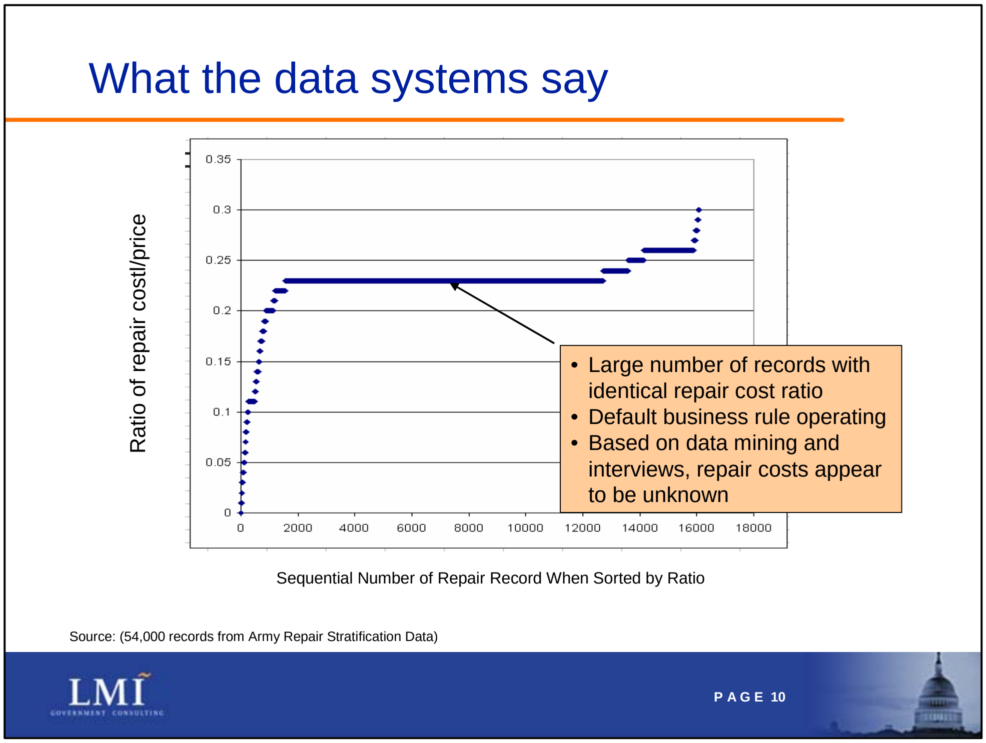
PAGE 16

As indicated by in the pie chart, the cost to return reparables to serviceable status is the single largest support cost driver. Yet, as previously pointed out, with the exception of the MH-60S, none of the systems studied had usable data for these costs. As such, we were forced to use SME judgment and defaults.



When looking at the relationship between part price and repair cost, we expected to find a curve that increased initially with part cost and then flattened out.



LMI analyzed more than 54,000 repair cost records. The results are in the figure above. When the data are ordered by the ratio of repair cost to unit price, it becomes obvious that nearly all of the repair records have the same ratio—roughly 0.22. Hence, the data reflect a business rule (or rules) rather than valid repair costs. Discussion with subject matter experts indicates that the lack of valid repair cost data has been recognized (and unaddressed) for years. Since the single largest element of operations and maintenance cost is the cost of repair, and cost of repair is largely unknown, any attempt to reduce support cost stands on a tenuous foundation.

Impacts

	Problem	Pervasiveness/ Frequency	Consequences
1	Inadequate investment in goal development	Frequent (e.g., on in-service systems) but not ubiquitous	• Arbitrary goals or no goals
2	Unavailable or invalid usage data	Encountered in each system examined	• Lack understanding of field reliability performance, cost of support • Compromises understanding of where to invest improvement resources, track changes in performance over time, understand return on investments.
3	Inconsistent product data	Design and field data in general are either unavailable or ad-hoc	• Dependence on ad-hoc data, reverse-engineered data, and data developed through estimating relationships severely limits credibility of analytic results
4	Unavailable or invalid support process data	Only one system had any support process data	• Forced to use defaults; any estimate of support cost becomes guesswork • No or limited ability to credibly evaluate return on investment in support processes
5	Incomplete and/or inconsistent reliability investment data	Almost all data were problematic, incomplete, or inconsistent	• Limits ability to understand return on investment

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PAGE 11

Shown here is a summary of the problems previously covered and their impacts on our study. The bottom line: these data problems are pervasive and are getting worse.

Potential root causes

	Root cause	Timeframe emerged	Impact/Comments
1	Limited up-front funding	Not a new cause	**[Product]** Inadequate goal development, arbitrary priorities
2	Unintended consequence of cancellation of MIL-STD-1388 (Logistics Analysis) as part of MIL STD reform	Since 1994	**[Usage, product, support process]** Although some OEMs and subs still use MIL-STD-1388, use is non-standardized and ad hoc. Without an agreed-to standard, it is essentially impossible to assemble a consistent set of logistics data on a system
3	Unintended consequence of Placing Advanced Concept Technology Demonstrations into use without system development and demonstration	1990s	**[Usage, product, support process]** Data normally developed during system development and demonstration are unavailable.
4	Unrealistic expectation that performance-based logistics would obviate the need for data	C/A 2002, 2003	**[Usage, product (design and field), support process, investment]** Loss of data access and visibility
5	Lack of methods for capturing data when logistics is provided by contractors and/or DoD internal providers	C/A 1995	**[Usage, product, support process, investment]** Loss of data access and visibility

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PAGE 21

Potential root causes for the data problems are shown here. Limited up-front funding for data, cancellation of the MIL-STD-1388 requirement to collect logistics data, ACTD acquisitions, PBL, and CLS are primary contributors to this problem. All have resulted in loss of data, data access, and visibility.

Potential paths forward

	Root cause	Potential Approaches to Solutions
1	Limited up-front funding	Advocacy
2	Unintended consequence of cancellation of MIL-STD-1388 (Logistics Analysis) as part of MIL STD reform	Implementation in DoD acquisition programs of GEIA STD 0007, *Logistics Product Data*, or equivalent.
3	Unintended consequence of Placing Advanced Concept Technology Demonstrations into use without system development and demonstration	Provisions for early capture and analysis of field data.
4	Unrealistic expectation that performance-based logistics would obviate the need for data	Temporary project team to fully characterize the problems as a related set, determine what data are required and when under PBL arrangements, develop consistent approaches, develop implementing policy and guides, promote development of get-well plans for programs with data voids.
5	Lack of consistent methods for capturing data when logistics is provided by contractors and/or DoD internal providers	

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PAGE 13

Potential approaches to address the root causes of the data problem are shown here. Chief among the solutions is implementation of a replacement for MIL-STD 1388. At the time of this research, a leading candidate was GEIA STD 0007. An agreed-to standard is essential to assembling a consistent set of logistics data on systems.

Appendix C
Reliability, Usage, Investment, and Support Process Data

This appendix contains data used in this study to assess reliability, reliability investment, and support costs. The data are organized in tables, one for each of the five systems that have been produced and fielded:

- Table C-1—Predator UAV
- Table C-2—Global Hawk UAV
- Table C-3—MH-60S Fleet Combat Support Helicopter
- Table C-4—CH-47F ICH
- Table C-5—FBCB2 system.

Table C-1A. Predator Unmanned Aerial Vehicle: Reliability, Usage, and Investment Data, by Fiscal Year

Item	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Reliability data									
MTBF (hrs)	40	55	58	61	66	71	72	74	77
OPTEMPO and usage data									
Flying hours	3,185.3	5,134.1	6,363.9	7,344.3	19,228.30	20,487.4	31,297.0	40,957.9	57,833.4
Aircraft	30.0	40.0	51.0	53.0	51.0	45.0	60.0	69.0	87.0
Sorties			862.0	875.0	1,557.0	1,387.0	1,985.0	2,636.0	2,777.0
R&M investment data (FY03 BY $ thousands)									
R&M	$11,430	$2,289	$2,671	$2,218	$960	$950	$7,860	$5,627	$5,123
Cumulative	$11,430	$13,719	$16,390	$18,608	$19,568	$20,518	$28,377	$34,004	$39,127

Table C-1B. Predator Unmanned Aerial Vehicle: Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
System	77.0	0.01299	100%	$4,500	2,500.0				
Subsystems									
Airframe	1E+19	0.00000		$1,912	860.0				
Propulsion	94.3	0.01061	81.7%	$108	702.6				
Engine	770.0	0.00130	10.0%	$80	86.0	3	15%	40	$17.60
Propeller	360.0	0.00278	21.4%	$9	183.9	1.5	15%	NA	NA
Alternator	332.0	0.00301	23.2%	$14	199.5	1	15%	8	$3.01
Fuel tray	284.0	0.00351	27.1%	$6	233.2	1	15%	NA	NA
Flight controls	334.8	0.00299	23.0%	$430	197.8				
FCS computers	18,301.0	0.00005	0.4%	$140	3.6	0.5	30%	8	$30.80
FCS software	18,301.0	0.00005	0.4%		NA	0.5	30%	NA	NA
Actuators	400.0	0.00250	19.3%	$135	165.6	1	30%	24	$29.70
Air data system	639.0	0.00156	12.1%	$312	103.6	0.5	30%	24	$68.61
Communications	770.0	0.00130	10.0%	$500	86.0				
Navigation	2,310.0	0.00043	3.3%	$149	28.7	0.5	30%	8	$32.78
LOS data link	2,310.0	0.00043	3.3%	$168	28.7	0.5	30%	8	$36.96
BLOS data link	2,310.0	0.00043	3.3%	$183	28.7	0.5	30%	8	$40.26
Payload	1,177.2	0.00085	6.5%	$822	56.3	0.5	30%	8	$10.00
Sensors				$2,588.0	270				
EO/IR cameras	2,354.5	0.00042		$1,167.0	135	0.25	30%	48	$256.74
Synthetic aperture radar	2,354.5	0.00042		$1,420.0	135	0.5	30%	16	$312.40

Table C-2A. Global Hawk Unmanned Aerial Vehicle: Reliability, Usage, and Investment Data, by Fiscal Year

Item	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Reliability data								
MTBEF (hrs)	55.7	61.7	67.7	95.7	91.0	114.2	120.0	117.1
OPTEMPO and usage data								
Spiral block	Block 0				Block 10			
FH	6,261.6				318.3	468.1	1,203.9	1,024.7
Aircraft	7				5	5	7	7
Sorties	313				34	50	166	71
R&M investment data (FY03 BY $ thousands)								
R&M	$14,723	$0	$5,090	$197	$7,936	$59,804	$16,118	$18,062
Cumulative	$14,723	$14,723	$19,814	$20,011	$27,947	$87,751	$103,869	$121,931

Table C-2B. Global Hawk Unmanned Aerial Vehicle: Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
System	3.92	0.25510	100%	$31,500	11,400				
Subsystems									
Airframe	23.615	0.042346	16.6%	$6,981.0	5,608.1	2.671	0%		
Doors NOC	527.400	0.001896	0.7%	$75.0	276.7	3.223	0%		
Fuselage NOC	226.029	0.004424	1.7%	$1,623.0	1,591.3	2.191	0%		
Leading edge devices	316.440	0.003160	1.2%	$5,283.0	87.5	3.105	0%		
Landing gear	56.507	0.017697	6.9%	$660.0	763.2	2.159	9%		
Nose gear NOC	316.440	0.003160	1.2%	$566.0	165.2	2.448	0%		
Autobrake valve (ABV)	395.550	0.002528	1.0%	$94.0	5.8	2.917	0%		
Flight controls	58.600	0.017065	6.7%	$943.0	245.1	2.937	4%		
Engine starting	1,582.200	0.000632	0.2%	$100.0	34.8	2.500	0%		
Propulsion	87.900	0.011377	4.5%	$1,887.0	1,937.0	4.194	0%		
Turbofan engine	527.400	0.001896	0.7%	$1,887.0	1,611.2	6.348	0%		
Ice and rain protection	791.100	0.001264	0.5%	$17.5	0.4	3.645	33%		
Environmental control	113.014	0.008848	3.5%	$472.0	253.4	2.814	0%		
Electrical	63.288	0.015801	6.2%	$943.0	1,147.9	2.837	3%		
Electrical PWR NOC	395.550	0.002528	1.0%	$450.0	367.1	2.663	0%		
PWR and discrete cont.	316.440	0.003160	1.2%	$493.0	495.3	2.800	0%		
Lights	1582.200	0.000632	0.2%	$0.5	9.3	1.510	0%		
Hydraulic/ pneumatic PWR	197.775	0.005056	2.0%	$350.0	162.5	2.186	0%		
Hydraulic reservoir	527.400	0.001896	0.7%	$350.0	149.5	3.740	0%		

Table C-2B. Global Hawk Unmanned Aerial Vehicle: Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
Fuel	68.791	0.014537	5.7%	$472.0	179.5	3.444	6%		
Storage NOC	395.550	0.002528	1.0%	$172.0	125.0	4.395	0%		
Fuel distribution NOC	527.400	0.001896	0.7%	$300.0	54.4	4.208	0%		
Navigation/systems integ.	14.002	0.071420	28.0%	$943.0	1,930.1	2.721	7%		
Nav./systems integration	527.400	0.001896	0.7%	$25.0	32.4	4.585	0%		
Flight environment data	395.550	0.002528	1.0%	$33.4	21.0	0.000	0%		
Radio altimeter A	197.775	0.005056	2.0%	$66.8	22.7	5.320	0%		
See and detect camera package assembly	98.888	0.010113	4.0%	$188.0	38.6	4.276	12%		
Inertial nav. system Ln-100G	395.550	0.002528	1.0%	$33.4	51.8	2.750	0%		
Processing and integ.	226.029	0.004424	1.7%	$58.4	88.9	6.983	0%		
Processing integ. NOC	113.014	0.008848	3.5%	$116.8	51.1	2.100	0%		
IMMC	75.343	0.013273	5.2%	$175.2	81.7	7.428	13%		
Common airborne modem assembly	93.071	0.010745	4.2%	$141.9	21.0	5.058	5%		
UHF communications	98.888	0.010113	4.0%	$500.0	105.6	2.588	21%		
UHF communications	395.550	0.002528	1.0%	$125.0	34.1	2.191	50%		
UHF/VHF ATC Radio Arc 210	527.400	0.001896	0.7%	$93.8	66.6	2.920	25%		
CDL LOS RFA	395.550	0.002528	1.0%	$125.0	5.0	5.508	33%		
Identification, friend or foe	316.440	0.003160	1.2%	$188.0	17.7	2.625	0%		
Emergency communication	1582.200	0.000632	0.2%	$188.0	140.5	0.750	0%		
Satellite communications	83.274	0.012009	4.7%	$2,358.0	586.5	2.470	0%		
Ku Band SATCOM	316.440	0.003160	1.2%	$620.5	157.2	2.417	0%		
Ku SATCOM antenna	527.400	0.001896	0.7%	$372.3	124.9	6.760	0%		
UHF SATCOM	395.550	0.002528	1.0%	$496.4	105.9	7.750	0%		
Surveillance	43.950	0.022753	8.9%	$16,689.0	1,060.7	2.390	6%		
Surveillance	263.700	0.003792	1.5%	$1.0	65.4	5.417	0%		
Data processing NOC	395.550	0.002528	1.0%	$3,722.0	132.0	3.250	0%		
Sensor electronic unit	395.550	0.002528	1.0%	$1,666.0	519.9	4.724	25%		
Infrared sensors NOC	395.550	0.002528	1.0%	$11,300.0	343.5	2.000	0%		

Table C-3A. MH-60S Fleet Combat Support Helicopter: Reliability, Usage, and Investment Data, by Fiscal Year

Item	FY01	FY02	FY03	FY04	FY05	FY06
Reliability data						
MTBF (hrs)	6	7.1	9.3	8.8	6.5	6.8
OPTEMPO and usage data						
Flying hours		334	22,729	31,460	31,752	32,245
Aircraft		1	7	10	93	94
R&M investment data (FY03 BY $ thousands)						
R&M				$490	$11,752	$870
Cumulative				$490	$12,242	$13,113

Table C-3B (1). MH-60S Fleet Combat Support Helicopter: Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
System									
Subsystems									
Airframe	5.34	0.18727	18.9%	$1,630.0		7.1	0.59%	3.54	$1.0
Stabilator amplifier inst.	1,351	0.00074	0.4%	$38.4	20.0			24.2	$6.91
Beam-axle assembly	10,000.0	0.00010	0.1%	$23.2	105.0			12.7	$3.63
Aircraft floor	10,000.0	0.00010	0.1%	$18.5	101.0			13.6	$3.89
Auxiliary power systems	125	0.00800	0.8%	$82.6		6.3	0.00%	3.50	$1.0
Aircraft power unit	10,000.0	0.00010	1.3%	$72.2	338.0			8.6	$24.62
Helicopter drives/ transmissions	19.26	0.05192	5.2%	$3,302.1		6.7	0.12%	3.33	$3.0
Sections 2/3/4 drive shaft assembly	10,000.0	0.00010	0.2%	$3.5	NIF	Consum-able	Consum-able	Consum-able	Consumable
Integrated guidance/flight control systems	41.17	0.02429	2.4%	$1,367.7		9.9	1.20%	2.05	$2.7
CP-2428/A digital data computer	2,236	0.00045	1.8%	$76.0	100.0			45.4	$60.87
Weapons control systems	1,033.36	0.00097	0.1%	$11.2		20.8	0.00%	7.00	$2.0
CPU133/A digital comp.	1,944	0.00051	53.2%	$77.5	100.0			7.6	$9.90
Countermeasures systems	563.65	0.00177	0.2%	$25.3		20.0	1.82%	2.00	$2.0
Light infrared transmitter	10,000.0	0.00010	5.6%	$4.2	0.1	Consum-able	Consum-able	Consum-able	Consumable

Table C-3B (2). HH-60H:
Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
Airframe									
Stabilator amplifier install	548.5	0.00182		$30.3	20.1				$12.49
MLG drag beam/axle assembly	10,000.0	0.00010		$21.5	105.0				$14.48
Floor assembly	10,000.0	0.00010		$9.2	101.0				$1.91
Auxiliary power systems									
Auxiliary power systems	2,159.9	0.00046		$77.8	338.0				$26.51
Helicopter drives/ transmissions									
Sections 2/3/4 drive shaft assembly	6,479.7	0.00015		$3.5	NIF	Consum-able	Consum-able	Consum-able	Consumable
Integrated guidance/flight control systems									
CP1820/ASN150 nav. computer	433.8	0.00231		$89.0	126.0				$26.54
Weapons control systems									
CPU159/A AFCS com-puter	582.4	0.00172		$162.0	70.0				$6.81
Countermeasures systems									
T1360( )/ALQ144(V) transmitter	582.4	0.00172		$47.1	35.0				$16.49

Table C-4A. CH-47F Improved Cargo Helicopter: Reliability, Usage, and Investment Data, by Fiscal Year

Item	FY01	FY02	FY03	FY04	FY05	FY06
Reliability data						
MTBMA (hrs)		22.0	30.1	31.4	43.5	46.7
OPTEMPO and usage data						
Flying hours	799.15				391.27	86.93
Aircraft	2				1	2
R&M investment data (FY03 BY $ thousands)						
R&M		$13,859	$0	$4,666	$11,501	$9,568
Cumulative		$13,859	$13,859	$18,525	$30,026	$39,595

Table C-4B. CH-47F Improved Cargo Helicopter: Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
System	**Unable to obtain these data**								
Subsystems									

Table C-5A. Force XXI Battle Command, Brigade-and-Below System: Reliability, Usage, and Investment Data, by Fiscal Year

Item	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	2/14/07
Reliability data										
MTBEFF				47	121	333	364			
OPTEMPO and usage data										
Hours					13,457,826	19,812,095	27,291,628	32,693,957	40,626,794	74,662,000
Number of units					5,047	7,430	10,235	12,261	15,236	28,000
R&M investment data (FY03 BY $ thousands)										
R&M	$0	$3,048	$0	$29,600	$17,607	$18,295	$18,838			
Cumulative		$3,048	$3,048	$32.647	$50,255	$68,550	$87,388			

Table C-5B. Force XXI Battle Command, Brigade-and-Below System: Support Process Data

Item	MTBEFF (hours)	Fail rate (per hour)	Percentage of failures	MUC ($K)	Weight (lbs)	MTTR (Lvl 1)	RTOK	MTTR (Lvl 2)	Cost per repair ($K)
System	364.0	0.00275	100%	$38.7	26.1	< 0.5			
Subsystems									
Hardware	1,091.0	0.00092	33.4%	$6.8	26.1				
Processor unit	3,636.7	0.00027	30.0%	$4.22		0.5	17%	7.7	$1.382
Removable hard disk drive	3,306.1	0.00030	33.0%	$0.23		0.5	9%	NA	NA
Keyboard unit	9,091.7	0.00011	12.0%	$0.52		0.5	0%	0.5	$0.100
Display unit	4,364.0	0.00023	25.0%	$1.83		0.5	13%	4.9	$0.427
Software	546.0	0.00183	66.7%	$31.9					
GFE communications	149.0	0.00671							

Appendix D
CASA Summary-Level Input Data

This appendix contains a table (Table D-1) showing the summary-level data used as inputs in our CASA model. We used the model to analyze support costs for five of our six case studies. LMI did not analyze support costs for the CH-47F ICH because, to date, only five CH-47F aircraft have been produced and these systems are still in test. Moreover, a support process for in-service CH-47F aircraft has not been instituted, and data such as component unit costs, component weights, and repair cycle times are not yet available.

Appendix E
Abbreviations

ACTD	advanced concept technology demonstration
APUC	average production unit cost
BFT	Blue Force Tracker
C2	command and control
CASA	Cost Analysis Strategy Assessment
DARPA	Defense Advanced Research Projects Agency
DOT&E	Director of Operational Test and Evaluation
DT	developmental test
EMD	engineering and manufacturing development
EO	electro-optics
EOA	early operational assessment
FBCB2	Force XXI Battle Command, Brigade-and-Below
FDSC	Failure Definition Scoring Criteria
GFE	government-furnished equipment
GPS	global positioning system
ICH	Improved Cargo Helicopter
IOC	initial operational capability
IOT&E	initial operational test and evaluation
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
LCC	life-cycle cost
LRIP	low-rate initial production
LRU	line replaceable unit
MCMT	mean corrective maintenance time
MFHBR	mean flying hours between removal
MRT	mean repair time
MTBCF	mean time between critical failure
MTBEFF	mean time between essential function failure

MTBEMA	mean time between essential maintenance action
MTBF	mean time between failure
MTBMA	mean time between mission abort
MTBMAF	mean time between mission affecting failure
MTBOMF	mean time between operational mission failure
MTBSF	mean time between system failure
MTTR	mean time to repair
MUC	manufacturing unit cost
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OPTEMPO	operational tempo
ORD	operational requirements document
OSD	Office of the Secretary of Defense
OT	operational test
OT&E	operational test and evaluation
PDAs	personal digital assistants
PM	program manager
R&M	reliability and maintainability
RDT&E	research, development, test, and evaluation
ROI	return on investment
RTOC	reduction in total ownership cost
RTOK	retest okay
SAR	synthetic aperture radar
SRU	shop repairable unit
TRADOC	U.S. Army Training and Doctrine Command
UAV	Unmanned Aerial Vehicle