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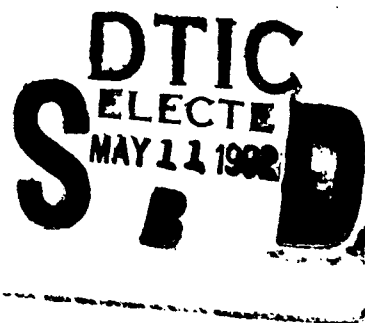
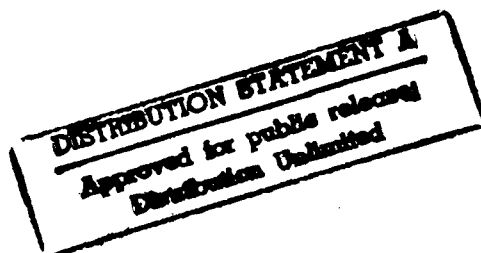


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Better Assessment of Operational Suitability

Volume II: Case Studies

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CHAPTER 1

INTRODUCTION AND SUMMARY

BACKGROUND AND OBJECTIVE

New weapon systems undergo an operational test and evaluation (OT&E) to determine their operational effectiveness and operational suitability before the Defense Acquisition Board makes a production decision regarding them. Operational suitability is the degree to which a system can be placed satisfactorily in field use, with consideration given to availability, reliability, maintainability, interoperability, compatibility, logistics supportability, transportability, documentation, manpower supportability, training requirements, wartime usage rates, safety, and human factors.

In all Military Services, the operational suitability of fielded systems often has been less than desired. In response to this situation, the Under Secretary of Defense (Acquisition) initiated an effort to build more suitable systems. As part of that effort, the Logistics Management Institute (LMI) was tasked by the Director, Operational Test and Evaluation (DOT&E), to study the treatment of operational suitability during OT&E.

We conducted the study in two phases. Phase I, which is documented in this volume, consists of case studies of seven weapon systems. For each case study, we compared the OT&E operational suitability results with field experience. In Phase II, we examined the causes of the differences between test results and field experience and investigated approaches for improving the assessment of operational suitability during OT&E.

In this chapter, we describe the study objective and our approach to assessing operational suitability testing. We also present a summary of our findings. In Chapters 2 through 8, we discuss the seven case studies. We summarize the salient acquisition history of each case, discuss how field experience compares with the OT&E results, and present detailed operational suitability aspects of the end items and logistic support elements.

APPROACH

We use seven cases – they are listed in Table 1-1 – to compare operational suitability results from OT&E with field experience. The cases, selected in consultation with DOT&E, are major systems that have gone through OT&E relatively recently and yet have sufficient field experience for suitability judgments to be made. They represent the Military Departments and each major tactical warfare area.

TABLE 1-1
WEAPON SYSTEMS FOR THE CASE STUDIES

Weapon system	Service
Mobile Subscriber Equipment (MSE)	Army
AH-64 Apache Attack Helicopter	Army
M939A2 5-Ton Truck	Army
Landing Craft Air Cushion (LCAC)	Navy
AV-8B Harrier II	Navy/Marine Corps
LANTIRN NAV Pod	Air Force
F-16 Block 40	Air Force

For each case study, we collected data on the scope and results of operational testing and on the suitability characteristics of the fielded systems. The operational test data were collected from DOT&E and from the operational testing agencies (OTAs) in the Services; the field data came from a variety of sources, including program offices, operational command headquarters, operational units, and contractors.

PHASE I FINDINGS

Introduction

A weapon system is a combination of the equipment directly involved in performing a combat mission – referred to as the “end item” – and its accompanying logistic support elements. The wartime capability and peacetime costs of a weapon system depend both on the end items and on the support elements. Similarly, the

operational suitability of a weapon system depends on the suitability both of the end item and of the support elements.

Some suitability elements are primarily associated with the inherent design characteristics of the end items. Examples include reliability, maintainability, interoperability, compatibility, and human factors. Other suitability elements, such as support equipment, supply support, and technical documentation, are primarily associated with providing logistic support to the end item. We use this categorization to discuss the case study findings. In addition, we present findings on several topics of special interest.

End-Item Suitability Findings

The findings in this subsection relate to the end items' inherent characteristics, which depend on the design and production of the equipment.

We found that OT&E identified numerous suitability problems with end items in the seven cases studied. Most of the problems were reliability and maintainability deficiencies associated with specific subsystems. In five cases, OT&E found the significant end-item suitability problems. Some examples are reliability of several avionics units in the F-16 Block 40, MSE software reliability, reliability of the M939's central tire-inflation system, reliability and maintainability of the AV-8B's communication system, and LANTIRN NAV pod reliability. Some of the end-item problems were fixed prior to full-rate production, and some were addressed after initial fielding. In one case (LCAC), the end-item suitability problems were sufficiently severe to delay full-rate production.

While OT&E identified most end-item reliability problems, it did not accurately predict the failure rates of all components. We found components with field failure rates that differ greatly from OT&E predictions. Because these components are only small contributors to the end-item failure rate, these discrepancies did not cause major errors in predictions of overall reliability.

In two cases, OT&E failed to identify several major end-item problems that later appeared in the field. Those problems are reliability and maintainability for the AH-64 (e.g., debonding of composite materials in the main rotor blades, failure of the shaft-driven compressor, inaccuracy of the fault-detection system), and unanticipated corrosion and structural fatigue of several bulkheads on the LCAC. A

frequent characteristic of the unidentified reliability problems is their association with cumulative effects. Cumulative effects also caused problems in other cases that were not detected in OT&E, such as heat shield wearout on the AV-8B.

We found that all of the suitability problems identified by OT&E as significant were true problems. No significant "false alarms" were sounded.

Support Element Suitability Findings

The findings in this subsection relate to the logistic support elements, such as test equipment, training, spares support, and documentation. We include resources that are peculiar to the end item and those that are part of the logistics infrastructure.

In five cases, OT&E failed to identify significant suitability problems associated with the support elements. The two cases in which all major support element problems were known in OT&E were modifications of earlier systems (M939A2 and F-16 Block 40).

Most of the major support element problems not identified by OT&E are associated with the test limitations of unavailable or immature support system elements. For example, in three cases that make extensive use of advanced electronics, support equipment (e.g., fault diagnostic and test equipment, test program sets) was not available for OT&E. Support equipment is a major field problem in one of these cases (AH-64) and a minor problem in two others (LANTIRN and F-16 Block 40). The LCAC operational test, for another example, used experienced operating crews and therefore failed to identify significant skill-level and training requirements. The OTA reports often cited the support element deficiencies as test limitations. In only one case (LANTIRN) did the OTA report include some assessment of the support elements that were not tested. Other observed examples of test limitations are the supply system, training, and technical documentation.

When support elements were included in operational tests, OT&E provided reasonable assessments of their suitability. However, we found many instances in which support elements were less than fully represented in the tests. These shortfalls represent risks of procuring systems with support element problems, which we observed in several cases.

Special Topics

Modeling and Analysis

Modeling and analysis has been proposed as a means of improving the assessments of operational suitability in OT&E. In two cases (LANTIRN and F-16 Block 40), modeling and analysis were explicitly used to project reliability growth (using test results and additional assumptions) and to assess system availability. Those efforts were performed to obtain insights that were beyond the scope of the tests.

Current field results show that LANTIRN and F-16 Block 40 meet or exceed the projected reliability values (although the accuracy of predictions for individual components varies widely). We did not find sufficient data to compare the actual reliability growth rates with the projected behavior. We noted that several other cases used the concept of reliability growth by selecting test thresholds lower than the desired mature values.

Test Limitations

Concerns exist about the impact of test limitations on judgments of operational suitability. The major suitability limitations to operational tests were use of pre-production equipment configurations, exposure to a limited range of possible operating environments, and nonavailability and/or immaturity of logistic support elements (e.g., lack of support equipment, use of contractors for maintenance support, use of nonrepresentative crews).

The impacts of these limitations on the accuracy of OT&E varied. Our case studies found no instances in which either the use of pre-production equipment configurations or limitations in the OT operating environment resulted in failures to identify significant suitability problems.

In contrast, the shortfalls in tests of the support elements are correlated with the existence of suitability problems in the field.

Point Estimates

In OT&E, most quantitative suitability measures are reported as point estimates. The ranges of observed values are rarely reported. For instance, in the AV-8B OT, direct maintenance man-hours per flight hour ranged from 11.9 to

19.7, and three out of four test aircraft did not meet the goal of 18 man-hours, but the suitability rating used only the average of 17.1 man-hours. In other words, the OTA reports did not indicate the uncertainties associated with their evaluations of operational suitability.

CHAPTER 2

MOBILE SUBSCRIBER EQUIPMENT

INTRODUCTION

System Description

The Operational and Organizational Plan for the Mobile Subscriber Equipment (MSE) system was approved on 6 October 1981 to "...replace the existing (circa 1950s) switched communications system at separate brigade and division, with a system which will provide rapid emplacement, flexibility, reliability, electronic survivability, and security for voice, data, and record traffic." MSE allows fixed base wire subscribers (such as command posts), and Mobile Subscriber Radiotelephone Terminal (MSRT) to (1) access each other within division and corps boundaries, (2) communicate across corps boundaries and to echelons above corps, (3) interface with NATO and Combat Net Radios (CNR) on a secure basis, (4) interface with commercial telephone systems in the United States and in NATO countries, (5) and interface with commercial and tactical satellites in the event of interruption of local MSE wire and area radio network linkage.

A corps-level MSE system covers an area of approximately 37,500 square kilometers and provides digital network capability for up to 8,200 wire (static) subscribers and 1,900 radio (mobile) subscribers. The network backbone consists of 42 node center switches (NCSs) distributed throughout the corps area and interconnected by line-of-sight (LOS) multichannel UHF radios. Each node is connected to at least 3 other nodes in a grid-like pattern. The nodes are the access points for wire and radio subscribers from other extension nodes [Large Extension Node (LEN), Small Extension Node (SEN), and Radio Access Unit (RAU)] and from systems outside the corps.

The MSE subscribers are assigned discrete directory addresses and are accessed on a flood search basis, with various conferencing, dialing, and essential-user bypass features. A System Control Center (SCC) provides automated traffic management, cellular-radio-like handoff around non-functioning nodes, and a number of path profiling and frequency assignment functions. As is the case with most modern

telecommunications systems, MSE features and performance can be upgraded and enhanced by means of software changes.

Acquisition History

The MSE procurement in December 1985 was a unique fixed-price Non-Developmental Item (NDI) award subject to a guaranteed performance and servicing agreement to ultimately serve 5 corps, 28 divisions, and 16 separate brigades in the Active Army and the National Guard. The MSE procurement philosophy was to (1) purchase a fixed price field communications system consisting of as much "off-the-shelf" equipment as possible, subject to call completion performance figures and available options quoted by bidders; (2) demonstrate hardware and software to meet Army requirements and to interface with other military and/or civilian communication systems; and (3) include a full system of support – in other words, a total system buy. Effectiveness and suitability issues were intermingled into a few criteria related to the Call Completion Rate (CCR).

The initial production buy plus option year 1 was exercised at contract signing on 19 December 1985. Following an Army Operational Test and Evaluation Agency (OTEA) produced Independent Operational Assessment, the option year 2 procurement was exercised in February 1987.

- The Follow-on Operational Test and Evaluation (FOT&E) was conducted 9 August to 25 October 1988.

Although declared operationally effective and suitable by OTEA, a Corrective Action Plan (CAP) was instituted on 5 December 1988 to correct performance deficiencies encountered in FOT&E. The option year 3 procurement was exercised on 8 December 1988. An OTEA assessment of the CAP supported the exercise of the option year 4 procurement in March 1989.

- A Follow-on Evaluation [FOE(Div)] was conducted 16 January to 9 March 1990 to assess improvements resulting from the CAP.

The FOE(Div) plus a Field Verification Test supported the exercise of the option year 5 procurement on 20 March 1990. The incorporation of upgrades and enhancements has resulted in partial deliveries subdivided into option years 3.5, 4.5, and 5.5.

The MSE was not subjected to an independent Developmental Testing (DT) program, and did not pass through the Milestone II/III initial production and full-rate production gates. The CAP, the FOE, and the resulting successful upgrades and planned enhancements practically place OT&E as part of the development process.

System Status

As of mid-May 1991, approximately 100 node centers and supporting MSE equipment had been delivered (out of about 218 NCSs for the notional 5 corps procurement). The corps level testing [FOE(Corps)], which was interrupted by Southwest Asia (SWA) theater actions, is being rescheduled for Fort Hood in the Fall of 1992, although at MSE deployment levels considerably below notional corps strength [42 NCSs as opposed to 20 for FOE(Corps)]. A number of system upgrades and enhancements have been identified and scheduled for retrofit.

OVERALL SUITABILITY

During FOT&E, MSE was judged operationally suitable by DOT&E for its level of maturity. Since then, MSE has materially benefited from the ongoing CAP, which resulted in major software reliability improvements and a major expansion of the training program. These improvements were demonstrated during FOE(Div). MSE has largely met its three Critical Operational Issues – performance, restoration after outage, and interoperability – subject to continued block improvements and corps-level testing during the upcoming FOE (Corps). The Training and Doctrine Command (TRADOC), OTEA, and DOT&E support issues have been substantially addressed in testing and continuing CAP actions.

The MSE has proved operationally suitable in the field. Field Service Reports covering October 1990 through March 1991, and interviews with the contractor and with Army personnel concerning SWA experience, indicate that overall field suitability has been consistent with OT&E results.

END-ITEM SUITABILITY ISSUES

Reliability

The MSE acquisition documents contained no quantitative reliability, availability, and maintainability (RAM) criteria at the component or assemblage level: "The assemblages should demonstrate RAM characteristics sufficient to meet

the user's design goal of a 1st attempt 90-percent Call Completion Rate (CCR) with a 20-percent off-hook factor." However, contractor estimates of assemblage mean time between failures (MTBF) were provided and are compared below with mean time between operational mission failures (MTBOMF) derived from the FOT&E and FOE(Div). With the marginal exceptions of the LEN and LOS(V1), the operational assemblage availabilities observed in FOE(Div) exceed Contractor estimates (see Table 2-1).

TABLE 2-1
MSE RELIABILITY

Assemblage type	Contractor-estimated MTBF (hours)	FOT&E MTBOMF (hours) ^a	FOE(Div) MTBOMF (hours) ^b
NCS	80	76	141
LEN	65	27	56
SEN(V1)	161	258	320
SEN(V2)	161	401	460
RAU	85	547	759
LOS(V1)	250	128	234
LOS(V3)	198	728	489
LOS(V4)	247	638	354

^a FOT&E record hours = 250.

^b FOE(Div) record hours = 56.

Specific reliability problems encountered in FOE(Div), which had been included in the ongoing CAP and Block Improvement Program, are listed below. These problems have shown up in the field during the period covered by the Sample Data Collection (SDC) and SWA theater activities, indicating that OT&E was a good indicator of these reliability problems. The problems are as follows:

- MSE unique (approximately half of MSE equipment)
 - ▶ SCC software overload crashes (SCC2 appears adequate)
 - ▶ Communications security (COMSEC) key distribution time-consuming and complex
 - ▶ Essential User Bypass (EUB) switch crashes

- ▶ LOS radio transmitter sidewall failures
- ▶ MSRT mount failures in High-Mobility Multi-Wheeled Vehicles (HMMWVs)
- Non-MSE unique (approximately half of MSE equipment)
 - ▶ Antenna coaxial cable and connectors breakage
 - ▶ Antenna guy winder breakage
 - ▶ NCS and LEN problems on vehicle alternator backup power
 - ▶ SEN Type VII circuit card assemblies (CCAs) (common item) exhibit high failure rate.

Fixes to most of these problems are in process. For example, the MSRT mount failures are undergoing a second fix, which is thus far successful. Workarounds were developed during the SWA campaign for several of the problems. For example, COMSEC key distribution problems were overcome by not changing the key frequently. A more definitive fix is in process involving software modifications and revised key management procedures.

Some problems encountered in SWA were *not* encountered in OT&E. Two of these are rapid dust accumulation in CCA slots and the failures of aging generators. The generator problem became significant. It is interesting as an example of a problem that stems from a cumulative effect and that is difficult to observe in OT&E if the test is limited to using new equipment. In fact, most of the breakdowns occurred after 7,000 hours of operation, when the generators were originally scheduled to be overhauled (the overhaul interval was lengthened prior to deployment).

No computed RAM data are available yet from SWA, but anecdotal information from contractor field representatives indicates the following:

- Under initial (static) deployment, MSE operated 24 hours/day, 7 days/week with no mission-essential problems; average traffic equaled about 1000 calls/day.
- Early Command Post Exercise (CPX) activity exhibited field performance similar to that experienced at Fort Hood, with traffic between 20,000 to 40,000/day.
- Operation Desert Storm force deployments of MSE moved with armored forces, achieving a peak of 200,000 calls/day, with few switch crashes

(mostly attributed to unknown software anomalies or operator error, such as uncleared fault registers, etc.).

- “Imaginative” in-the-field improvisations helped:
 - ▶ MRST access antennas were bolted to the sides of the transporting HMMWVs to eliminate setup time.
 - ▶ NCSs were transported in the “power-up” mode at armored brigade speeds and were initialized at setup – a savings of 50 out of 60 minutes setup time. No crashes recorded, even though use of the technique became widespread.
 - ▶ Headquarters greatly reduced the frequency of key changes for COMSEC operation.
- SWA MSE equipment was drawn in from a variety of sources: Fort Hood, Germany, and GTE equipment not yet delivered. The equipment included four different software and retrofit versions, all of which were made to talk with each other.
- About half of the SWA units had MSE equipment, while the other half had the old equipment. They were mostly made to talk to each other, although with frequency, data base, and precedence override problems.

These observations portray a system that is operationally suitable.

Availability

Contractor estimates of assemblage operational availabilities (A_{os}) are compared with derived A_{os} from FOT&E, FOE(Div), and SDC for the period 16 March to 30 November 1990 in Table 2-2. The contractor estimates were generally exceeded.

Maintainability

Contractor estimates of assemblage repair times, which are consistent with Army practice for operator-level fault identification and repair, are compared with derived FOT&E and FOE(Div) data in Table 2-3. The CAP has generally produced substantial reductions in mean time to repair (MTTR) between FOT&E and FOE(Div), and the OT&E repair times are assemblage related – unlike the contractor-estimated standard times, which are constant at 30 minutes. The estimated times are not good indicators of current MTTR experience and are probably not indicative of mature MTTR values.

TABLE 2-2

ASSEMBLAGE OPERATIONAL AVAILABILITY (A_o)

Assemblage type	Contractor-estimated	FOT&E	FOE(Div)	SDC
NCS	.87	.97	.99	.93
LEN	.87	.92	.92	.95
SEN(V1)	.89	.98	.94	.95
SEN(V2)	.89	.99	1.00	
RAU	.89	.98	1.00	.91
LOS(V1)	.95	.97	.99	.93
LOS(V3)	.95	.99	1.00	
LOS(V4)	.95	.99	1.00	

TABLE 2-3

MEAN TIME TO REPAIR (MTTR)

Assemblage type	Contractor-estimated MTTR (minutes)	FOT&E MTTR (minutes)	FOE(Div) MTTR (minutes)
NCS	30	93	56
LEN	30	149	111
SEN(V1)	30	106	111
SEN(V2)	30	106	111
RAU	30	188	77
LOS(V1)	30	150	57
LOS(V3)	30	60	57
LOS(V4)	30	157	68

SUPPORT SYSTEM SUITABILITY ISSUES

Logistics Supportability

The MSE logistics support concept was judged adequate from the FOT&E; however, the forward support concept was not used in FOT&E or FOE(Div) (all of the assemblage spares were centrally held in one motor pool rather than co-located with

the assemblages) and was not reflected in the CAP. The use of built in test/built in test equipment (BIT/BITE) was judged acceptable 76 percent of the time during FOT&E (acceptable performance is judged by the subject components "...not being inappropriately evacuated to the next higher level of maintenance more than 25 percent of the time."); FOE(Div) BIT/BITE performance was acceptable 95 percent of the time.

Preliminary after-action review reports from SWA state that adequate logistics supportability in the field requires a reexamination of how an MSE area signal battalion sustains itself in battle. The actual use of MSE in combat differed substantially from that originally envisioned: MSE was deployed linearly along the path of the advance over a narrow front rather than as a grid. In addition, the Regional Support Center (RSC) was moved to a divisional location to be closer to the operators (this move was soundly endorsed by all of the Signals Battalions in SWA).

The location ("logistics release points") of the RSC, stockage of essential items and provisioning of field risk kits for NCSs, SENs, and RAUs are among the issues to be reconsidered.

Interoperability

CNR users were able to interface with MSE units during FOT&E. The interface with commercial networks was judged satisfactory, but the division-level tests did not permit evaluation of interoperability with adjacent U.S. forces. The functionality of interoperability with equipment from echelons above corps and NATO forces was validated, but not operationally tested. Anecdotal data from the SWA theater indicate that the MSE network from one corps accessed overseas telephone networks via an earth station trailer brought in to the theater and interfaced with Marine divisional headquarters and with adjacent non-MSE Army units.

Mobility and Transportability

Prior to FOT&E, the Military Traffic Management Command (MTMC) certified transportability of the MSE-sheltered systems to be suitable, but no attempt was made to evaluate airborne transportability with C-130 and C-141 aircraft during FOT&E. During FOT&E, the MSE system was found to meet operational mobility requirements. System transportability to the SWA theater was reported to have been effective by air and by sea.

Compatibility

During FOT&E, MSRT users were capable of operating with shared frequency bands. During the SWA theater actions, old signals communications systems were successfully interfaced with MSE systems, and MSE systems with several different software and hardware retrofit versions were able to communicate with each other.

Training

Because of operator problems encountered prior to and during FOT&E, the "Train the Trainers" plan was abandoned. An expanded all-operators classroom, hands-on and periodic sustainment training curriculum was instituted. The current program is considered adequate, with an emphasis on continued assemblage operation. Contractor technical representatives in SWA provided substantial ongoing refresher activities for MSE users.

Documentation

Because of the form of the MSE acquisition, MSE users have limited access to system software documentation and source code, and to schematics for off-the-shelf equipment such as the MSRT radios. As long as the contractor retains contractual liability for the maintenance, upgrading and enhancement of software, and demonstrates incremental performance improvements at the Beta test site(s), this situation is acceptable. However, if the Army opts to assume responsibility for MSE software, then lack of ongoing familiarity with design and maintenance of the software system could become a problem.

The lack of LOS radio schematics is a maintenance problem since it denies the use of conventional oscilloscope trouble shooting and forces the operator to use the USM626 circuit tester, which was reported by the Communications and Electronics Command (CECOM) Logistics Area Rep (LAR) to be slow and unreliable during SWA operations.

Safety

The FOT&E found all equipment and assemblages safe to operate and maintain.

Human Factors

The FOT&E found system operation and maintenance by representative users to be efficient and acceptable. However, a number of Criticality 1 issues (shortcomings that have an impact on the successful and/or safe operation of systems or components) were found; they are listed below:

- The SCC management shelter is too small to accommodate operators and system planners.
- Antenna coaxial connectors are difficult to install at the entry panel.
- Repeated use of the antenna guy winders causes fraying of the nylon ropes.
- HMMWV tailgate chains are too light to sustain operator weight.
- Short power cables result in generator noise interfering with audible switching operations.
- Mispositioning of the DC power switch causes frequent accidental equipment turn offs.
- The SCC visual display unit locks up with certain teletype characters from the node centers.
- Many SCC-related software problems are aggravated by complex key combination requirements.

Some of these issues were found still to be a problem during SDC and during SWA operations, but are being addressed through the CAP and the Block Improvement Program.

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CHAPTER 3

AH-64 APACHE ATTACK HELICOPTER

INTRODUCTION

The purpose of this chapter is to review the treatment of operational suitability during the development and fielding of the AH-64 Apache attack helicopter. Using the components of operational suitability as a basis, we compare the results found during OT&E with the operational suitability experienced in the field.

We begin with a detailed description of the Apache system. We then summarize the acquisition and development history and provide the current status and number of systems fielded and deployed.

After an overview of the system's operational suitability, we describe in detail the AH-64 end-item and system support issues related to operational suitability. We report data from OT&E and field experience and compare the results.

We conclude with a summary of our findings.

System Description

The AH-64 Apache attack helicopter, manufactured by McDonnell Douglas Helicopter Company (Hughes Helicopter Incorporated, awarded the original contract, was purchased by McDonnell Douglas in 1984), is a two-place, tandem-seat, twin-engine helicopter.

The helicopter is powered by two 1,560-shaft-horsepower General Electric T700-GE-700 turboshaft engines. Both main and antitorque rotors are four-bladed. The main rotor, 48 feet in diameter, is fully articulated with elastomeric lead-lag dampers. The rotors incorporate a 9-degree twist and operate at a tip speed of 726 feet per second. The antitorque rotor is 9.2 feet in diameter. Blades are mounted in teetering hubs and are separated at a 55-degree angle (as opposed to 90 degrees), for noise reduction. A stabilator is mounted below the tail rotor.

Two flight control systems are employed: an automatic wing flap control and redundant fly-by-wire backup control system. Armament is composed of a 30 mm lightweight (chain gun) weapon mounted in a flexible turret on the underside of the forward fuselage, a 2.75-inch rocket system, and the Hellfire Modular Missile System, mounted on the wing stations.

Fire control systems include the target acquisition designation sight (TADS), the pilot night vision sensor (PNVS), two integrated helmet and display sight subsystems (IHADSS), an air data system, a fire control computer, and necessary controls and displays needed to fire the weapons. Armament and fire control subsystems are operated on a multiplex data bus subsystem for improved reliability and redundancy as well as reduced weight.

The avionics suite contains a lightweight Doppler navigation system, an identification friend-or-foe transponder system, and a standard set of communication and secure voice equipment.

A fault detection/location system (FD/LS) provides a means for testing subsystems and isolating faults to the line replaceable unit (LRU) level.

The primary mission payload for the AH-64 is eight Hellfire missiles and 320 rounds of 30 mm ammunition.

The Apache is designed to survive to the impact of 23 mm rounds on the aircraft basic structure and the main rotor blades. Transparent armor is placed between the pilot and copilot to prevent incapacitation of both from a single 23 mm fragmentation round. Aircraft flight controls are made redundant and located so that no single 12.7 mm round can destroy both primary and secondary systems. The main transmission and gear boxes have a 30-minute run-dry capability.

Survivability features include integral hot metal plus exhaust plume suppression to counter infrared missile threats. In addition, the aircraft has crashworthy fuel cells, foam in the fuel cavity, fire-resistant hydraulic fluid, and crashworthy crew seats.

Six AH-64 aircraft can be transported in a C-5A aircraft, and two can be transported in a C-141B.

Acquisition History

In January 1972, the Army convened a task force to conduct an independent study of the operational requirements for an attack helicopter. In its report, presented to the Secretary of the Army and the Army Staff in August 1972, the task force identified a need for an aircraft more agile, smaller, and less complex than the Cheyenne helicopter. Army leadership endorsed the task force's recommendations, approved the start of a new development program for an advanced attack helicopter (AAH), and terminated the AH-56 Cheyenne development program.

The AAH acquisition strategy was based on the "fly-before-buy" concept. A competitive development phase culminated in a comparative evaluation and selection of the best prototype airframe. Mission equipment was developed and integrated into the winning airframe during a full-scale engineering development phase. Production followed full-scale development. The turbine engines were Government-furnished equipment (T-700 engines) acquired under a separate contract with the General Electric Company.

The Defense Systems Acquisition Review Council (DSARC) I program review for the AAH took place on September 1972. Authority to release requests for proposals was granted. Acquisition and operating costs were prime considerations in the competition. An initial production buy of 472 aircraft was set. Five helicopter contractors responded to the request for proposals.

On 22 June 1973, the Army awarded Phase I competitive development contracts to the Bell Helicopter Company and to Hughes Helicopter Incorporated to design, fabricate, and test two prototype air vehicles and one ground test vehicle within 36 months. The Hughes contract also included development of the XM-230 chain gun, which had been selected by the Army as the AAH's 30 mm area weapon subsystem. Both contractors completed their initial development and ground test vehicle qualification test programs in mid-1975; the first prototype flights followed on 30 September 1975 (Hughes YAH-64) and 1 October 1975 (Bell YAH-63). Each contractor also completed approximately 300 hours of flight testing before delivering two test flight vehicles for Government testing on 31 May 1976.

Government testing consisted of a combined development test (DT) and operational test (OT) in July, August, and September 1976. DT was conducted by the Army Engineering Flight Activity, while OT was run by the Army's Operational Test

and Evaluation Agency (OTEA) during September. Edwards AFB, California, was the site of the testing. The Hughes YAH-64 was judged superior in the technical and operational military areas. It met or exceeded stated requirements in all areas and exhibited better flight performance and handling qualities than did the YAH-63.

On 10 December 1976, Hughes was awarded a \$317.6 million cost-plus-incentive-fee contract for full-scale engineering development. The 6-year contract (later accelerated to 56 months in response to an increase in FY78 funds appropriated by Congress, in excess of budget requests) covered modifications of the three Phase I prototypes, fabrication of three additional aircraft, development and integration of subsystems, testing of the total weapon system, and producibility engineering planning. The contract included a maximum award fee of \$8.8 million (3 percent of the airframe development portion of the contract) to provide incentive for the contractor to achieve the revised design-to-unit-production cost goal. This goal was based on an increased planned procurement of 536 aircraft, with deliveries from 1983 through 1990.

Earlier in 1976 several events significantly affecting the AAH program had occurred. First, in February 1976, the DSARC II approved the Army's request to use the Hellfire missile system in lieu of the TOW missile system as the AAH's primary antiarmor weapon. According to the General Accounting Office (GAO), this change added \$67.2 million to development cost for airframe integration, extended the schedule by 6 months, and added 400 pounds to the aircraft. The additional Hellfire system weight made it necessary to reduce the 30 mm ammunition payload from 800 to 500 rounds to meet performance requirements [1]. The Army awarded the full-scale engineering development contract for the Hellfire system to Rockwell International in October 1976.

Also, in March 1976, a separate AAH DSARC review directed that TADS/PNVs be developed competitively instead of sole source as originally planned. The TADS/PNVs is the subsystem that gives the AH-64 its unique attack capabilities in adverse weather and is probably the most complex system in the aircraft. In hearings on the AAH program, the Senate Armed Services Committee had also encouraged competitive development. The GAO estimated that this decision increased program development costs by \$196 million and extended the schedule by 3 months [1]. Seven contractors responded to the Army's request for proposals on TADS/PNVs. Martin Marietta and Northrop were selected for competitive development. Martin Marietta

was ultimately awarded a production contract in April 1982, with items to be delivered as Government-furnished equipment to Hughes for incorporation on the AH-64 production line.

The last development involved Congressional concern with NATO standardization and interoperability. On 29 September 1976, the Secretary of Defense directed the AAH program manager to develop a new class of 30 mm ammunition that would be interoperable with the British Armament Development Enfield and French Direction d'Etudes et Fabrication d'Armement guns of the same caliber. Accordingly, in March 1977, Hughes let a sole-source subcontract to Honeywell for development of interoperable ammunition. The XM-789 round that was developed performs well against light armored vehicles but is heavier than the original round. This added weight further reduced 30 mm ammunition payload from 500 to 320 rounds [1].

In the full-scale engineering development phase, Hughes developed and tested airframe design modifications to correct deficiencies noted in DT I/OT I, to improve flight handling characteristics, and to confirm the airworthiness of the modified design. The contractor also developed a mission systems simulator in support of system integration, embedded computer software verification, and mission equipment in flight test aircraft. Finally, three new prototypes were fabricated to production configuration for Government test and evaluation.

The major airframe shortcomings noted during full-scale engineering development included tail rotor horsepower limitations, restricted field of view, vibrations, and canopy "drumming" (vibrations of the flat canopy window plates, linked to the frequency of the main rotor system). After a series of three modifications, most of the airframe shortcomings were corrected, although the pilot's field-of-view restriction continued to be recognized as a problem.

The Army decided in late 1980 to upgrade the General Electric T700 engine to the T700-GE-T701. This improved engine was needed to offset increased aircraft weight and to meet performance requirements.

A physical teardown-logistic demonstration (PT-LD), intended to evaluate design maintainability and validate the YAH-64 system support package before OT II, took place from January through April 1981. This was an extensive effort involving removal and replacement of all LRUs in the aircraft and those other

maintenance tasks judged to have safety implications or to cause significant maintenance man-hour burdens. A total of 988 maintenance tasks were accomplished by 91 Army personnel who expended 15,000 man-hours in 61 working days. The PT-LD evaluators concluded that the YAH-64 system support package was adequate and that there were no major deficiencies in equipment design related to maintainability.

In retrospect, the PT-LD, although a creditable effort, was limited by the fact that fault diagnostics and troubleshooting were specifically excluded. First, because flying prototype aircraft were available for only 1 week of the demonstration, most of the maintenance tasks were conducted on the ground test vehicle and training equipment. Second, since two major items of ground support equipment – the automatic test equipment (ATE) and the pylon test stand – were not available for the PT-LD, the demonstration did not examine any YAH-64 test program sets (TPSs) or the maintainability of the ATE itself. Third, on-aircraft troubleshooting was not included. Finally, FD/LS was operated through all the programs in the "GO" path only. In other words, the only test performed was to determine whether FD/LS would indicate that operational components were, in fact, operational. No faults were introduced, and no attempt was made to test the ability to indicate failed components correctly. FD/LS is the on-board fully automatic built-in-test (BIT) equipment for AH-64 avionics and mission equipment. To evaluate FD/LS properly, both the "GO" and "NO-GO" paths should be tested.

OT II was conducted mostly at Fort Hunter Liggett, California, under the auspices of the Training and Doctrine Command (TRADOC) Combat Development Experimentation Command, in 1981. We provide a complete description of the testing procedure and results in a later section.

As OT II was being performed, other Government DTs were conducted, including TADS/PNVS countermeasure (CM) testing by the Office of Missile Electronic Warfare and the Joint Test and Evaluation Directorate. This CM testing included analysis of electromagnetic countermeasures, electro-optical counter measures, and special electromagnetic interference.

DSARC III took place on 3 December 1981. Three alternatives were considered: (1) entering production at a rate that minimizes unit cost, (2) entering production at a most likely affordable rate, or (3) terminating the program.

The production decision was deferred until March 1982 because the program had become controversial; acquisition cost had escalated, causing the Army to reduce the planned initial procurement from 536 aircraft to 446; the Army was involved in difficult negotiations with Hughes from November through March on the FY82 program; and Congress was divided (the Senate Armed Services Committee voted to defer production 1 year, while the House Armed Services Committee voted in favor of starting production and for restoring initial production to 536 helicopters). Ultimately, the production contracts were awarded on 15 April 1982.

System Status

The Army has established a requirement for 1,031 AH-64 Apaches. This figure is based on the force structure for active, reserve, and National Guard units. The number of aircraft that will actually be funded will, of course, depend on AH-64 affordability and the needs of other programs. As of July 1991, the Army plans to buy 807 Apaches. Through April 1990, 675 aircraft were under contract; over 600 had been delivered; and funds for the remaining 132 aircraft had been appropriated.

During the recent Desert Shield/Desert Storm operations, 275 Apaches were deployed to Saudi Arabia; they played a significant role in the action.

A plan is in place to convert about 227 AH-64s to "Longbow" Apaches. This program, begun in 1989 at a cost of \$3.4 billion, involves placing a targeting radar above the rotor mast and replacing the Hellfire's laser seeker with a radar seeker. Other changes will be made to the airframe to accommodate the Longbow modifications and associated avionics, such as an enlarged avionics bay with an enhanced cooling system, increased electrical power, and an advanced cockpit. A decision on the Longbow modifications is scheduled for October 1992.

Besides the Longbow program, the Army is planning to add the air-to-air Stinger missile system and an airborne target handover system. The Stinger will give the AH-64 a defensive air combat capability, and the target handover system will support the passing of target information between helicopters.

OVERALL SUITABILITY

Introduction

Since fielding, the AH-64 Apache has had a history of major operational suitability problems. The most serious are in the areas of reliability, availability, maintainability, and logistics supportability. While many suitability issues were identified during OT, many more severe difficulties involving the reliability of major components went undetected. The low observed reliability has, in turn, degraded availability, maintainability, and logistics supportability.

Reliability

Apache reliability was rated in OT as adequate, with the exception of TADS and the 30 mm chain gun, which were judged to be marginal.

In the field, the aircraft has had serious problems with major components such as the main and tail rotor systems, the shaft-driven compressor (the main component of the AH-64 cooling system), and TADS. These components have been failing far sooner than expected. For example, the main rotor blades have an average replacement interval of 164 flight hours, in contrast to an expected one of 1,500 hours.

The components with poor reliability performance have long repair times requiring high maintenance man-hours. It has also been difficult to supply replacement parts and components in a timely manner.

Availability

The AH-64 has often been unable to achieve the Army goal of a 75 percent mission capable (MC) rate [at least 70 percent fully MC (FMC) and no more than 5 percent partially MC (PMC)]. This has occurred even though, during OT, availability was judged adequate.

Many of the conditions present in OT may have led to an overly optimistic assessment of availability. First, actual flying hours were limited. Three test AH-64s flew a total of slightly more than 500 hours. Because flying hours were so low, a major phase maintenance inspection and service was not conducted. This maintenance action has been a major source of downtime in the field. Also,

contractor personnel participated in over half of all maintenance actions during testing.

Experts have suggested that, had the test aircraft been subjected to more flying hours under more strenuous conditions, some of the reliability problems with major components might have been detected. The unanticipated low reliability of these components has undermined availability.

Maintainability

The OT for the AH-64 was not able to assess maintainability accurately. While some of the maintainability problems that are plaguing the Apache in the field were noted (shortness and crimping of wires, for example), the reliability failures in essential components did not surface during testing. The impact of these failures could not be judged.

There have also been significant difficulties with the FD/LS. Inaccurate fault detection by FD/LS was recorded during OT but was not judged to be a serious problem. Today, FD/LS still has a 40 percent error rate in fault detection.

The FD/LS is designed to function with the electronic equipment test facility (EETF). During OT, the EETF was incomplete and could not be assessed. The impact of the fact that this set of test equipment was incomplete is discussed next.

Logistics Supportability

The cornerstone of the AH-64 maintenance concept is the interactive functioning of FD/LS and the EETF. But, because fewer than half of the 76 test program sets comprising the EETF were available for OT, in effect the concept could not be tested.

Performance and support from the EETF has been poor. This poor performance, combined with unexpected reliability failures in major components, has resulted in long repair turnaround times, inadequate inventories of spares, and low aircraft availability.

END-ITEM OPERATIONAL SUITABILITY ISSUES

Introduction

In this section, we discuss the results of the AH-64 AAH OT II and field experience for operational suitability components that relate to system design.

Our approach consists of listing the results for selected components of operational suitability as described in the AAH OT II report documents, discussing the results, and comparing them to the field experience. We also provide a brief overview of AAH OT II and the sources of data on field experience.

AAH OT II Overview

The AAH OT II was conducted in three phases. Phase I, training, took place at Castle Dome Heliport, Yuma Proving Grounds, Arizona and the Hughes Helicopter Facility at Culver City, California, from 1 January to 29 June 1981. The non-live-fire phase of the test, Phase II, was run during the period 15 July to 28 August 1981 at Fort Hunter Liggett, California; Fort Ord, California; and Vandenberg AFB, California. Phase III, live fire, consisted of two subtests conducted from 16 to 28 August 1981 in the Gabilan Valley, Fort Hunter Liggett.

An AH-64 test section and baseline section was formed for AAH OT II. The AH-64 test section was made up of three AH-64 aircraft and two AH-1G/R aircraft equipped with airborne target acquisition fire control systems. The AH-1G/Rs represented scout helicopters with laser designation capability compatible with the AH-64. The baseline section consisted of three AH-1S modernized Cobra and two OH-58C helicopters.

A total of 165 personnel were used as players in the test (36 aircraft crew members and 129 maintenance personnel). This total does not include observers, monitors, and test committee members.

Data generated by the test were reviewed by the AAH OT II Validation Committee prior to acceptance. The validation process was intended to ensure that the data were as accurate as possible, that tester-induced errors were corrected, and that the data were representative of actual results.

Field Experience Data Sources

We used several sources and types of information to assess the operational suitability field experience for the AH-64 Apache.

The Army Material Readiness Support Activity (MRSA) provided data in a wide variety of formats. In addition to equipment MC rates, we were provided records from the deficiency reporting system data base, regular and special reports of integrated logistic support lessons learned, national training center reports of equipment and logistics lessons learned, and logistics status reviews.

The Army Aviation Systems Command (AVSCOM) granted access to files that documented the organization and proceedings of the Apache Readiness Improvement Program (ARIP), previously called the Apache Action Team (AAT). AVSCOM also supported our review of general officer steering group meetings, safety of flight messages, and maintenance information messages pertaining to the AH-64. We also examined selected SDC monthly reports.

We interviewed representatives of the Army Operational Test and Evaluation Command (OPTEC) – formerly the Operational Test and Evaluation Agency (OTEA) – and staff members from the aviation logistics office in the Office of the Army Deputy Chief of Staff for Logistics to obtain a general understanding of AH-64 testing and fielding history. These offices also furnished copies of the in-process report of the Department of the Army-level special evaluation.

End-item Operational Suitability Results

General

On the basis of the results of OT II, OTEA concluded that no operational test and evaluation issues precluded acquisition and deployment of the AH-64. However, the reliability of TADS and the 30 mm chain gun along with the overall maintainability of the aircraft were judged to be marginal. Further, OTEA noted that intensive work should be expended to improve these marginal areas.

We provide more detailed information on the OT II results and conclusions in the following paragraphs.

Availability

Test Results. Operational availability for the AH-64 was measured in terms of mission capability, or the probability of the system's being available to accomplish its mission, if called, at a random point in time. Mission capability is defined so that not every component need be operational to perform a specified mission (for the AH-64 the mission is antiarmor). The test criterion was an operational availability of at least 0.75.

The mission capability formula includes four types of "available" time (fully operational, operating degraded, standby fully operational, and standby degraded) and an additional five categories of "not available" time. During the test, a total of 6,284.82 status hours were recorded and classified for the three Apaches in the test section. The results for the three test aircraft and totals are shown in Table 3-1.

TABLE 3-1
AH-64 AVAILABILITY DATA

Status	Aircraft			
	AV02	AV03	AV06	Combined
Fully operating	16.28	0.00	20.72	37.00
Operating degraded	138.00	181.93	156.98	476.91
Standby, fully operational	157.12	0.00	162.58	319.70
Standby, degraded	1,077.22	1,001.50	1,200.40	3,279.12
Down, unscheduled maint, inop	264.72	355.22	201.82	821.76
Down, unscheduled maint, op	3.95	0.42	0.17	4.54
Down, scheduled maint, inop	3.23	0.00	0.00	3.23
Down, scheduled maint, op	0.00	0.00	0.00	0.00
Down, admin/log delay	364.72	357.05	248.88	970.65
No-test	115.23	158.15	98.53	371.91
Total hours	2,140.47	2,054.27	1,090.08	6,284.82
Calculated mission capability	0.69	0.62	0.77	0.70

Notes: maint = maintenance; inop = inoperable; admin = administrative; and log = logistics.

An operational availability or mission capability (the ratio of operating and standby for both fully and degraded modes to the total time) of 0.70 was computed on

the basis of test results. This figure, although below the criterion threshold, was considered close enough to justify a rating of "adequate." OTEA also noted that one of the test aircraft (AV06) was configured differently (more closely to the envisioned production version) from the other two. The fact that the aircraft that more closely resembled the production version displayed an operational availability of 0.77 was considered further justification for the adequate rating.

Discussion of Results. The adequate rating for operational availability may have been overly optimistic. While it is reasonable to argue that, for a pre-production system, a .070 availability is close enough to 0.75 to consider the criterion met (given expected reliability growth, a maturing logistics support system, etc.), an equally convincing case can be made for rating availability "marginal" or "inadequate".

First, operational availability may have benefited from favorable test conditions. The operational availability formula is affected by the time that the aircraft is "down" for scheduled and unscheduled maintenance actions. During OT II, scheduled maintenance was virtually excluded. Two primary types of scheduled maintenance inspections are prescribed for the Apache: a preventive maintenance service inspection (to be performed every 10 flight hours or 14 days), and a much more intensive phase maintenance (to be performed every 250 flight hours). During testing, only 3.23 hours were devoted to scheduled maintenance for all three aircraft. Further, the phase maintenance inspection was not performed (none of the three test AH-64s were flown for 250 hours). Field experience has shown that it generally takes about 1 month to complete a phase maintenance inspection. The scheduled maintenance clearly would have added significantly to "down" time and lowered the computed availability. Also, contractor personnel participated in half of the maintenance actions performed. It is unclear how well contractor-provided maintenance personnel perform in relation to trained and experienced Army personnel. (Are personnel provided by the contractor for a test much more skilled, slightly more skilled, or approximately the same as Army personnel?) This uncertainty clouds the results.

Second, it is dangerous to draw conclusions from data generated by such a small number of aircraft. On the basis of the test data, we performed a simple statistical analysis to determine an interval for estimating the operational availability. We found that in order to be 95 percent confident that the estimated interval contained the true operational availability, it would have to range as low as 0.57 and as high as

0.81. Clearly 0.57 is not close enough to 0.75 to consider the criterion to have been met.

Field Experience. The field measures of availability are fully mission capable (FMC), partially mission capable (PMC), and nonmission capable (NMC). Army Regulation 700-138 sets forth the requirements and procedures for tracking these measures.

Mission capability is reported as a ratio of hours in the various categories to total hours. For example, if an aircraft is FMC for 12 hours of the 24-hour day, its FMC rate would be 50 percent (12 divided by 24). Any time spent in depot maintenance is excluded from the available hours, however. This means that an Apache that was fully mission capable 12 hours and spent four hours in depot maintenance would be reported as 60 percent FMC (12 divided by 20). Times in each of the three categories are recorded and totaled for each AH-64 in a unit, and mission capability rates are reported each month.

An Apache is considered FMC if it can perform all of its assigned missions. This means that the aircraft can fly and that TADS, PNVIS, IHADSS, the Hellfire missile system, the 30 mm gun, the 2.75-inch rockets, and aircraft survivability equipment are all operational. "Partially mission capable" means that an aircraft can fly and perform at least one, but not all, of its missions. When an AH-64 cannot be flown and cannot perform any of its missions, it is classified as NMC.

We obtained worldwide mission capability rates for the AH-64 for the period March 1990 through February 1991. The rates are based on 605 aircraft, of which 532 are assigned to units. FMC, PMC, and NMC rates are shown in Figure 3-1. We also include the sum of FMC and PMC rates as the overall MC rate.

The best overall mission capability achieved by the Apache fleet during the period of our data review was 81 percent. This figure included a 66 percent FMC rate and a 15 percent PMC rate. The highest FMC rate observed was 68 percent.

The Army has established a FMC goal of 70 percent and a PMC goal of no more than 5 percent. These goals were not achieved during the period covered by our review.

In a separate study, the GAO examined mission capability rates in 11 Apache combat battalions in the field during the period January 1989 through April 1990.

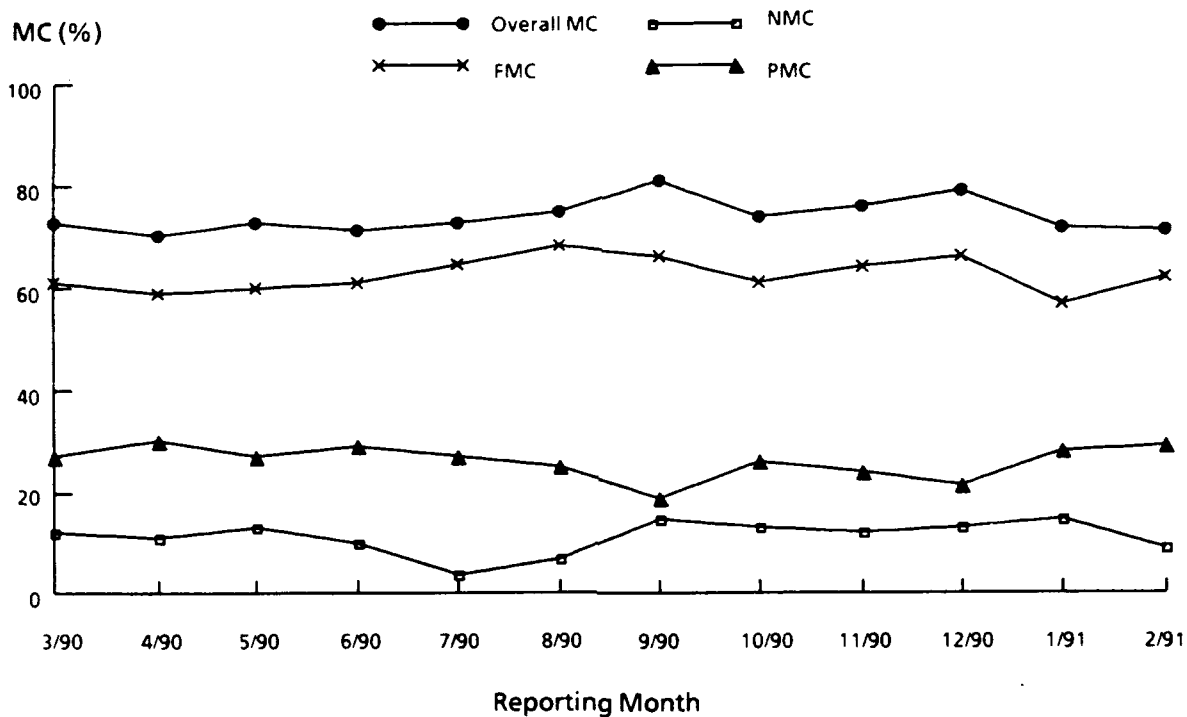


FIG. 3-1. AH-64 WORLDWIDE READINESS - MARCH 1990 THROUGH FEBRUARY 1991

For the period, the GAO found that FMC rates averaged about 50 percent, PMC rates were 15 percent, and NMC rates were 35 percent. These rates do not meet the Army goals. The GAO was careful to acknowledge that part of the problem for low MC rates for the period can be attributed to a severe storm at Fort Hood, Texas, in May 1989 that damaged over 100 AH-64 aircraft. Two serious aircraft component problems that required inspections and modifications were also discovered by the Army during this period [2].

Reliability

Test Results. Measures of AH-64 reliability included mission reliability, total system reliability, and reliability for the various subsystems. The criterion for mission reliability was a 0.9 probability of completing a 1-hour typical attack helicopter mission without a mission-essential failure. The probability of 0.92 was derived from a 17-hour MTBF rate for mission-essential equipment (the 30 mm chain gun and 2.75 inch rocket area weapon systems were excluded from this criterion).

The system reliability criterion was set at 1.95 hours MTBF and was calculated in terms of mean time between corrective maintenance actions (MTBCMA). Subsystem reliability was set at a MTBF of 10 hours or more for TADS, and a MTBF of 120 hours or more for PNVs. For the area weapon systems, the 30 mm chain gun was to demonstrate a 0.92 probability of firing a 320-round complement, while the 2.75-inch rocket was to demonstrate a successful firing. The criterion for the Hellfire system is classified.

Mission reliability of the Apache was judged adequate. A 0.95 probability of completing a 1-hour antiarmor mission was observed (based on an MTBF of 17.91 hours). System reliability was also adequate. A 2.41-hour MTBF was calculated. TADS reliability was adequate for combat operations (MTBF of 17.04 hours) but did not meet the user-specified criterion of 100 hours MTBF. No PNVs failures were observed during OT II, and the subsystem thus met the 120 hours MTBF standard. Although insufficient data were generated during OT II to assess 30 mm chain gun reliability, a 0.4 probability of firing a 320 round complement was measured on the basis of later development tests. Even though well below the 0.92 threshold, this figure was still considered "marginal" by OTEA. Further development tests for the 2.75-inch rockets showed a 0.79 probability of firing 38 rockets, meeting the nonquantitative user criterion. Hellfire results are classified.

Discussion of Results. The AH-64 Apache met the criteria set for mission reliability. However, the standards may have been too restrictive to be meaningful. The Army was very limited in its accounting for the frequency of failures significant enough to affect mission performance. Only failures that were caused by hardware, occurred in flight, and caused a mission to be aborted were considered. Failures that occurred before the start of a mission, that degraded but did not abort a mission, or that were caused by crew or maintenance error were specifically excluded. Further, the 30 mm chain gun and 2.75-inch rocket subsystems, two area weapon systems that may have major impact on mission performance, were not considered in judging mission reliability.

Total system reliability results for the AH-64 during OT II were not as favorable as those for mission reliability. Both the 30 mm chain gun and TADS were far below the established thresholds. OTEA suggested that system reliability was probably not the most meaningful value for an operational evaluation, indicating

that it counted many minor failures in areas not necessary to mission accomplishment [3]. However, system reliability does give a good indication of maintenance actions that will have to be performed even though the failures are in "nonessential" areas (OTEA noted that TADS was the single greatest contributor to reliability problems, accounting for 27 percent of the malfunctions and 23 percent of the maintenance time). Also, if apparently mission-critical subsystems are included only in considering system reliability and not in calculating mission reliability, the impact of failures in them should be seriously studied.

Field Experience. Several serious reliability problems have been identified since the Apache has been fielded.

One of the most prominent areas of concern is the main and tail rotor systems. The main rotor blades comprise the aircraft's lifting surfaces. These blades are secured and controlled by the main rotor strap pack. The tail rotor swashplate actuates the tail rotor blades, which, in turn, control lateral movement. Each of these components has an expected life of 1,500 hours; all are failing much more rapidly than expected. The GAO determined the demonstrated replacement/failure intervals of the main rotor blade, main rotor strap pack, and tail rotor swashplate to be 164, 520, and 250 hours, respectively [2].

The aircraft maintenance officer for the U.S. Army Aviation Center and School at Fort Rucker, Alabama, reported that in the 12-month period from March 1988 to February 1989, 166 main rotor blades had been replaced and a total of 300 repaired or replaced. During the same period, 57 main rotor strap packs and 111 tail rotor swashplates had also been replaced [4]. Both the in-process report of the Department of the Army-level special evaluation and the memorandums describing the activities of the ARIP list these three key components of the rotor systems as top-priority issues.

There are other problems associated with the rotor systems. McDonnell Douglas Helicopter Company operates a field deficiency reporting system (FDRS) to monitor AH-64 reliability and maintenance. The system utilizes technical representatives located at selected installations where Apaches are in operation who report problems on a regular basis. A similar process, the quality deficiency reporting system (QDRS), is operated by the Army. In Table 3-2, we show rotor

system reliability problems these have two systems reported, by type and number of occurrences [5].

TABLE 3-2
AH-64 ROTOR SYSTEM DEFICIENCIES

Deficiency	Number of events reported by	
	FDRS	QDRS
Tail rotor elastomeric bearing debonding	159	5
Main rotor head lower seal leaking	1	0
Main rotor head upper seal leaking	4	0
Main rotor blade number 1 spar debonding	10	0
Main rotor hub linear disengagement	2	3
Main rotor blade finger doublers debonding	26	1
Main rotor blade root bushing displacing	9	2
Main rotor blade lower bearing seal displaced	4	1

It must be noted that the deficiencies and number of occurrences listed in Table 3-2 are based on reported instances and may not represent the Army as a whole. The table does illustrate the range of problems experienced with the rotor systems, however.

The shaft-driven compressor is part of the aircraft's environmental control system; it provides cooling to many Apache components. While it has an expected life of 2,000 hours, it has demonstrated only a 400-hour replacement/failure interval. There have been at least 10 different confirmed causes of failure of the shaft-driven compressor and many cases of failure in which the cause could not be determined. The seventeenth version of the compressor design is currently in effect. Reliability problems with the shaft-driven compressor are magnified by the fact that Army units cannot repair it; contract repair by the manufacturer is required. From March 1988 through February 1989, the Army Aviation Center and School reported that 115 shaft-driven compressors had to be replaced on its aircraft.

A variety of problems have been noted with the 30 mm chain gun – most associated with jamming and stoppages in the feed system. Although some tests have

demonstrated firing of up to 4,700 rounds without a stoppage, the gun has not yet met the criterion of 0.9 probability of firing 320 rounds with no stoppage. Many design changes have been applied to the gun and its feed system. There have also been reports of uncommanded gun movements and of the turret drifting in azimuth.

Electrical and avionics systems have also caused important reliability concerns. The Army Aviation Center and School has noted that about one of every two of its AH-64 aircraft returns from a mission with a maintenance problem. Of these problems, 90 percent are electronics-related, and 60 percent of the electronics problems involve TADS/PNVs.¹ Some of the TADS/PNVs problems are related to the maintenance diagnostic equipment and will be discussed under maintainability.

In Table 3-3, we show other reliability problems that have been reported in the FDRS and QDRS. The issues are grouped by AH-64 subsystem.

Maintainability

Test Results. AH-64 maintainability was measured in terms of MTTR and the ratio of maintenance man-hours to flight hours. Both aviation unit maintenance (AVUM) and aviation intermediate maintenance (AVIM) were examined. The maintenance criterion was 0.9 hours MTTR, and a maintenance ratio not to exceed 14.4 man-hours per flight hour.

On the basis of 445 maintenance actions, an MTTR of 1.69 hours was computed. This figure exceeded the criterion of 0.9 hours and was considered marginal.

Although the MTTR did not meet the criterion, the maintenance ratio was dramatically better than the test standard. A ratio of 4.68 maintenance man-hours per flight hour was recorded – less than one-third of the criterion.

Discussion of Results. Conclusions on Apache maintainability based on data from OT II must be taken cautiously. Several conditions may have compromised the test's realism.

On the one hand, the military maintenance personnel were newly trained on the AH-64 and likely did not have sufficient opportunity to develop proficiency

¹The Aviation Center and School typically uses aircraft older than those found in regular Army units. While we are unable to relate reliability failure rates to aircraft age, we acknowledge that Aviation Center and School rates may be affected by the fact that its aircraft are older.

TABLE 3-3
AH-64 RELIABILITY PROBLEMS

Deficiency	Number of events reported by	
	FDRS	QDRS
Airframe		
Longer on adapter fitting cracking	6	1
Chafing tape separates from fairings	3	0
Tail boom oil contamination	5	0
Stabilator mounting bushing galling spar box	4	1
Hinge pin from equipment bay door wearing	5	0
Vertical stabilator fairing support cracking	14	0
Skin cracking around wide-band antenna doubler	6	0
Gearbox and drive system		
Transmission lubrication hose deterioration	3	1
Intermediate gearbox leaking grease	1	0
Nose gearbox expelling oil	7	0
Tail rotor gearbox input seal leaking	5	0
Transmission generator seal leaking	9	0
Mechanical flight controls		
Main rotor swashplate leakage	6	0
Main rotor swashplate uniball wearing	14	1
Stationary tail rotor swashplate clevis cracks	15	0
Power plant and auxiliary power unit		
Auxiliary power unit takeoff clutch leaking	2	0
Pressurized air system		
Shaft-driven compressor elbow fitting clogging	2	0
Engine air turbine starter problems	33	0
Hydraulic system and actuators		
Solenoid failures on hydraulic manifold	9	0
Hydraulic hand pump leakage	6	0
Switch failures on hydraulic manifold	17	12
Transducer failures on hydraulic manifolds	16	6
Brake assembly puck seal leakage	0	1
Hydraulic hose failure	20	1
Accumulator pressure gauge leaking nitrogen	4	0
Electrical system		
De-ice system failures	24	0
Generator wires chafing generator case	4	0
Generator spline adapter wearing	5	0
Instrument system		
Airspeed transducer water contamination	15	0
Visual display units losing video	18	9
Corrosion of air data sensors	28	1
External and internal lighting		
Tail navigation light bulb failing	25	0
Fire control system		
Fire control computer software malfunction	25	0

through experience. Manuals, tool lists, spare stockage, and ATE were in the early stages of development and contained some previously undetected flaws. These conditions could indicate that maintainability has the potential for significant improvement. However, there were also conditions that could indicate that the results were overly favorable. For example, of the total of 752.88 clock hours of maintenance expended during OT II, 128.11 hours were performed entirely by contractor maintenance personnel, who also assisted in the 589.76 hours of AVUM actions and the 35.01 hours of AVIM actions. It is not clear how great an impact contractor support had on MTTR, but it is probable that such assistance may create conditions more favorable than can ever be expected in the field.

The ratio of maintenance man-hours to flight hours is surprisingly low. This low ratio can be attributed at least partly to the fact that no phase maintenance (a major scheduled maintenance action that contributes heavily to down time) was performed during OT II (because the aircraft were not operated to the point requiring phase maintenance). Had phase maintenance been performed, the ratio would have been significantly higher.

There were also component specific problems with maintainability. It was reported that it was difficult to remove and replace the Doppler signal data converter, the AM/FM radio, the anticollision light power supply, and the digital automatic stabilization equipment computer.

It was necessary to bend wires sharply when removing and replacing the Doppler computer display unit for the Doppler signal data converter, the digital automatic stabilization equipment computer, and the TADS electronic unit number one. Wires were also reported to be particularly subject to chafing or pinching in the forward avionics bays when the access door to either bay was closed.

Field Experience. Maintenance field experience for the AH-64 has been much different from that demonstrated during the AAH OT II. The problems of sharply bent and crimped wires have been manifested in many instances of broken and chafed wires, as noted in the section on reliability. Even more critical problems have appeared. In most cases the maintenance issues can be linked to the poor reliability of major components and the inadequacy of the diagnostic test equipment, which were not noted during testing.

The high volume of component failures creates a high corrective maintenance workload. It takes a considerable amount of effort to remove and replace failed components. In Table 3-4, we show the estimated figures for three components with major reliability problems [2].

TABLE 3-4
ESTIMATED HOURS TO REMOVE AND REPLACE
MAJOR AH-64 COMPONENTS

Component	Maintenance man-hours	Aircraft downtime
Main rotor blade	14 – 16	8 hours
Main rotor strap pack	32 – 44	3 – 4 days
Tail rotor swashplate	8	8 hours

The preventive or scheduled maintenance workload is also increased, because the reliability failures generate the requirement for special inspections or increase the number of items to be examined during regular inspections. As these inspections progress, they often reveal more faults that lead either to more corrective maintenance downtime or to more required inspections. We examined 41 maintenance information messages issued since 1986 – each requiring a specific maintenance action or inspection.

Maintenance problems (some related to low reliability and some not) are sometimes serious enough to motivate the issuance of safety of flight (SOF) messages. We analyzed 103 SOF messages issued through March 1991. Nine required an immediate grounding of the entire fleet. Forty-four called for one-time inspections, while 21 required both one-time and recurring inspections. The remaining 29 messages either ordered an immediate maintenance action or redefined an inspection or maintenance procedure.

The aircraft maintenance office at the Army Aviation Center and School has reported that there are now 26 recurring special inspection items, which are performed at a cost of \$1.4 million annually. Thirty-three items have been added to the regular phase inspection (5 for TADS/PNVS, 4 for IHADSS, and 24 for a variety

of other components). Most of these inspections were not visualized by the manufacturer and were not indicated during AAH OT II.

The other main cause for the high-maintenance burden in time, personnel, and dollars concerns the Apache automatic test and diagnostic equipment, which has not yet proven capable of quick and accurate troubleshooting of faults in electrical equipment. This issue is discussed in the section on support system suitability issues.

Safety

Test Results. A number of safety problems involved with maintenance activities were noted. There was no quantitative criterion covering safety.

Two hazardous maintenance procedures on the main rotor were noted. To perform the 50-hour feather axis bearing check, a maintainer must stand on the rotor head, attach a fish scale, and pull upwards to exert a force of 100 pounds of tension. Any slip or unexpected release of the fish scale could result in a fall. Also, the main rotor blades can rotate freely when the drive shaft is removed, and there is no warning to secure the rotors when the drive shaft is removed.

The auxiliary power unit shaft is not shielded. It is sometimes necessary to work near that shaft with the auxiliary power running, exposing personnel to danger.

Mechanics noted that there was a very small lip (approximately 1/4 inch) on the transmission removal plate. The lip is not large enough to prevent the 800-pound transmission from sliding off the lip if the transmission is moved too rapidly during a repair operation.

Discussion of Test Results. The safety problems noted in OT II were largely related to maintenance. Some could be corrected with equipment modifications. Others required that precautionary warnings be more prominently affixed to equipment and noted in manuals. For these reasons, OTEA considered the safety problems to be minor.

Field Experience. Apache safety field experience has been characterized by much high-level attention. Accidents have resulted in loss of both life and equipment. We were unable to compare AH-64 accident history to experience with other similar aircraft to determine whether there has been an unusually high rate for

the Apache. However, we did review some information in an attempt to determine whether the accident cause was related to equipment or human error.

There were instances of both types of causes. In this section, we discuss only equipment-related problems (accidents caused by human error are discussed in the human factors section). As noted earlier, nine of 103 SOF messages required grounding the entire Apache fleet. Examples of safety problems noted in these messages are independent slewing of the 30 mm chain gun and removal, inspection, and replacement of the main rotor retention nut. Again, many of these AH-64 safety issues are related to poor reliability. We do not view the AH-64 as an inherently unsafe system. However, as component reliability problems are discovered, the Army must institute an inspection and corrective action program to detect and eliminate the problems. Any such program is costly in dollars and maintenance downtime.

Human Factors

Test Results. No major human factors problems were found during the AH-64 OT II (no quantitative criterion was specified). However, a number of areas were noted where improvement was considered to have potential for enhancing the effectiveness of the weapon system.

A number of display devices are located in places where they are difficult to see or reach. The engine, rotor, and torque gauges are located behind the optical relay tube. The copilot would have difficulty seeing them if he were required to take control of the aircraft. In the pilot's cockpit, communications equipment is located low on the center console behind the cyclic, where it is difficult to see and reach.

A communications problem is caused by the need to hold the weapons action switch on the pilot's cyclic control grip during firing of the 30 mm gun or the 2.75 inch rockets. With one hand involved in holding the switch, it is difficult to switch between intercom and external communications during weapons firing.

Lighting problems included insufficient light for map reading and in some instrument panels. Cockpit floodlights not only provided inadequate illumination but also caused glare on the canopies.

Some information system inconsistencies were recorded. Data entry keyboards for the fire control computer and the lightweight Doppler navigation system (LDNS)

were quite different, even though the subsystems have similar functions. The laser glasses (used for protection) were incompatible with the IHADSS.

Crews also had to maintain a heavy workload. The limited storage capacity of the LDNS, a Doppler drift problem, inaccurate way-point targeting, and a requirement to re-inventory missiles frequently in order to adapt to the fire control computer missile management procedures all caused pilots and copilots to be overly busy during certain periods.

Inadequate cooling and ventilation were two of the major flight environment difficulties. The cockpit needs to be cooled to allow electronics to function properly. On at least one occasion, smoke and fumes from the transmission were vented into the cockpit.

Excessive aircraft vibration under certain operating conditions was considered possibly degrading to crew performance.

Discussion of Test Results. Human factors issues noted during AAH OT II were generated by responses to written questionnaires and interviews. For the most part, human factors issues consisted of a list of problems that, although not considered major, were so numerous as to give a good indication of the field experience that would follow.

Field Experience. The deficiencies noted in AAH OT II clearly make operation and maintenance of the AH-64 more difficult. We examined SDC monthly progress reports on the AH-64 to compare test and field experience. At times the human factors deficiencies actually cause maintainability problems.

For example, during Operation Just Cause, the environmental cooling system not only did not supply enough cooling effect but — by design — directed cool air at the indirect view display (IVD) of TADS. The combination of cool air and a moist component resulted in a large amount of water (maintenance crews reported being able to literally pour water out of the IVD) accumulating in the unit and shorting it out.

SUPPORT SYSTEM SUITABILITY ISSUES

In this section, we discuss the results of AAH OT II and field experience with operational suitability components that relate to system support.

As in the design section, we list the results for selected components of operational suitability as described in the AAH OT II report documents, discuss the results, and compare them with experience.

Logistics Supportability

Test Results

No quantitative criterion was set for AH-64 logistics supportability. Tools and test equipment and spare parts and expendables were considered in OT II. Tools and test equipment were judged as marginal. Spare parts and expendables were judged as adequate.

Apache maintenance requires 229 types of common tools in 22 kits, as well as 25 special items peculiar to the system. Few problems were observed with tools, but there were important difficulties with ATE. Only 62 of 152 failure cases were accurately fault-isolated. Part of this poor performance was attributed to the fact that fewer than half of the TPSs were available for AAH OT II.

During testing, 664 parts replacements were made, involving 122 different components. The most frequently replaced items were the electric unit-1 on TADS (40 times), the fuel injector on the engine (35 times), the laser transceiver unit of the laser range finder (27 times), the laser electronic unit of the laser designator (24 times), and the heading attitude reference system of the fire control computer (15 times). Of the 495 valid parts demands, 386 (or 78 percent) were covered by the authorized stockage list. Also, 319 (83 percent) of the 386 authorized stockage list demands were completely filled. Petroleum, oil, lubricants, and cleaners were consumed at a normal rate for aircraft.

Discussion of Results

Testing of logistical supportability during AH-64 OT II was limited by the lack of a complete established logistical support system. While it is not uncommon for the support package to be incomplete at the time of OT II, the immaturity of the AH-64 system was especially critical.

The Apache's maintenance concept is predicated on its modular design, in accordance with which LRUs are detected as being failed, removed, and replaced at AVIM. Component repairs and other heavier maintenance tasks are performed at

AVIM or depot. The FD/LS software and Automatic Test Facility (later to become the EETF) were incomplete at the time of the test, providing only limited opportunity to assess diagnostic capability.

The reason for conducting the AAH OT II without the complete set of ATE is unclear. The PT-LD report indicated that the ATE had been waived for the AAH OT II. However, this statement appears to be incorrect. Our research shows that at no time in the program was there a blanket waiver of ATE for operational testing. The Army did grant a waiver in December 1978, but it applied only to augmentation ATE being developed under a Phase II full-scale engineering development contract. After the Apache program was restructured in July 1979, the original waiver was replaced by the Army in December 1980. The updated version listed in specific detail the TPS waived from the AAH OT II but required that they be evaluated in a subsequent force development test and experimentation of the first equipped unit in 1984.

Given the incomplete diagnostic capability and limited actual flying hours, OT II may have been unable to find important logistics support problems. For example, all of the maintenance inspectors reported that FD/LS sometimes incorrectly indicated which components had failed. This usually occurred when the failed component was one of a set of several interacting components and the erroneous indication was that another component in the set had failed.

Field Experience

Apache field experience has shown the problems noted with FD/LS in AAH OT II were not only real but, in fact, far understated. As the on-board automatic test and diagnostic equipment, FD/LS has not proven capable of quickly and accurately troubleshooting faults in electronic components. There are two basic problems. First, FD/LS does not accurately find the component that is the root cause of the problem. For example, if a power supply component fails and makes other components inoperable, FD/LS may identify one of the other components as the problem. Second, about 40 percent of the time, FD/LS indicates faults that do not actually exist.

We noted that electronic components in general and TADS/PNVS in particular are the source of many maintenance problems. Electronics problems and poor performance by automatic test and diagnostic equipment combine to undermine AH-64 availability. In addition to the high incidence of post-flight maintenance

problems, 40 percent of the Apaches operating at Fort Rucker during the March 1988 to February 1989 period required some kind of maintenance assistance during pre-flight runup and launch. This requirement for maintenance assistance was made more difficult because the TADS electronic unit cannot be tested on the aircraft during runup. Another, flight-ready Apache is needed to test the subsystem.

The EETF (formerly the Automatic Test Facility) tests removed components at the AVIM level. The EETF was not completely tested in the AAH OT II. It is not only slow, it does not have the capability to repair the circuit boards within the components.

Maintenance assistance from the EETF is limited because of a lack of repair parts for its computer equipment. The TPSs that comprise the EETF also do not adequately identify faults in components by card number. Furthermore, while several engineering changes have been made in the AH-64, but the EETF has not always been modified accordingly. The result is that some hardware assemblies are not compatible with certain TPSs.

The demand for spare parts has been much higher than indicated in the AAH OT II. Again, the root of the problem is the unanticipated demand for replacement parts. The shortages do not involve a large number of parts relative to the total number of parts on the Apache. However, the parts that are difficult to obtain are essential to aircraft operation. In Table 3-5, we show the Army's estimates of parts back-ordered as of January 1990.

The Army Aviation Center and School also reports major difficulties with AH-64 spare parts. There is typically a requirement to execute special actions to obtain critical spare parts (a controlled parts exchange, for example). Of the top 20 parts subject to controlled exchange, 13 are from the Apache. In addition to the components listed in Table 3-5, the shaft-driven compressor, the drive motor housing, and the processor for the fault detector are in short supply.

Manpower Supportability

Test Results

The AAH OT II rated the manpower supportability of the Apache as adequate. The number, type, and level of skill of personnel to be assigned to AH-64 battalions according to the Table of Organization and Equipment was considered capable of

TABLE 3-5
EXAMPLES OF BACK-ORDERED CRITICAL SPARE PARTS
FOR THE AH-64

Component	Number back-ordered
Main rotor blade	233
Main rotor strap pack	176
Tail rotor swashplate assembly	11
Main rotor pitch link assembly	372
Main transmission	25
Target sight electronic unit	27
Night vision sensor turret	25

fulfilling mission requirements. The proposed training program for operators, maintainers, and armament personnel was also assessed as being adequate to support the Apache in an operational environment.

Only two concerns were noted. The first was that the aircraft electricians (Military Occupational Specialty 68F) used during the test were exceptionally skilled and experienced and may not have been representative of the typical soldier. Also, no FD/LS repairer (Military Occupational Specialty 68J) was used in the test.

Discussion of Results

The Apache battalion is responsible for 18 Apaches, 13 OH-58 observation helicopters, and 3 UH-60 utility helicopters. This structure was developed on the basis of data from the less complex Cobra helicopter. According to the standard manpower analysis, the battalion should have 366 personnel, with about 160 devoted to maintenance. However, because of size and budget restrictions, a more austere organization has been implemented. The Apache battalion that was fielded had 264 people with 100 unit maintainers. A total of 129 Army maintenance personnel were employed during the AAH OT II (these personnel serviced both the Apache and the baseline section). Contractor-supplied maintenance personnel assisted.

Assistance rendered by contractor personnel, combined with the relatively low number of hours flown during the test, may have created an environment that did not

accurately represent the typical maintenance environment. The field experience has been much different.

Field Experience

Apache maintenance sections that were initially fielded were too small. A higher-than-expected component failure rate, poor performance of FD/LS, and the limited number of actual clock hours for personnel to actually perform maintenance have combined to cause an unacceptable situation. Both the ARIP and related general officer steering committees have noted the problem and are taking action to correct the shortfall.

Documentation

Test Results

Documentation was tested as part of logistics supportability during OT II. A total of 40 technical manuals were consulted 172 times during the test. There were 34 instances of some difficulty (either the manual was inadequate, or the procedure was not followed correctly), involving 15 of the manuals. The difficulties with the manuals were considered an indication of the immaturity of the maintenance support package prior to production.

Discussion of Results

Several mechanics noted that the manuals were not organized in accordance with their work responsibilities. Frequent references were made from one volume to another, and then to another, so that three or four manuals were needed to perform a simple procedure.

The difficulties with the technical manuals were caused, at least in part, by the fact that more than one aircraft configuration was being tested. A complete set of manuals was not available for the two earlier Apache configurations. This gap in technical coverage contributed to some of the inadequacies. OTEA felt confident that the difficulties with the manuals could be corrected.

Field Experience

Problems with manuals were also noted in the field. These problems were systematically overcome, however. The manuals were modified as errors and

inconsistencies were discovered. Also, as the FD/LS and EETF matured, the structure of the manuals became more aligned with their original use.

CONCLUSIONS

General

In this section, we present our conclusions on the treatment of operational suitability during OT&E. These conclusions are based on a comparison of the results of the AAH OT II and the field experience.

Our conclusions focus on four major areas: reliability, availability, maintainability, and logistics supportability. We also include a fifth area covering issues in other areas.

Reliability

The AAH OT II measured reliability in terms that were so restrictive as to be misrepresentative. Mission reliability, total system reliability, and the reliability of all tested subsystems except the 30 mm chain gun were judged as adequate. The 30 mm chain gun was judged marginal. These findings from AAH OT II are at odds with the demonstrated field performance.

The mission reliability criterion of 0.92 probability of completing a 1-hour mission without a mission-essential failure was derived from a mission MTBF of 17 hours. The 17-hour MTBF figure was reasonable and was selected in anticipation of reliability growth to 19.5 hours at system maturity. However, as previously noted, the mission reliability definition embraced only failures that are caused by hardware required to complete that specific mission, occur in flight, and cause a mission to be aborted. In addition, the performance of the 30 mm gun and 2.75-inch rocket systems was not considered in calculating mission reliability. In fact, the mission reliability definition excluded most failures that affect mission capability.

The most troubling disparity between the AAH OT II results and field experience is the numerous cases of essential operational components that are failing far more rapidly than expected. This phenomenon was not observed during testing and resulted in an OT&E reliability rating far more favorable than the reliability experienced in the field. Although we were unable to determine with any certainty why this disparity occurred, several hypotheses were offered by representatives from

AVSCOM, the Aviation Center and School, and the GAO. First, the number of flight hours in operational testing may have been too low to allow the problems to appear. Second, the aircraft may not have been subjected to performance requirements (flight loads, banking, etc.) in the AAH OT II equivalent to those they would encounter in the field. Finally, the operating environment in OT may well have been less demanding than that typically experienced in the field.

Availability

The AAH OT II, although limited in flying hours, provided data that should have accurately predicted availability rates experienced in the field. We believe that the 0.7 operational availability measured during testing should have signaled the fact that availability of 0.75 would be difficult to attain during normal field operations.

We acknowledge that, at the time of operational testing, the fact that logistics support system was immature and the maintenance personnel were inexperienced could justify predictions of better future availability. However, such factors must be balanced against the advantages of contractor support and the almost total dedication of maintainers' time to maintenance, which are atypical of the field situation.

Maintainability

The AAH OT II was not able to assess maintainability accurately. It is true that many of the maintainability problems that would plague the Apache after fielding were noted during the AAH OT II (shortness and crimping of wires, for example). However, since the major reliability failures in essential components did not surface during testing, their impact could not be judged. Further, the significant role of contractor maintenance personnel probably biased the results. And the fact that phase maintenance was not conducted contributed to the low and unrealistic maintenance-hours-to-flight-hours ratio.

The incompleteness of the EETF also detracted from the tests' validity. We comment on this problem in the next subsection.

Logistics Supportability

The AAH OT II could not assess the logistics support system for the AH-64 Apache because the EETF was incomplete. As previously mentioned, the FD/LS and the EETF are the cornerstones of the Apache maintenance concept. The Army cannot afford uncertainty about EETF support to the AH-64. The maintenance plan for the helicopter assumes that the EETF programmed for each echelon will be adequate to handle the workloads generated for that echelon. If support is not adequate, repair turnaround times will be long, inventories of spares will be exhausted, and aircraft availability will plummet. This is exactly what occurred after the fielding of the Apache (although a great part of the problem was also caused by the short failure times of components like rotor blades and the shaft-driven compressor, which are not analyzed by the EETF).

Fewer than half of the 76 TPSs that comprise the EETF were available for testing during the AAH OT II. In effect, the logistics support system could not be tested. When this factor is combined with the poor performance of FD/LS, it can be seen that the marginal rating for the tools and test equipment package was better than was justified.

Other Issues

Other operational suitability problems noted during testing included documentation, human factors, and safety. For the most part, problems in these areas were regarded as minor faults and deficiencies that should not slow fielding but that should be corrected. Some of the problems continue to appear in the fielded Apaches. However, the continued existence of these problems is not related to operational testing's ability to detect them but rather is a function of the time required to plan and implement corrective actions.

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CHAPTER 4

M939A2 FIVE-TON TRUCK

INTRODUCTION

This chapter reviews the history of the OT&E process for the M939A2 series 5-ton truck. For each component of operational suitability, we compare the results found during OT&E with the operational suitability experienced in the field. The components of operational suitability are categorized into two groups: issues related to the design of the system (availability, reliability, maintainability, etc.), and issues that reflect on the support system, such as logistics supportability and documentation.

System Description

The M939A2 series 5-ton truck is a diesel-powered, 6-wheel tactical vehicle. It is the primary medium-weight-class tactical transport vehicle for the Army in local and line haul movement.

There are five body styles: cargo, dump, tractor, wrecker, and van. The different body styles support the 15 variants in the series. In terms of numbers to be produced, the major variants are the M931A2 tractor, the M923A2 cargo truck, and the M936A2 wrecker. Other variants include a long-wheelbase cargo truck, three trucks with bare chassis, two trucks with van bodies, and a dump truck. Most of the variants can be equipped with a front winch (a different model number is used when trucks are equipped with winches).

The M939A2 is the result of a program of improvements in the M809 series 5-ton truck. The M809 has a transmission and transfer case that are under capacity and mismatched to the engine/axle ratio and performance requirements. There is no way to prevent the engine from overspeeding or overworking in many gear ratio selections. A fully automatic transmission and new transfer case were introduced in the M939 series to correct these problems. The M939 also introduced full air brakes (having four times the brakeshoe life of the M809's air-over-hydraulic brakes) with a fail-safe mechanical spring brake backup. Maintenance for the M939 was made

easier by bonnets and bumpers that tilt forward so that maintenance can be performed while the mechanic is standing on the ground. Special connectors for attaching maintenance diagnostic equipment are also included. Other improvements added to the M939 are a larger cab to accommodate three people, and the routing of intake/exhaust ports behind the cab to reduce noise hazard.

An M939A1 update to the M939 series 5-ton truck replaced the dual rear tandem tires with 14.00-by-20 "super single" radial tires.

The M939A2 incorporates four modifications to the M939A1. The engine is changed to a Cummins 6CTA8.3 that produces 240 horsepower with an increased operating range of 644 kilometers and is lighter than the previous Cummins diesel engine. A Chemical agent resistant coating (CARC) paint is applied to the vehicle. It is also equipped with modified axles and a central tire inflation system (CTIS).

The CTIS control assembly is mounted on the shift column; it allows the operator to adjust the tire pressures to one of four preset positions (highway, cross-country, sand, and emergency mode). Decreasing pressure increases the tire's footprint to generate better traction and mobility.

The cargo truck (M923A2) can transport payloads of 10,000 pounds (4,540 kilograms) and has the capacity to tow an additional trailer load of 15,000 pounds (6,810 kilograms).

The truck tractor (M931A2) is a fifth-wheel vehicle used to haul semi-trailer loads up to 37,000 pounds. It is equipped with a pintle hook for hauling eye-hook trailer loads up to 15,000 pounds.

The wrecker (M936A2) is a multipurpose vehicle with capabilities to recover and lift tow or tow all supported vehicles of equal or lower weight class. It can also be used in crane operations to lift up to 20,000 pounds at a radius of 10 feet, with boom supported from the vehicle and outriggers extended and emplaced.

Acquisition History

Development of the M939A2 began in 1951 with the fielding of the M809. Extensive testing, conducted in 1970, indicated that improvements were needed in the transmission, transfer case, and brake system. A product improvement program was planned but was canceled with the withdrawal of U.S. forces from Viet Nam.

The program was reinstituted in 1975. The M939 series 5-ton truck resulted from this M809/M939 Product Improvement Program.

After over 230,000 kilometers of testing, the M939 was type-classified in 1979. In April 1981, AM General Corporation was awarded a contract for 11,394 trucks. The U.S. Army Tank Automotive Command (TACOM) later increased the number to 22,789, with a total value of the 5-year contract at \$1.6 billion. Production began in the first half of 1982 at AM General's plant in South Bend, Indiana. Fielding began in 1983.

The M939A2 program was originally structured as a 5-year re-buy of the M939A1 vehicle, with the addition of CARC paint in a three-color camouflage pattern. However, to increase competition, Congress directed that the engine be defined by performance specification. Additionally, the Army directed that the CTIS be included on the vehicle.

In May 1986, ARVECO (a joint venture between BMY Corporation and the General Automotive Company) won a contract to produce 15,218 M939A2 vehicles over a 5-year period. The initial 1-year buy was for 2,046 vehicles at a cost of \$145 million. The 5-year contract is expected to be worth \$1 billion.

System Status

As of mid-June 1991, 12,949 M939A2 series vehicles had been manufactured at BMY Corporation plants and accepted by the Army. This total includes all variants. Overall, 7,159 M923A2 cargo trucks had been shipped to Army units. Corresponding figures for the M931A2 tractor and M936A2 wrecker are 2,671 and 688, respectively.

The M939A2 series trucks were first fielded in large numbers at Fort Drum, New York. The trucks also were used extensively in Operation Desert Shield/Desert Storm. About 4,000 vehicles of all variants were in the theater.

OVERALL SUITABILITY

The 1988 IOT&E found the M939A2 operationally suitable. (The wrecker variant underwent a separate IOT&E and was found not suitable.) An aggressive improvement program was used to correct faults that showed up during the M939A2 test; it succeeded in correcting many of the faults before the test was completed [1].

Field experience shows that the IOT&E correctly identified problems and did not miss any major problems. Measures of field suitability show that the conclusion from IOT&E that the M939A2 is operationally suitable was correct.

END-ITEM SUITABILITY DESIGN ISSUES

Introduction

In this section, we discuss the results of the M939A2 IOT&E and field experience regarding operational suitability components that relate to system design. We present specific information on test procedures when it is critical to support our discussion.

Our approach consists of listing the results for selected components of operational suitability as described in the IOT&E report documents, discussing the results, and comparing them with field experience. We also provide a brief overview of IOT&E and the sources of data on field experience.

IOT&E Overview

The M939A2 IOT&E was conducted by the Test and Experimental Command Armor and Engineer Test Board (TEXCOM ARENBD) at Fort Knox and Fort Campbell, Kentucky, from 8 August through 14 October 1988. Additional test data from the initial production test (IPT) conducted by the U.S. Army Test and Evaluation Command at Aberdeen Proving Ground, Maryland, and Yuma Proving Ground, Arizona, from July through December 1988 supplemented the IOT&E data.

Our discussion of the M939A2 series is based on test results for the M923A2 cargo truck, the M931A2 tractor, and the M936A2 wrecker. Two M923A2 cargo trucks were driven a total of 5,765 miles during IOT&E, while one M931A2 tractor was driven 2,633 miles. The M936A2 wrecker experienced several problems during technical safety release certification and was withdrawn from IOT&E. An IOT&E for the wrecker was conducted from August to September 1989.

During the conduct of operational testing, 23 problem areas were noted in the M923A2 cargo and M931A2 tractor trucks [2]. The problems are listed in Table 4-1.

The program manager, with the support of other Army elements, launched a unique program in reaction to these faults. This program featured a rapid and aggressive attempt to resolve each problem while the test was still in progress. The

TABLE 4-1
PROBLEMS NOTED DURING OPERATIONAL TESTING

Problem area	System effect
Transportability	Will not meet Military Standard 209
Salt-water fording	Potential problem for electrical system
Cold starting	Not capable of starting on own power for temperatures between -26 and 50 degrees F
Front winch	Winch cable wraps poorly; inconsistent pulling capability
CTIS quick dump valve	CTIS becomes contaminated
Fan belt	Broken belts stop coolant flow and battery charging
Manuals	Vehicle maintenance hindered by vague instructions
Bearing cup punch	Race bearing cup cannot be removed
Mirror bracket	Potential problem of cut fingers
Transmission check	Requirement to check while hot creates the potential for burns
Power steering	Steering mechanism overheats, loses fluid, and binds
Maintenance platform	No stable platform to support mechanic while performing maintenance on engine
Engine seal	Engine loses oil
Deep-water fording	Will not ford required 78-inch depth
Cold test CTIS	System does not function properly between -26 and -50 degrees F
Gauges	Gauges provide false readings
Electrical protective control box	Vehicle will not start
Wiper hose	Loss of air pressure
Cab bushings	Increased shock to cab
Engine shut-off solenoid	Engine will not shut off electrically
Battery location	Potential safety problem of battery fumes entering cab
Tire changing	Potential safety problem of person crawling under truck
Electromagnetic interference	Radiated electromagnetic force may effect other systems

approach was considered highly successful. Only four problem areas still required action by the end of testing: transportability, cold starting, engine shut-off solenoid, and the winch capacity. We relate the problems listed in Table 4-1 to the components of operational suitability in the following subsections.

A special OT&E, designed specifically for the M936A2 wrecker, was conducted in August and September 1989 by TEXCOM ARENBD at Fort Knox, Kentucky. The results of this test are discussed in conjunction with those for the M923A2 and M931A2.

Field Experience Data Sources

The Material Readiness Support Activity (MRSA) provided most of the data on field experience for the M939A2 series 5-ton truck. We were able to review mission capable (MC) rates from the Readiness Integrated Data Base. Problem areas noted in the Deficiency Reporting System were also made available.

We also conducted extensive discussions with representatives of the M939A2 series program executive officer at TACOM, which is in the process of assembling an extensive report on M939A2 experience in Operation Desert Shield/Desert Storm. Since the report is not final and has not been officially released, our information in this area is limited to preliminary views of expert observers. We were unable to obtain quantitative data.

Operational Suitability System Design Results

Availability

Test Results. The criterion for operational availability (A_o) was at least .89; A_o is derived using on the following formula:

$$A_o = \frac{OFMC + SFMC}{OFMC + SFMC + TCMT + TPM + ALDT}$$

where

OFMC = total operational time accumulated

SFMC = total standby time accumulated (not operating, but assumed operable)

TCMT = total time performing corrective maintenance

TPM = total time performing preventive maintenance

ALDT = total administrative and logistics downtime.

The A_0 for the M923A2 cargo truck was .80, while the M931A2 tractor had an A_0 of .99 [3]. Data for these calculations are provided in Table 4-2.

TABLE 4-2
HOURS BY OPERATIONAL CATEGORY

Category	Hours	
	M923A2 cargo	M931A2 tractor
OFMC	517.43	266.17
SFMC	766.57	1,058.68
TCMT	55.51	4.64
TPM	12.19	6.51
ALDT	248.30	0.00

Discussion of Results. The M923A2 cargo truck did not meet the test criterion for operational availability, while the M931A2 tractor did (and in fact exceeded the criterion). Other data from the IPT and two test proving ground reports (where the trucks accumulated even greater mileage) convinced OTEA and the Transportation Center to conclude that the M939A2 series should be considered to have met the criterion, with a low risk of being a future problem.

We could not find evidence to challenge that conclusion, especially since the test actually used data based on the system fault definition/scoring criteria (FD/SC) and computed system availability (A_s). The operational availability criterion of .89 was based on operational FD/SC. In order to be equivalent, the test scenario and logistics environment must match the conditions used to develop A_0 . Otherwise, the conditions could bias the result. We could not determine how closely the operational conditions emulated the system conditions. However, given the information available from other sources and the actual IOT&E data, we believe that the conclusion is justified.

Reliability

Test Results. Reliability for the M939A2 series was measured in terms of mean miles between operational mission failure (MMBOMF) which is defined as follows:

$$MMBOMF = \frac{2M}{X^2}$$

where

- M = Total operational miles accumulated on the test item
- X² = A chi-square value, with .1 area under the curve, and 2r + 2 degrees of freedom
- r = The total number of operational mission failures that occur during testing.

For the cargo and tractor variants, there were four failures in 8,398 miles of operation. The X² value was 15.99. These data yielded a MMBOMF of 1,050.4, well above the criterion of 675 MMBOMF. Additionally, with about 42 percent of the scheduled 100,000 IPT miles completed at Aberdeen Proving Ground and 54 percent of the scheduled 80,000 IPT miles completed at Yuma, Arizona, the mean miles between system failure (MMBSF) were 900 miles and 4,361 miles, respectively.

The wrecker was driven 1,018 miles before being withdrawn from testing in 1988. During the 1989 IOT&E, it was operated 2,802 miles. One operational mission failure was noted in the first test, 10 in the second. These results cause the wrecker to fall below the criterion [3].

Discussion of Results. Taking into account the limitations of the test (the number of vehicles operated, the type of climate and terrain, etc.), the conclusion for the M923A2 cargo truck and M931A2 tractor appears valid. Since only one M936A2 wrecker was tested, the results concerning it are inconclusive.

Maintainability

Test Results. Maintainability was measured in terms of maintenance ratio, as follows:

$$MR = \frac{CMT + PMT}{OT}$$

where

MR = maintenance ratio
CMT = total time performing corrective maintenance
PMT = total time performing preventive maintenance
OT = total operating time accumulated

The criterion was an MR of not more than .28 for any maintenance level. In Table 4-3, we show the data and results of the calculations for MR.

TABLE 4-3

MR DATA

Maintenance level	Category	M923A2 cargo	M931A2 tractor
Unit level	CMT	68.81	8.81
	PMT	12.55	5.33
	OT	517.43	266.17
	MR	.16	.05
Intermediate level	CMT	35.82	0.00
	PMT	0.00	0.00
	OT	517.43	266.17
	MR	.07	0.00
Overall	CMT	104.63	8.81
	PMT	12.55	5.33
	OT	517.43	266.17
	MR	.23	.05

Note: CMT, PMT, and OT are given in hours.

We could not locate quantitative data on how the wrecker performed during the 1989 IOT&E. It was reported that it did not meet the maintainability criterion in IOT&E. In IPT, when the wrecker was operated for a greater number of miles, the

criterion was met, however. Again, the fact that only one vehicle was tested must be noted.

Discussion of Results. Both the cargo and tractor variants met the maintainability criterion. There is no reason to believe that maintainability will be a problem area.

Also set was a criterion of .60 probability of 20,000 miles of operation without replacement or overhaul of the engine, transmission, transfer case, or differential, at a 50 percent confidence level. Although no such failures occurred, there were insufficient test miles to conclude that the criterion was met.

Transportability

Test Results. The M939A2, according to criterion, is to be air-transportable by C-130 and C-141 aircraft. These tests were to be performed during IPT. At the time of the IOT&E report, the actual loading had not been accomplished. However, on the basis of a preliminary analysis of dimensions and weight, no problems were anticipated in loading M939A2 series vehicles, and the U.S. Air Force subsequently certified the transportability of the cargo and tractor variants [3].

Difficulties were noted with the vehicle tie-downs during the test, however. The M939A2 trucks are fitted with tie-down devices on the front and rear bumpers to aid in securing them during transport. During the test, the front bumper of one truck was torn loose, and the rear device on another truck failed.

The wrecker is air-transportable in the C-5 aircraft only. This is the same standard achieved by the M936A1 and is not considered to degrade the mission performance of the M936A2.

Discussion of Results. The M939A2 trucks are considered transportable. The difficulties with the tie-down devices were acknowledged by OTEA and considered in need of correction. By using the existing procedures for the M939A1 truck (which requires that chains be secured to the vehicle frame rather than to tie-down points), the M939A2 can still be transported.

Safety

Test Results. No major deficiencies were observed during IOT&E (or in data taken from IPT) for the M923A2 cargo truck or the M931A2 tractor. Several

shortcomings needing attention and possible correction were noted. The problem areas include the following: the position of the rearview mirror is such that the driver's or assistant driver's fingers could be injured when the door is opened or closed; the location of the batteries under the passenger seat makes them difficult and dangerous to remove and could subject occupants to a hazard from fumes; the transmission oil dipstick is close to the hot transmission oil hoses, a fact that could lead to burning of hands or arms while maintenance checks are being performed; there is no platform to stand on in order to perform daily checks and services; and changing the rear tire is hazardous because one soldier must crawl under the truck after lug nuts have been removed.

In addition to the problems cited above, two other design features generated possible safety problems. The design of the transmission and converter lockup system is such that the engine can stall during a maximum braking effort, resulting in loss of power steering assistance and in backward rolling, if the stall occurs on a slope. The engine fuel cut-off solenoid failed several times during testing. Thus, fuel flow could not be electronically stopped when the engine was shut down [2].

The wrecker had an additional safety hazard associated with the light front end. Weight transfer from the front to rear axles, particularly during towing operations, made steering control very difficult.

Discussion of Results. All of the problems noted under safety were considered shortcomings. In some cases, like the cut-off solenoid, a satisfactory manual backup was available and was considered adequate. For other issues (such as the mirror, hot transmission check, and maintenance platform), warning placards were affixed to the vehicle and notices were placed in the manuals while the condition was monitored.

Operational Suitability Design Field Experience

General

Since the vehicles have been in the field only a relatively short time, field experience on the M939A2 series was limited. However, we were able to draw some inferences on the basis of available data. Of special interest in our analysis was the corrective action program initiated during IOT&E. In the final section of this chapter, we summarize the actions taken in response to IOT&E test results.

Mission Capable Rates

The MC rates indicate that the problems detected in IOT&E were effectively rectified. We found that the fielded M939A2 series trucks showed MC rates at least as high as – and often higher than – the A₀ demonstrated in testing. Table 4-4 shows the MC rates by variant.

The reduction in the number of vehicles reported on, particularly for the M923A2 cargo truck, during January and February 1991 is due to lack of information for trucks deployed to SWA.

Information From the Deficiency Reporting System

Only a few instances of problems were noted in the Deficiency Reporting System. The problems followed no pattern, and no single part or component displayed repeated or regular failures.

Examples of problems noted for the M923A2 cargo truck (six deficiencies were reported) included the following: a service line from the treadle valve crossed with the trailer change or emerge line; trailer brake release and tractor brake lock, an air leak at the fan control unit adapter, and front differentials overfilled with lubricant. Some of these faults can be attributed to errors in the assembly and initial service of the vehicles.

A cracked washer on the key ball screw actuator was noted on one M931A2 tractor. Two exhaust valves were stuck in the open position on another tractor. Finally, an alternator mount flange was noted cracking and causing the mount bolts to loosen on a third vehicle. Again, there was neither pattern nor large number of problems.

The wrecker had problems with oil spewing out of the filler neck on the hydraulic reservoir, hydraulic oil flowing out of the oil tank breathers, and one boom hoist winch case with casting holes.

Operation Desert Shield/Desert Storm Experience

About 4,000 M939A2 series trucks of all variants were used in the SWA campaign. The consensus is that the vehicles performed well. Some problem areas

TABLE 4-4

MC RATES

Report date	Category	M923A2 cargo	M931A2 tractor	M936A2 wrecker
Jul 1990	Reporting	XXX	195	0
	% FMC	XXX	97	-
	% NMCS	XXX	2	-
	% NMCM	XXX	1	-
Aug 1990	Reporting	XXX	195	5
	% FMC	XXX	97	100
	% NMCS	XXX	2	0
	% NMCM	XXX	1	0
Sep 1990	Reporting	292	250	10
	% FMC	98	97	100
	% NMCS	1	1	0
	% NMCM	1	2	0
Oct 1990	Reporting	351	230	10
	% FMC	98	97	100
	% NMCS	1	2	0
	% NMCM	1	1	0
Nov 1990	Reporting	457	368	34
	% FMC	96	97	87
	% NMCS	3	2	1
	% NMCM	1	1	12
Dec 1990	Reporting	388	412	60
	% FMC	95	98	94
	% NMCS	3	2	3
	% NMCM	2	0	3
Jan 1991	Reporting	299	206	30
	% FMC	94	95	95
	% NMCS	5	3	3
	% NMCM	1	2	2
Feb 1991	Reporting	443	289	38
	% FMC	92	95	91
	% NMCS	6	5	5
	% NMCM	2	0	4

Notes Reporting = number of vehicles reported upon
 % FMC = percentage fully mission capable
 % NMCS = percentage not mission capable for supply
 % NMCM = percentage not mission capable for maintenance
 xxx = data not available

that did not appear in operational testing were noted, however. They were generally not mission-threatening.

The CTIS registered problems because of the difficulty in maintaining adjustment of the valve system. In order to keep the CTIS free of air leaks, it is necessary to adjust the torque periodically on connector nuts and bolts. This adjustment should be done to pairs of connectors evenly, so that tension remains approximately equal. Soldiers often adjusted one connector completely before turning to the corresponding part, sometimes causing misalignments and leaks in tubing near the connectors. The indication is that more durable components may be needed in the CTIS and that adjustment instructions should be more obvious.

Tire wear was also a problem. While it is not uncommon for tires to wear during heavy use in rough terrain, the wear observed in the operation seemed to be related to suspension problems.

Finally, some structural components and brackets developed cracks because of the vibration associated with almost continuous operation. The most prominent problem concerned the spare tire carrier bracket.

None of the problems mentioned in preliminary discussions were mission-threatening.

SUPPORT SYSTEM SUITABILITY ISSUES

In this section, we discuss the results of the M939A2 IOT&E and field experience for operational suitability components that relate to system support. We present specific information on test procedures when it is critical to support our discussion

Logistics Supportability

Test Results

The only logistics support problem noted for the M923A2 cargo truck and M931A2 tractor concerned the system support package (SSP). While the SSP was sufficient in quantity, it was insufficient in type. Thirty-four parts were needed during IOT&E. Of these parts, 15 were in the SSP and 19 had to be ordered.

Special tools provided were also insufficient. An air seal test kit was not available. The punch for removing the bearing cups from the wheel hubs was not tempered correctly and broke several times during normal use. The puller set used for removing the fuel injection pump was too small. A deep well socket needs to be added for removal of the straight air connector on the rear wheel hub. A deep well socket is also needed for removing the nuts from the wheel rim assembly.

Repair parts were the most significant logistics support problem for the wrecker. An exhaust gasket, pipe flanges, "O" rings for fuel tank drain plugs, and a modified tachometer adapter on the engine access cover were the critical parts needed and not available [3].

Discussion of Results

System support package problems noted during IOT&E were easy to correct and were judged low risk for delaying fielding, even though the criterion was considered not met at the time of the test.

Documentation

Test Results

Draft manuals were employed in both IPT and IOT&E. These manuals met the standard of being simple and readable at the eighth grade level. There were, however, some concerns raised about the manuals for all three variants.

In general, the manuals were incomplete, confusing at times, missing caution statements, and lacking in troubleshooting information.

Discussion of Results

At the time of the IOT&E, the manuals needed to be revised and the criterion was not met. This was true for all three variants. However, during the test, required revisions were noted, and these changes were provided at a session on 15 December 1988. The revisions met the criterion.

CONCLUSIONS

General

The Army Operational Test and Evaluation Agency, on the basis of the results of the IOT&E and supporting information from the IPT, concluded that the M939A2 cargo and wrecker variants were operationally effective and suitable. It recommended that fielding be contingent on application and verification of the corrective actions identified for the faults noted during IOT&E.

The Transportation School noted in its independent evaluation that the M939A2 series is superior to the M939A1 series that it is replacing. This consideration clearly affected the final judgment on operational suitability.

In its separate IOT&E, the M936A2 wrecker was judged not to be operationally effective and suitable. This conclusion acknowledged that, while some problems that did exist were low risk issues with programs in place to correct them, the light front end was sufficient reason to delay fielding. The Ordnance Center and School also recommended delay in fielding until the front-end problem was corrected. The Army Material Systems Analysis Agency took a similar position. All of the agencies rated the M939A2 as superior to the M939A1.

Correction of Faults

The program to correct faults identified during IOT&E was effective and appears to have enhanced the performance of the M939A2 in the field. Table 4-5 lists the corrective actions taken in response to the identified problems.

All of the problems were addressed, and verification of the fixes was pending only in the areas of the tie-down shackles, cold starting, the engine shut-off solenoid, and the front winch.

Central Tire Inflation System

The CTIS was the most innovative feature on the M939A2 series truck. Its criterion was a minimum of 12,000 MMBSF. Because only 8,398 miles were accumulated in IOT&E, no conclusion was reached.

During IPT at Yuma Proving Ground, 14,349 miles were driven with no failures. This performance met the criterion. At Aberdeen Proving Ground,

TABLE 4-5
SOLUTIONS TO PROBLEMS IDENTIFIED DURING TESTING

Problem area	Corrective action
Transportability	Addition of 2 shackles, improved bolts
Salt-water fording	No changes required, waterproof system
Cold starting	Additional grounding straps, rerouting of preheate exhaust
Front winch	Limit hydraulic circuitry to 17,000 pounds
CTIS quick dump valve	Cover over quick dump valve
Fan belt	Kevlar belt with time-delay fan clutch
Manuals	Corrected and verified
Bearing cup punch	Refabricate tool and heat-treat
Mirror bracket	No change required
Transmission check	Modify manual to call for cold check
Power steering	Add power steering fluid cooler
Maintenance platform	No change required
Engine seal	No change, seal will reseal
Deep-water fording	Test redone successfully
Cold test CTIS	Vent system at wheel valves
Gauges	Replace grounding bolts
Electrical protective control box	Modify coating on one set of contacts
Wiper hose	Replace with new-specification hose
Cab bushings	Replace with larger bushings of different material
Engine shut-off solenoid	Added boot to cover solenoid
Battery location	No change; batteries inside to protect from environment
Tire changing	Procedure revised
Electromagnetic interference	Add 2-microfarad capacitor

however, 10 reliability failures were noted for a computed MMBSF of 4,161 miles. Air leaks accounted for 7 of the 10 failures. Some of these failures were attributed to inconsistencies in the operator's manuals (crew members were not allowed to perform minor tightening of some screws and bolts that would have prevented the faults). Had the crew been allowed to make adjustments, and the air leaks avoided, the MMBSF would have been 13,870 miles. On the basis of the additional IPT data, the CTIS was judged operationally suitable, pending changes to the manuals.

Summary

The M939A2 series 5-ton truck did not represent a dramatic leap in technology. Rather, it is part of a continuous purchase within the M939 series. This continuous development, combined with the aggressive program to correct faults noted in testing before completion of the testing, produced a suitable system for the M923A2 cargo truck and M931A2 tractor. We found no evidence to suggest that operational suitability problems not noted in IOT&E were occurring in the field.

The M936A2 wrecker displayed more serious problems with the light front end. The solution was being developed by TACOM.

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CHAPTER 5

LANDING CRAFT AIR CUSHION

INTRODUCTION

System Description

The Landing Craft Air Cushion (LCAC) is a high-speed (greater than 35 knots), fully amphibious landing craft capable of carrying a 60-ton payload. LCAC can travel over both land and water, exposing 70 percent of the world's beaches to amphibious assault (as opposed to 17 percent with conventional landing craft). LCAC operates from well-deck-equipped amphibious ships of the LSD-41, LSD-36, LPD, LHA, and LHD types. The role of LCAC is to transport, ship-to-shore and across the beach, weapon systems, material, cargo, and personnel organic to the assault elements of a Marine Corps air/ground task force. The LCAC embarks material, troops, and/or supplies; is launched from a well deck; transits at high speed to the beach being assaulted; transits the surf zone and beach; proceeds to a suitable offload site; offloads rapidly; and returns to the amphibious ship for reload and follow-on sorties [1].

Background

The LCAC is the culmination of the Advanced Amphibious Landing Craft (AALC) program begun in the mid-1960s to explore alternatives for a future generation of landing craft to replace the World War II-technology craft then in the fleet. The most promising landing craft identified in these concept studies was a 60-ton-capacity air-cushion vehicle (ACV) [2].

The ACVs operate by using fans to blow large volumes of air below themselves to lift off from the surface. A flexible skirt system contains these cushions of air when the ACV is moving above either land or water. A unique feature of ACVs is that, when operating over water, they cease to produce a large wake when traveling in excess of certain "hump" speeds, greatly reducing the amount of energy needed to propel the vehicle at high speeds.

The AALC program continued through the 1970s with two prototype JEFF craft (the Navy had traditionally called landing craft classes by men's first names). The two prototypes were developed by Aerojet General Corporation (JEFF A) and Bell Aerosystems Company (JEFF B), which later became Bell Aerospace and then became a division of Textron. The two craft were to be functionally and dimensionally identical but would employ variations of the technology. Original plans calling for the two companies to produce two production prototypes, JEFF C and JEFF D, were scrapped because of resource constraints.

The JEFF craft were operationally evaluated by the Navy's Commander, Operational Test and Evaluation Force (COMOPTEVFOR) during a series of tests from 1979 to 1981. COMOPTEVFOR found the craft to be potentially operationally effective and potentially operationally suitable and recommended that the JEFF craft be approved for full-scale development.

Initially, the LCAC acquisition strategy called for production of two craft using FY82 funding, to be followed 3 years later -- after testing -- in FY85 with production of 10 craft. Production would proceed at 10 craft per year thereafter. On the basis of the LCAC's perceived low technical risk, the Deputy Secretary of Defense waived Milestone II for the craft. Milestone decision authority was subsequently delegated to the Secretary of the Navy. The Navy revised the acquisition schedule of the first 12 craft to be 3 in FY82, 3 in FY83, and 6 in FY84, with testing of the first 3 craft to be completed before the award of a contract for construction of additional craft [3].

The development contract for the first 12 craft was awarded to Bell (later Textron), which had developed the JEFF B craft. LCAC 001 was delivered by Bell in December 1984 and immediately began a period of developmental testing (DT) in late December that continued through January 1985. In January 1984, the Navy had started actions to contract for a second manufacturer of LCAC. This contract was awarded to Lockheed (Avondale Gulfport Marine). Table 5-1 summarizes early program history.

Operational test and evaluation (OT&E) of the first production craft (LCAC 001) occurred in February 1985. LCAC was found to be potentially operationally effective but not operationally suitable, as a result of numerous system failures [4].

TABLE 5-1
LCAC PROGRAM SUMMARY

Period	Number contracted	Total under contract	Approvals	Deliveries (during period/ total)	Testing
FY82 1Q 2Q 3Q 4Q	12	12	IIIA LRIP		
FY83 1Q 2Q 3Q 4Q					
FY84 1Q 2Q 3Q 4Q			2nd source		
FY85 1Q 2Q 3Q 4Q	2	14		1/1	DT-IIIA1 OT-IIIA potentially effective/ not suitable DT-IIIA2
FY86 1Q 2Q 3Q 4Q				1/2 1/3 1/4	DT-IIIB1 OT-IIIA2 no change OT-IIIA3 potentially suitable
FY87 1Q 2Q 3Q 4Q	2 17	16 33	continue low rate IIIB full production	2/6 1/7 2/9 1/10	OT-IIIB effective/suitable

Following the finding of "not suitable," FY85 procurement of nine craft was postponed and another phase of operational testing (OT-III A2) was scheduled for August 1985. This phase was specifically to make it possible for COMOPTEVFOR to find LCAC potentially suitable, to permit additional limited production. Following several delays in certifying readiness for OT-III A2, FY86 production was also delayed. Later, limited production was authorized to keep the Bell/Textron production line open.

When OT-III A2 was conducted in May 1986, COMOPTEVFOR found that problems with LCAC 002 and the limited period of operations did not warrant a change in the previous finding of not suitable. COMOPTEVFOR recommended accumulating additional time on-cushion and correcting deficiencies before repeating the test [5].

When OT-III A3 was conducted in June 1986, LCAC was found to be potentially suitable. On the basis of this finding, low-rate production was allowed to continue [6].

When OT-IIIB of LCAC was conducted in April 1987, the craft was found to be suitable, although additional testing was recommended on employment of multiple craft (OT-IVA) and in arctic conditions (OT-IVB). OT-IVA was subsequently canceled because the critical issues had been adequately demonstrated in the field during deployments and exercises. OT-IVB arctic testing is scheduled for the spring of 1992 [7, 8].

System Status

Thirty-three LCACs had been fielded as of 30 June 1991, with craft on both coasts. An additional 39 are under contract. The Navy plans to buy a total of 84. In Operation Desert Shield/Desert Storm, the craft served as a major portion of General Schwarzkopf's amphibious feint. A total of 20 of the 21 craft then in the fleet were deployed during Operation Desert Shield mobilizations (17 to Southwest Asia; 3 to Liberia and later to the Eastern Mediterranean) [9].

OVERALL SUITABILITY

We have identified five significant suitability issues having an impact on LCAC. Three of these are related directly to the craft's design and production, while two are related to its support. The issues related to the end item itself are reliability,

corrosion, and maintenance of the basic craft (as opposed to its components). The issues related to LCAC support are supply and manpower and training. Of these issues, reliability is the most significant and was the only issue identified during operational testing.

Reliability of the early LCAC (LCACs 001 and 002) was poor. During the first period of operational testing (OT-III A), LCAC was found to be not operationally suitable because of repeated material failures. Two more periods of operational testing were required before LCAC was found to be potentially operationally suitable. In the interim, acquisition of 17 craft was deferred. Ever since identification of the early reliability problems, the Naval Sea Systems Command (NAVSEA) has, through its engineering agents, been engaged in modifying the craft to increase its reliability. Mean time between critical failures on the craft is currently over three times the LCAC goals established in the system's Top Level Requirements (TLRs).

Although some minor deficiencies were noted, corrosion was not identified as a major suitability issue during operational testing. Corrosion has emerged as a significant issue in the field, consuming over a man-year per craft each year in routine cleaning and inspections and additional time repairing the effects of corrosion when it is discovered. To fix corrosion-related problems, over 150 (mostly minor) modifications have been made to the craft or to its components.

Field experience in craft maintenance has required changes in the LCAC maintenance concept. Under the original concept, LCAC did not require a depot overhaul at any point during its life cycle, relying instead on removal and replacement of components -- which could be sent to depots for overhaul -- and repairs as necessary. A mid-life overhaul was instituted in response to corrosion problems; the need to repair the basic structure, piping, and electrical systems; and the desirability of upgrading the craft with a large number of alterations. The craft's structure has also consumed a large number of maintenance man-hours spent repairing fuel tank cracks and damage from bumps and collisions. An alteration has been developed to eliminate the fuel tank problem. The maintenance concept was not an issue in OT&E.

Supply support of LCAC through the Defense supply system has been poor, causing reliance on the interim support contractor for longer than originally planned.

OT&E addressed supply support as a limitation in scope during early testing, and it identified some shipboard sparing shortages during later testing, but it did not specifically address the wholesale supply system.

Manpower and training of LCAC craftmasters has been a problem in the field. LCAC acts like both a surface craft and an aircraft. Operators "fly" the LCAC, and its controls are very similar to those of an aircraft. LCAC craftmasters, the primary operators of the craft, originally were planned to be chief boatswain's mates. Boatswain's mates have traditionally operated the Navy's small craft and tugboats. In the past few years, a high percentage of craftmasters have failed training on ACV operation. The Navy is beginning to screen craft operators for psychomotor skills and has opened the craftmaster billet to other rates. This problem was not identified during operational testing.

Suitability issues affecting LCAC have been identified both during OT&E (reliability) and after (corrosion, craft maintenance, supply support, and manpower and training) it. The program manager has conducted an aggressive program to provide effective solutions and implement corrective actions.

END-ITEM SUITABILITY ISSUES

Reliability

LCAC reliability has been critical since the initiation of the program as a successor to JEFF. The TLR and Navy Decision Coordinating Paper for LCAC specify a program reliability goal (0.94 probability of a successful 90-minute mission), threshold (0.90), and acceptable level during operational testing (0.86) (this acceptable level implicitly assumes some growth in reliability). The documents define a reliability, maintainability, and availability (RMA) scenario timeline for use in evaluating LCAC reliability. They also define a basic assault mission scenario that differs in duration from the RMA mission scenario.¹ (See Tables 5-2 and 5-3). By direction of the Chief of Naval Operations, operational testing of reliability was conducted using the RMA scenario, because the RMA scenario represent a more typical average utilization of LCAC [9, 10, 11].

¹The RMA scenario is less stringent, defining a shorter mission than does the basic assault mission scenario, as a result of shorter transit times. Also, the basic assault scenario calls for multiple missions.

TABLE 5-2
TIME DIFFERENCES BETWEEN TWO LCAC TLR MISSION
SCENARIOS

Basic assault scenario (minutes)	LCAC activity	RMA mission scenario (minutes)
5 ^a	Leave well	5
20	Loiter ^b	20
35 – 40 ^c	Transit to beach	15
15	Transit beach/surf	5
	Unload	5
	Transit beach/surf	5
35 – 40 ^c	Transit to ship	15
5 ^a	Enter well	5
15 ^a	Reload	15
Unknown ^d	Refuel	N/A
130 – 140	Total	90
260 – 280	Repeat mission	N/A

^a Event assumed to take same amount of time as RMA event.

^b Loiter can occur at any point in mission.

^c Based on basic assault mission scenario distance (24 nautical miles).

^d Can occur partially in parallel with reloading.

TABLE 5-3
MTBF (HOURS) NEEDED TO ACHIEVE SPECIFIED
RELIABILITIES FOR VARIOUS MISSION LENGTHS

MTBF = $\frac{-t}{\ln R(t)}$	Mission reliability [R(t)]		
Mission length	.86	.90	.94
90 minutes	9.95	14.24	24.24
130 minutes	14.37	20.56	35.02
140 minutes	15.47	22.15	37.71
260 minutes	28.73	41.13	70.03
280 minutes	30.94	44.29	75.42

Reliability was the most significant suitability element regarding LCAC. Initial operational testing found LCAC unsuitable and caused deferral of the FY85 and FY86 projected buy of 17 crafts. Since the initial findings, LCAC has experienced significant reliability growth.

Operational Test and Evaluation Results

LCAC was found not suitable in its first two OT&Es, primarily for reasons of reliability. During its first operational test (OT-III A), conducted by COMOPTEVFOR during February 1985, the first production LCAC experienced 35 critical or major failures² and numerous deficiencies. (See Table 5-4.)

Among the more significant of these were gearbox, drive shaft, and radar failures; bow thruster malfunctions; and numerous electrical problems with power distribution and control, and alarm and indication circuitry. In the February 1985 test, mission reliability was 0.61, in contrast to the TLR specifications of 0.86 for acceptability. Availability was 0.61 versus the specified 0.70. Observed availability on demand (no specification) was 0.57, based upon 20 missions of 37 called for [4].

A repeat of the suitability portion of OT-III A (OT-III A Phase 2) was conducted in May 1986. At the last minute, LCAC 002 was substituted for LCAC 001, which had problems with material. During this phase, the craft experienced seven critical/major failures and a number of deficiencies. (See Table 5-5.) COMOPTEVFOR also noted a number of severe limitations in the testing. These included

- Testing was limited to suitability issues only.
- "The limited duration of OT-III-A-Phase 2 precluded a determination of the reliability of propulsion, lift, control, electrical, electronic, lubricating, and hydraulic systems."
- Extra personnel were used to maintain and operate the craft.³

²A critical failure on LCAC is defined as one that occurs after a mission begins and prevents the craft from loading or off-loading combat vehicles and cargo, accelerating through hump speed with a design payload, sustaining above-hump speed, or maintaining adequate command and control interface with the beachmaster or task group commander. A major failure is one that would have likely led to the mission's cancellation if it had been discovered prior to the start of the mission.

³According to program personnel, this extra manning was provide additional crew training and was the decision of the Assault Craft Unit's commanding officer.

- Special logistic support was available.
- LCAC 002 had accumulated an insufficient number of on-cushion operating hours to enable COMOPTEVFOR to evaluate the configuration changes made to improve reliability.

TABLE 5-4
COMOPTEVFOR EQUIPMENT RELIABILITY FINDINGS
DURING LCAC OT-III A

Critical/major failures	Canon plugs and transducers ^a Craft control circuits ^a Electrical shorts ^a Latching valve on lube oil reservoir Rudder and bow thruster controls Heading/pitch/speed/roll indicators ^a Smoke alarms Lube oil leaks from propellers Offset and engine gearboxes ^a Lube oil cooler Engine auto start shutdowns ^a Lift fan drive shaft Scavenge fans ^a Bow thruster motors ^a Fuel transfer pump Propeller centerbody dome hinges Skirt/fingers/keelbag Cushion vanes Bow ramp dogging device LN-66 radar Auxiliary power unit (APU) fuel nozzles ^a Chip indicators ^a Blow-in doors ^a Hydraulic ruptures ^a Fuel fill valve actuator circuit
Deficiencies	Windshield wipers/motors Bus-tie circuit breaker Deck switches Exposed leads Fuel shutoff valve High speed log Anemometer Fuel oil tank heaters Propeller leading edge delaminations Yoke and petal bind Propeller centerbody dome hinges

^a Multiple failures.

TABLE 5-4

**COMOPTEVFOR EQUIPMENT RELIABILITY FINDINGS
DURING LCAC OT-III A (Continued)**

Deficiencies (continued):	- Fuel coalescer drain valves - Leaky spaces - Foreign object damage screens - Fendering - Windshield washer - Skirt spray suppressor bonding - Skirt hold-back straps - Tie downs - Radar had no connection for dummy load - Tie down rails could not be cleaned - APU fuel nozzles - Navigation lights - Air conditioning units - High frequency antenna coupler - Switches: - APU low pressure - Fuel pump low pressure - APU pressure - Alarm monitoring system lacks indicator check capability - Indicators: - Heading - Gearbox pressure - Hydraulic quantity - Rate of turn - Fuel/water - Low lube oil pressure - Engine air inlet pressure - Lube oil pressure - Alarms/warnings: - Lube oil high temperature
----------------------------------	--

COMOPTEVFOR found that the limited scope and results of OT-III A2 did "not warrant a change in the previous finding of not suitable." [5]

The suitability retest of LCAC (OT-III A3) was repeated during June 1986 following repairs and an extensive period of operations to accumulate operating hours on LCAC 002. The retest was initially halted after four of 10 scheduled missions because of equipment failures. All 10 missions were conducted following the restart of testing. Three critical or major failures occurred during this phase of testing. (See Table 5-6.) During this period, MTBF (critical failures) was 12.25 hours

TABLE 5-5
COMOPTEVFOR EQUIPMENT RELIABILITY FINDINGS
DURING LCAC OT-III A2

Critical/major failures	Hydraulic leaks ^a Bow thruster bearings ^a Gearbox chip indicator ^a Skirt and fingers
Deficiencies	Transducer failures Windshield wiper Smoke detectors False alarms (but improved over OT III-A) Skirt system Fendering Anemometer Air vanes (bow thruster) Propeller blade leaking grease Window leak

^a Multiple failures

in comparison to the level implied in the TLR of 9.95 hours to achieve a 90-minute mission reliability of 0.86. Observed availability (no specification) was 0.70, based upon 7 successful missions started of 10 attempted. LCAC was found to be potentially suitable [6].

During April 1987, LCAC OT-III B was conducted. This testing involved two craft (LCACs 003 and 004) and accumulated nearly 100 operating hours. During this phase of testing, LCAC experienced 10 critical or major failures. Table 5-7 summarizes LCAC reliability during each phase of operational testing to date. After OT-III B, LCAC was found to be suitable except for deficiencies with spurious alarms and the windshield wiper system [7].

Field Experience

Reliability in the field has been much greater than that observed during all phases of operational testing. The program office [through the Naval Coastal Systems Center (NCSC) – the in-service engineering agent for LCAC – and the two shipbuilders – one of which is also the interim support contractor for LCAC supply,

TABLE 5-6
COMOPTEVFOR EQUIPMENT RELIABILITY FINDINGS
DURING LCAC OT-III A3

Critical/major failures	First attempt: Longitudinal stability bag Bow thrusters Actual OT: Ruptured hydraulic line Bow fingers Main engine oil pressure alarm
Deficiencies	Lube oil leaks Radar antenna motor Windshield wiper motors Blow-in doors Scavenge fans Alarm transducer and canon plug Lift cushion vanes Engine control channel circuit Utility pump casing Gearbox sprayed oil Flight data display Propeller blades to new grease Lift fan rubbing Lift fan shaft coatings Longitudinal stability bag end cap

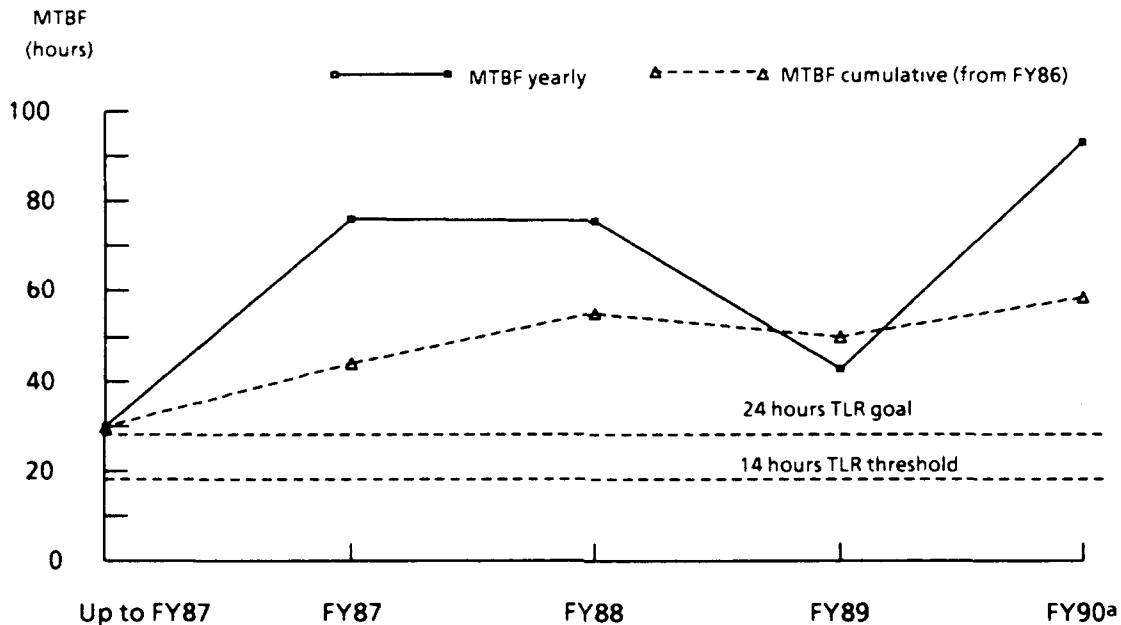
TABLE 5-7
LCAC RELIABILITY DURING OPERATIONAL TESTING

Phase	Date	Operating hours	Critical failures	Major failures
OT-III A	February 1985	107.0	11	24
OT-III A2	May 1986	54.2	3	4
OT-III A3	June 1986	24.5 ^a	2	1
OT-III B	April 1987	99.3	3	7

^a Reliability evaluation included 150 hours accumulated on cushion.

engineering, and training] has maintained an aggressive program to improve LCAC reliability. The increased reliability is due to configuration changes and to improvements in operating and maintenance procedures [9, 12].

The results are impressive. FY90 mean time between critical failures (all causes) was over 90 hours, more than 3 1/2 times the system goals established in the TLR (see Figure 5-1) [13].



Source: LCAC reliability and maintainability summaries produced by NCSC [13].

Note: Rates reflect all critical failures, including those caused by operator error and by failures of other components.

^a includes data through June 1990 only.

FIG. 5-1. LCAC MEAN TIME BETWEEN CRITICAL FAILURES

Corrosion

The materials used in fabricating the JEFF craft had to be inherently corrosion-resistant (or permanently protected, as appropriate) to continuous exposure to a salt-water environment, and the electrical system had to be suitable for marine use and for the anticipated vibration levels [14]. This critical operational issue was satisfactorily resolved during testing of the two JEFF craft [15]. Corrosion was not

specifically addressed during LCAC testing. Corrosion has been a maintenance problem in the field.

Operational Test and Evaluation Results

The LCAC OT-III reports covering LCAC's 001, 002, 003, and 004 do not discuss any suitability issues related to corrosion. Some minor corrosion (principally due to standing water from debris-clogged drains and to improper sealing of electrical boxes) was noted, but corrosion was not identified as a potential future maintenance problem during OT&E.

Field Experience

Following delivery of LCAC 001 in December 1984 to Assault Craft Unit 5 (ACU 5), the accumulating LCAC field experience presented a growing list of corrosion sites throughout the aluminum hull, electrical junction boxes, standard nonmarine machinery, and LCAC-unique components. A corrosion survey team was formed in 1985 from NAVSEA and ACU 5 personnel to study and recommend appropriate inspection/maintenance procedures. A formal corrosion control program was instituted on 14 October 1987; oversight was provided by an corrosion control team comprised of members from NAVSEA; NCSC; Naval Ship Systems Engineering Station; Supervisor of Shipbuilding, Conversion, and Repair, Boston; ACU 4; and ACU 5. The program is basically a preventive maintenance program involving specialized training courses for all LCAC personnel and including post-mission, biweekly, and quarterly cleaning, inspection, and preservation tasks. Unlike other LCAC maintenance activities, corrosion control requires deployed detachment preventive maintenance to the same level as ACU maintenance [16]. The currently allocated quarterly labor hours per LCAC for these tasks are

Cleaning	200
Inspection	150
Preservation	<u>110</u>
TOTAL	<u>460</u> hours/quarter/craft.

Personnel responsible for LCAC corrosion control maintenance are required to document all failures and damage, to produce an informal logbook for each craft for simultaneous tracking of problems, preventive actions, and new corrective actions possibly requiring design modifications or alterations. To date, more than

150 (mostly minor design modifications have been authorized to hull, machinery, electrical, and piping components, and more than 100 material preservation procedures have been activated to overcome corrosion problems identified during routine and corrosion control team inspections.

Deficiencies identified during inspections are entered in a class item file (a class item is any specific deficiency that appears on more than one vehicle). The number of individual corrosion site citations grew to a maximum of 282 (out of a total of 503 class items from all causes), and as of October 1990, there were still approximately 75 open items (identified corrosion sites that had not been repaired or altered on the vehicles inspected up to that date) [17, 18].

The program's effectiveness in closing out (by means of repairs or vehicle modifications) sources of corrosion is shown in Figure 5-2. The beginning of the corrosion control program is identified at the start of FY88. Few corrosion repair sites are indicated for the first four LCACs (FY85 and FY86), because the contractor, under the terms of the original contract, corrected deficiencies as they were found, and the extent of the corrosion problem was not known until sufficient operational hours had been accumulated.

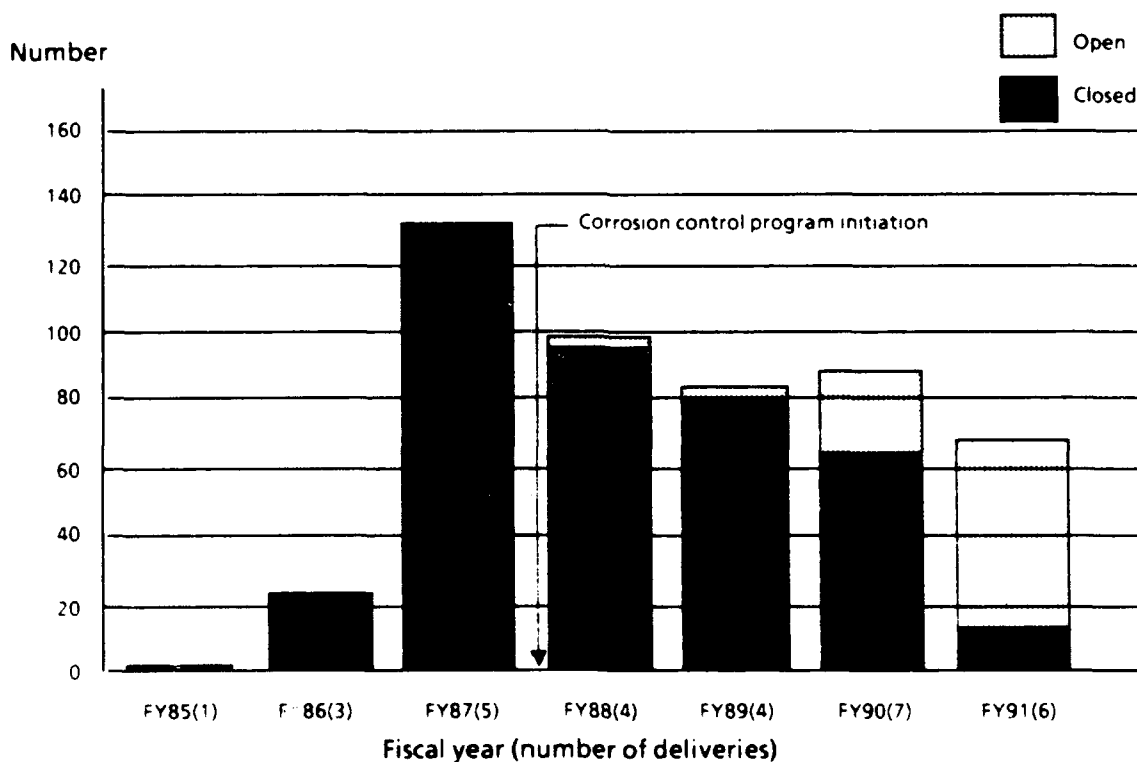


FIG. 5-2. NUMBERS OF CORROSION REPAIR SITES, BY FISCAL YEAR

Although the level of effort expended – approximately one full-time equivalent for corrosion prevention maintenance – is substantial, the corrosion control program seems worthwhile in having overcome the original material design deficiencies.

Maintenance of the Basic Craft

Operational Test and Evaluation Results

During OT&E, the early unreliability of a number of hull and machinery components focused corrective actions on reliability improvements. Maintenance was more commonly associated with repair and replacement of damaged or faulty components than with prevention. The operational plan called for the ACUs to assign approximately two-thirds of their shore element to the maintenance department, divided between the power-plant, structural, electrical, and electronics divisions. Depot-level maintenance of components was to be accomplished on a remove-and-replace basis, with removed components shipped to the appropriate depot for return to stock. No depot period was planned for the LCAC hull itself. From the standpoint of OT&E, viability of the maintenance concept was not an issue [19].

Field Experience

As craft hours in the field increased, cumulative corrosion and vibration effects began to emerge. The corrosion control team's growing experience made it clear that the projected 20-year LCAC service life would be difficult to achieve without a depot repair period for the craft itself. At the direction of the Atlantic Fleet, NAVSEA has instituted a mid-life overhaul period for the craft at about the 8- to 10-year point. The 4-month overhauls will take place at the ACUs but will use contractors. At overhaul time, basic hull, electrical power distribution, piping, skirt, and structural repairs will be made. Components will be removed, inspected, and repaired or replaced if necessary; block upgrades will be accomplished as illustrated in Table 5-8. The first of these overhauls will take place in FY92 [9].

Two types of repairs to the craft structure not mentioned in the previous paragraph have been consistent users of maintenance time. The first of these is repairs to fuel tank cracks. Investigations show this problem to be the result of vibrational resonance. Alterations to add stiffeners to the tanks are underway. The problem has been eliminated on those craft that have received the alterations [12, 20]. Also, significant amount of maintenance time is spent fixing damage due to

TABLE 5-8

LCAC MID-LIFE OVERHAUL PLANNED WORK

Inspect and repair or replace	Candidate alterations
Machinery deck • Engine and lift fan modules and propeller shrouds Command and passenger modules • Remove armor, repair corrosion Engine modules • Engines, gear boxes, firewalls, piping and flex hoses, filtration Ramps • Remove, repair, renew traction bars Tanks, voids, penetrations • Open, inspect, repair Propeller shrouds • Propeller, shroud and supporting structures Electrical cables/connectors • Equipment racks, connectors, exposed cabling Hydraulic systems • Rudders, bow thrusters, propellers, tubing, flex hoses, bulkhead penetrations Rudders • Replace Non-skid surfaces • Replace Skirt system • Remove, inspect, repair Hull structural • Stiffeners and plating, drain holes, deck replacement under engine modules	Armor enclosure Frame 15 • Engine lube oil and control systems • Corrosion/debris control Bumper system replacement • Full craft length • Strengthened structure Skirt system • Install improved system • Planing stern fingers Cargo deck strengthening • Support increased weight Cargo tie-down capacity • Increase to 70K tons Install E-Nav • Revamp navigation suite Engine filtration system modifications

bumps or collisions. Most of these repairs are to the fendering system or the structure beneath and around it, although there have been cases of damage to propellers and their shrouds. Bumps and collisions are not due to the design of the craft, but the ability to make repairs following these occurrences is influenced greatly by the design [12].

SUPPORT SYSTEM SUITABILITY ISSUES

Supply Support

The supply system was slow to react to the introduction of LCAC into the fleet. Initial attempts by the ACUs to procure replacement parts from either the Navy or Defense Logistics Agency (DLA) supply stocks were often frustrating. As a result, the program manager has maintained interim supply support much longer than originally intended.

The supply concept for LCAC centers on the ACUs and on their deploying detachments rather than on individual craft. There are only very limited spares (fuses, filters, emergency repair kits, etc.) on board each LCAC. Most spares are carried by the ACUs as authorized by the ACU Coordinated Shipboard Allowance List (COSAL). (The COSAL is the standard means by which the Navy authorizes organizational-level spares for ships.) In addition, NAVSEA has purchased a spares package for each six craft called the Craft Repair and Maintenance Load List (CRAMLL). When a detachment deploys, the number and configuration of craft in the detachment, the length and location of the deployment, and the available storage on board the host ships is factored in to determine what the detachment will carry with it in Pack Up Kits (PUKs). Each PUK is a subset of the CRAMLL and COSAL [21, 22, 25].

The maintenance concept for LCAC calls for many organizational-level (either detachment or shoreside) repairs to be of the remove-and-replace type, with repairable components to be shipped to an organic or commercial depot for repair and return to stock [19].

Operational Test and Equipment Results

Supply support was not identified in OT&E as a major suitability problem for LCAC. Logistics supportability, including supply, was a limitation in scope during both OT-III A and OT-III A2, because special logistics support was provided. Although

it was not an issue in OT-III A3 and was not specifically addressed as a limitation in scope, it is unlikely that the support system changed in the month between OT-III A2 and OT-III A3. Logistics supportability was directly addressed in OT-III B, where some discrepancies were identified in the shipboard availability of spare parts.

Field Experience

With the first LCAC deployments and their associated casualty reports in 1987, supply support emerged as a major issue. The standard Defense supply system did not have many spare parts. The interim support contractor had to provide much more support than anticipated, and many items had long leadtimes, resulting in parts being pulled from production to satisfy emergency requirements [9, 20].

Since most systems on board the craft contain LCAC-unique items, initial stockage of parts by either DLA or the Navy's supply system relied upon contractor-provided provisioning estimates and the timetable for introduction of craft into the fleet. Reliance on the estimates and timetable contributed to the supply system's poor performance in support of LCAC [24, 25].

Many of the LCAC provisioning estimates in logistics support analysis records provided over-optimistic estimates of reliability. The supply system identified many expected low-usage items as "buy on demand." The supply system usually uses demand history to recalculate the expected usage of parts to correct errors. However, when the supply system did not respond, the interim support contractor often furnished the parts. This practice did not generate a demand history for the supply system to use [9, 12].

The second factor contributing to the poor support initially provided LCAC by the supply system is the lack of recognition of the anticipated introduction of craft to the fleet. Evidently, when production was delayed following OT-III A, the supply system expected a total of six craft to be introduced into the fleet. When production was later restarted, the Navy's Ships Parts Control Center (SPCC) was not aware of the planned production levels. In addition, many LCAC-unique items are managed by DLA commodity managers. DLA did not have LCAC identified as a weapon system in its management system and therefore did not build supply inventories to support fleet introduction of craft.

As a result of these factors, the Navy's material support date (MSD) for LCAC – the date on which the normal Navy supply system will fill LCAC requisitions for all items managed by it – has slipped twice. It is currently scheduled for late 1991. DLA has no equivalent to MSD.

NAVSEA identified the supply problems to the Naval Supply Systems Command and DLA in 1988. These organizations reviewed the problem, used demand history provided by the interim support contractor and took action to alleviate the problems. Table 5-9 summarizes LCAC supply support as it existed in 1988 and as it exists now [25].

TABLE 5-9
LCAC REPAIR PARTS STATUS SUMMARY

Type of repair parts	Approximate number of repair parts		
	SPCC-managed items	DLA-managed items	Total
Total LCAC	1,200	16,000	17,200
Total LCAC-unique	700	3,800	4,500
Problem items identified in 1988 by SPCC supportability study and other initiatives	300	2,600	2,900
Current (1 May 1991) problem items supported by interim support	100	300	400

Manpower and Training

This subsection discusses and correlates the OT&E findings/recommendations and field experience regarding LCAC manpower supportability and training suitability. In particular, it emphasizes the issues associated with LCAC craftmaster manpower and training.

The atypical nature of the LCAC environment relative to craft operation, and the corresponding unique manpower supportability and training requirements, were

recognized early in the LCAC acquisition program. These facts were clearly spelled out in the Navy Decision Coordinating Paper dated 21 January 1982 [11]:

V.D. Manpower. The LCAC program manpower requirements have been delineated in a Preliminary Shore Manpower Document.... Changes in capabilities do... not allow direct comparisons with conventional craft requirements.

V.E. Training. The LCAC training approach recognizes the unique operational and maintenance concepts of the LCAC as a new class of landing craft.

The LCAC Preliminary Shore Manning Document (PSHMD) includes a detailed discussion of the differences in required capabilities for operating and maintaining the LCAC. Also, it provides the rationale for manning the LCAC with the following ratings [26]

Craftmaster	BMC
Assistant craftmaster and craft engineer	GSE1/GSM1
Radar operator/navigator	OS2
Cargo handler	BM3
Deck engineer	GSE3/GSM3

The PSHMD also notes that selected Naval enlisted classifications (NECs) are prerequisites for craftmaster candidates. These NECs were chosen to ensure previous familiarity with the Rules of the Road, exposure to small craft "command" responsibility, and experience in amphibious operations, thereby enhancing the candidate's chances of successfully completing LCAC training.

Operational Test and Equipment Results

Training was clearly recognized as an area requiring review and evaluation during the OT&E process. It was specifically called out as an operational suitability issue to be examined during OT-III A, but it was not evaluated with the rigor accorded other elements of the test program. In fact, training was not evaluated during OT-III A Phase 1 (7 - 26 February 1985). It was cited as a limitation that "require[d] additional testing to complete evaluation of operational effectiveness and operational suitability." [4]

One OT-III A Phase 2 objective was to verify that operational suitability issues identified during OT-III A Phase 1 had been corrected. Nevertheless, OT-III A Phase 2 (24 April - 8 May 1986) did not evaluate the operational suitability of training. Training was not specifically noted as a limitation that would require

additional testing, despite the fact that Phase 2 involved the same crew (LCAC 001) that was evaluated during OT-III A Phase 1. Phase 2 also evaluated LCAC 002 and its crew; the LCAC 002 crew had received the same training as the LCAC 001 crew.

OT-III A Phase 3 objectives were the same as those for OT-III A Phase 2. Again, training was not identified as a limitation to the operational suitability testing. Phase 3 (10-20 June 1986) testing results made no mention of the operational suitability of training or manpower supportability except for the following recommendation:

Review manpower and maintenance costs being experienced with LCAC and verify that projected manpower planning and operating costs are acceptable. Review Navy Training Plan to ensure that it reflects actual manpower to be applied to LCAC maintenance. [6]

OT-III B objectives included an operational suitability evaluation of training. OT-III B (7-15 April 1987) found training to be adequate except in the area of electrical system corrective maintenance and troubleshooting procedures.

Field Experience

Since inception of the LCAC training program, NCSC, Panama City, Florida, has been accumulating data on operator candidates. To date, the data base contains information on some 135 students (this constitutes the entire population of LCAC operator candidates who have received training). By correlating the training data, NCSC determined that there was a higher than expected attrition rate for LCAC craftmaster candidates. Specifically, there has been a 20 percent failure rate since 1981 and a 30 percent failure rate between January 1990 and January 1991. These rates compare to a 10 percent failure rate for engineer candidates and a 7 percent failure rate for navigator candidates over the same period. Further review of the data revealed that the most common student weaknesses leading to course failure could be categorized as related to psychomotor skills [12].

In response to the initial finding that craftmaster candidate failures appeared to be directly linked to a lack of psychomotor skills, NCSC initiated a study by the Naval Aerospace Medical Research Laboratory (NAMRL). The purpose of this study was to verify the NCSC findings and to develop a screening test to "identify candidates that lack basic psychomotor skills to operate LCAC." Validity of the screening battery has been completed and "true" predictive testing began in May 1990. Results

indicate that the NAMRL psychomotor screening battery is about 90 percent accurate, with failure rates having decreased to about 8 percent for the craftmaster candidates selected using this screening method [12].

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CHAPTER 6

AV-8B HARRIER II

INTRODUCTION

System Description

The AV-8B Harrier II is a follow-on to the Marine Corps AV-8A/C vertical/short takeoff and landing (V/STOL) light attack aircraft. The aircraft is a single seat, subsonic aircraft powered by a single vectored thrust turbofan engine. Improvements over the AV-8C include extensive use of composite structures, a super critical wing, positive circulation flaps, lift improvement devices, enlarged intakes, and a more powerful engine. It can carry a wide variety of conventional air-to-ground ordnance as well as the GAU-12 25mm gun and the AIM-9 air-to-air missile.

Acquisition History

In 1973, the Marine Corps issued a requirement for an advanced V/STOL aircraft to replace aging A-4s and AV-8As. Milestone I was passed in 1976 with approval to develop two prototype YAV-8Bs. Milestone II followed in 1979 and the first flight occurred in late 1981.

Suitability was a consideration in the acquisition. As the Fleet Supportability Evaluation [1] stated: "Unlike its predecessor, the AV-8A, supportability played a major role during the aircraft design and development process, . . ." Two of the goals of the AV-8B program were to "Improve operational readiness by enhancing reliability and maintainability," and "Provide a rugged aircraft with a lightweight durable structure and a 6000 flight hour life." [2]

As was the case with the AV-8A, the AV-8B is a joint production by British Aerospace and McDonnell Douglas. However, in the case of the AV-8B, McDonnell Douglas is the lead contractor and does most of the manufacturing.

OT&E History

Three phases of IOT&E were conducted prior to the operational evaluation (OPEVAL) (also referred to as OT IIC). These tests totaled 8 weeks during 1982 through 1984. This case study focuses on the results of the OPEVAL conducted from 31 August 1984 to 30 March 1985. OPEVAL was conducted in two phases. Phase I, from 31 August 1984 to 5 February 1985, concentrated on air-to-ground missions and was conducted from a variety of bases encompassing climactic and operational extremes. Phase II concentrated on air-to-air missions flown from Marine Corps Air Stations Yuma and China Lake. Most of Phase I (289 out of 315 flight hours) utilized two pilot-production aircraft. The remainder of Phase I (26 flight hours) and all of Phase II (232 flight hours) utilized two production aircraft.

System Status

By the end of FY91, 238 AV-8Bs will have entered service. They include the TAV-8Bs (the two-seat trainer version of the aircraft) and the night attack version. Current plans call for 22 additional aircraft to be delivered in FY92 and 24 in FY93. Approximately 160 aircraft are now in the 9 Marine Corp squadrons in the fleet. The AV-8B was used in the recent SWA conflict.

OVERALL SUITABILITY

The overall suitability finding of the OPEVAL was: "The AV-8B aircraft is operationally suitable." [3] We will briefly review the test results that led to this conclusion and then compare findings from OT&E with field experience in two categories: findings related to the end item directly, and findings that go beyond the end item and address the logistics system needed to support the AV-8B.

OPERATIONAL EVALUATION

During OPEVAL, the AV-8B met the reliability and maintainability criteria set out in the Test and Evaluation Master Plan (TEMP) [4]. Table 6-1 shows the results. Table 6-2 shows several of these measures plus one other, the arithmetic

mean time to repair, MTTR(a),¹ for each of the four aircraft participating in the OPEVAL. Several points should be noticed in Table 6-2. The first is that the criterion for both MTTR measures is the same. This would not seem to be reasonable because MTTR(geometric) has the effect of lowering the weight of high time to repair values in comparison with MTTR(a), which gives equal weights to all values. One would expect MTTR(g) to be less than MTTR(a) in most cases. It is also interesting to note that MTTR(a) does not meet the criterion of 2.5 hours.

TABLE 6-1
SUITABILITY CRITERIA AND RESULTS FOR AV-8B OPEVAL

Suitability measure	Criterion	Result
Reliability		
Mission reliability	.80	.88
Overall reliability	.57	.86
Mission capable rate ^a	.70	.78
Maintainability		
Mean time to repair, geometric	2.50 hours	1.08 hours
Direct maintenance man-hours/flight hour	18.00 hours	17.10 hours

^a OT&E definition equivalent to fully mission capable.

The second point of interest is that although the average demonstrated direct maintenance man-hours per flight hour (DMMH/FH) of 17.1 hours is less than the criterion of 18.0, only one of the four aircraft met the criterion. The other three aircraft exceeded the stated criterion of 18 DMMH/FH. OPEVAL concluded the average DMMH/FH met the criterion. Another conclusion would be that 75 percent of the test articles failed to meet the criterion. Both are true. Our conclusion is that it might be useful to report not only the point value of the average but also the range

$$MTTR(a) = \frac{\sum_{i=1}^n t_i}{n} \quad MTTR(g) = \exp \left[\frac{1}{n} \left(\sum_{i=1}^n \ln t_i \right) \right]$$

where,

t_i = elapsed maintenance time of the i th maintenance action

n = the total number of maintenance actions.

TABLE 6-2

AV-8B OT&E RELIABILITY AND MAINTAINABILITY DATA

Suitability measure	AC1	AC2	AC3	AC4	Average	Criterion
Reliability mission	85%	86%	93%	89%	88%	>80%
Fully mission capable rate	74%	78%	75%	88%	78%	>70%
Mean time to repair arithmetic	2.9	3.6	3.6	2.5	3.1	<2.5
Mean time to repair geometric ^a	-	-	-	-	1.8	<2.5
Direct maintenance man-hours per flight hour	18.8	19.7	18.3	11.9	17.1	<18.0

Note: AC = Aircraft.

^a Data not available by aircraft from OPEVAL report.

of the values for the test articles. This would give the decision maker a sense of the uncertainty in the test results.

OPEVAL identified several major subsystems whose reliability could result in major readiness degradation and maintenance headaches after fielding, although not of sufficient magnitude to prevent the AV-8B from being suitable. These observations proved to be accurate, as did the overall conclusion that the AV-8B is operationally suitable.

Operational suitability was demonstrated when the AV-8B achieved extremely high MC rates (reportedly above 90 percent) and reliability in the SWA conflict. Moreover, this performance was achieved with a minimum of extraordinary efforts. The regulation maintenance manning prevailed as did reliance on previously defined pickup kits of spares. Contractor support forward was not relied on to any great extent.

Field Experience Data Sources

We have relied on two primary sources for field experience. The first is the Navy 3-M system for readiness and maintenance data. This includes the (NAMSO) 4790 series [5], which contains data on not mission capable (NMC) impacts by five digit work unit code (WUC) and on the DMMH by maintenance level and type of work. Other sources of 3-M data used were the Fleet Supportability Evaluation (FSE) Phase III performed from February 1985 to June 1986 [1], the Fleet

Supportability Evaluation Assessment (FSEA) performed July 1986 to June 1987 [6], and the Fleet Supportability Evaluation Phase IV, Post Deployment Phase performed from October 1987 to March 1988 [7]. Phase III recorded the experience of Marine Air Group 32 (MAG 32), which is made up of the first AV-8B squadrons fielded, and Phase IV was based on the experience of VMA-231 squadron deployed at sea on the U.S.S. Nassau. These latter sources also provided useful commentaries beyond the numerical 3-M-type data.

The other primary source of data is a set of interviews conducted with AV-8B program office personnel, Product Support Directorate personnel, and squadron maintenance personnel. This last group was our primary source for field data from Operation Desert Storm/Desert Shield.

COMPARISON OF OT&E RESULTS WITH FIELD EXPERIENCE

Figure 6-1 shows the MC rate observed in OT&E (78 percent, which exceeded the criterion of 70 percent) and the MC rates achieved over the last 5 years for the AV-8B. Field experience for fully mission capable (FMC) rates achieved met the rate observed in OT&E only in two quarters in early operations. Since that time, FMC rates have failed to achieve that experienced in OPEVAL. MC rates have also declined from early experience and have fallen short of the goal of 80 percent set for the AV-8B (the goal was recently changed to 76 percent).

The FSE report predicted that MC rates would decline because of a one-time replacement of stainless steel control cables with carbon steel control cables² and because of a decline in spares availability. The FSEA report observed that a decline in spares availability continued to plague the program, but the situation was improving. It also observed that delivery of logistics support elements for support equipment (SE) remained a problem, particularly for the Electronic Equipment Test Set.

²This control cable substitution resulted from fraying of the control cables. This fraying was not noted in OPEVAL although it had been noted in the Initial Sea Trials of the AV-8B, which took place in 1984 [8]. At that time a fix was implemented that changed the material in the fairleads. The report stated "Due to the long term wear type failure mode, a large number of flight-hours will be required to verify the contractor's corrective action is a Part**IK deficiency which must be corrected prior to deployment." Evidently this fix was not good enough and the cable material had to be changed. The failure of OT&E to identify the problem may result from its being a "long term wear type failure mode."

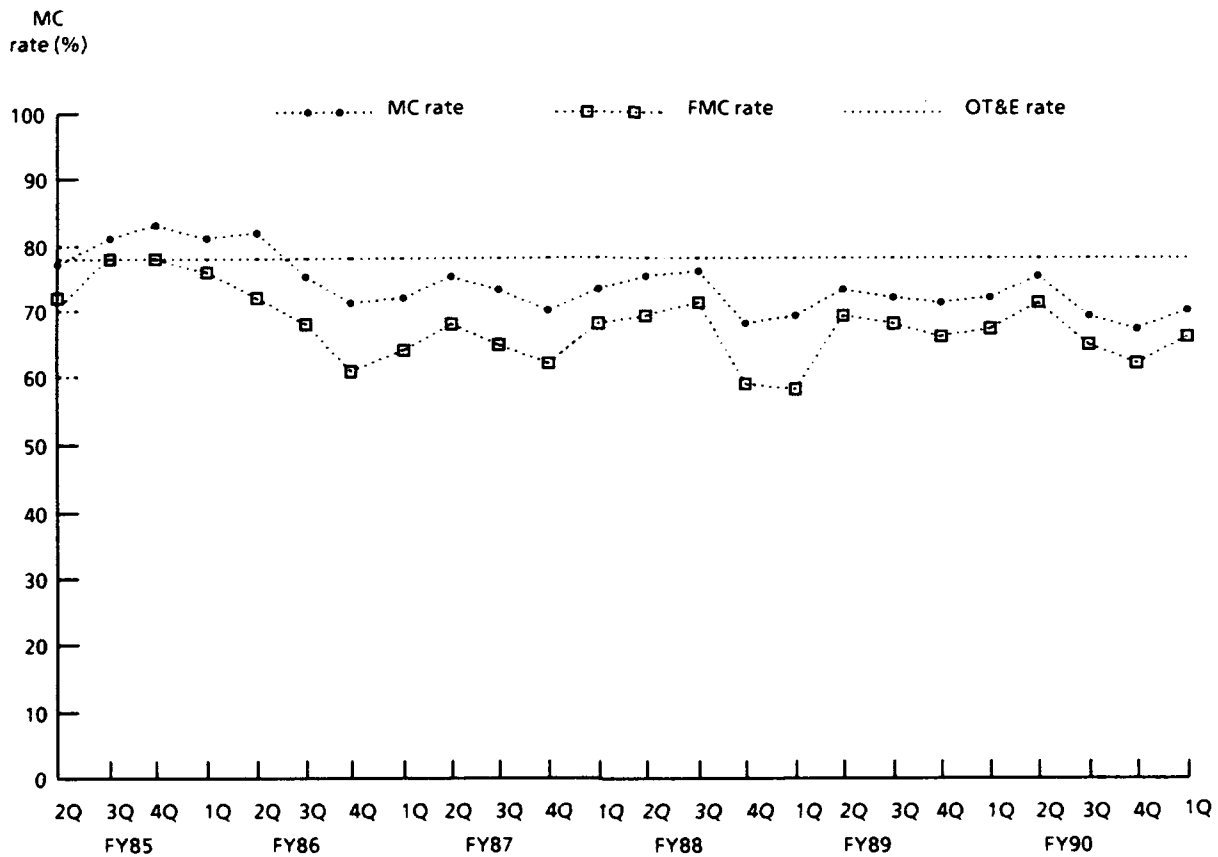


FIG. 6-1. AV-8B MISSION CAPABLE RATES

Currently, field personnel attribute the lower-than-desired MC rate to supply problems and reduced maintenance manning. A parallel symptom of this may be the increasing I-level maintenance turnaround time being experienced. (Average turnaround times have increased monotonically from less than 10 days in 1986 to 1987 to over 16 days in 1990 to 1991.)

It is interesting that, although in peacetime the MC rates are lower than the goal of 80 percent, the wartime MC rate was well above that goal. (It is also of interest that the MC rate goal for deployed AV-8Bs is 85 percent.) Because OT&E is designed to simulate wartime conditions, this wartime performance is the appropriate indicator for true operational suitability. However, it might be desirable to also set goals and measure suitability in a peacetime environment. This would be

useful in that most of the time a system is possessed is in peacetime and that is when most of the costs of ownership are incurred.

Figure 6-2 shows the DMMH/FH observed in OT&E, and the most comparable field experience numbers available (O-level DMMH, including scheduled and unscheduled Maintenance Actions and Support Actions). Many factors can influence the behavior of DMMH/FH. For example, if flight hours go down in a month and maintenance hours remain constant, then DMMH/FH goes up. If maintenance hours go up in response to a supply problem, then DMMH/FH will go up, particularly if the supply problem results in grounded aircraft (which reduces flight hours). Suffice it to say that there was a great deal of volatility in the experienced DMMH/FH in the early years (FY86 and FY87). In the later years (FY88 through FY90), the value of 17.1 DMMH/FH observed in OPEVAL was a remarkably good indicator of actual field experience, as Figure 6-2 shows. The last quarter of FY90 includes August, which may show some effects of preparing for deployment to SWA.

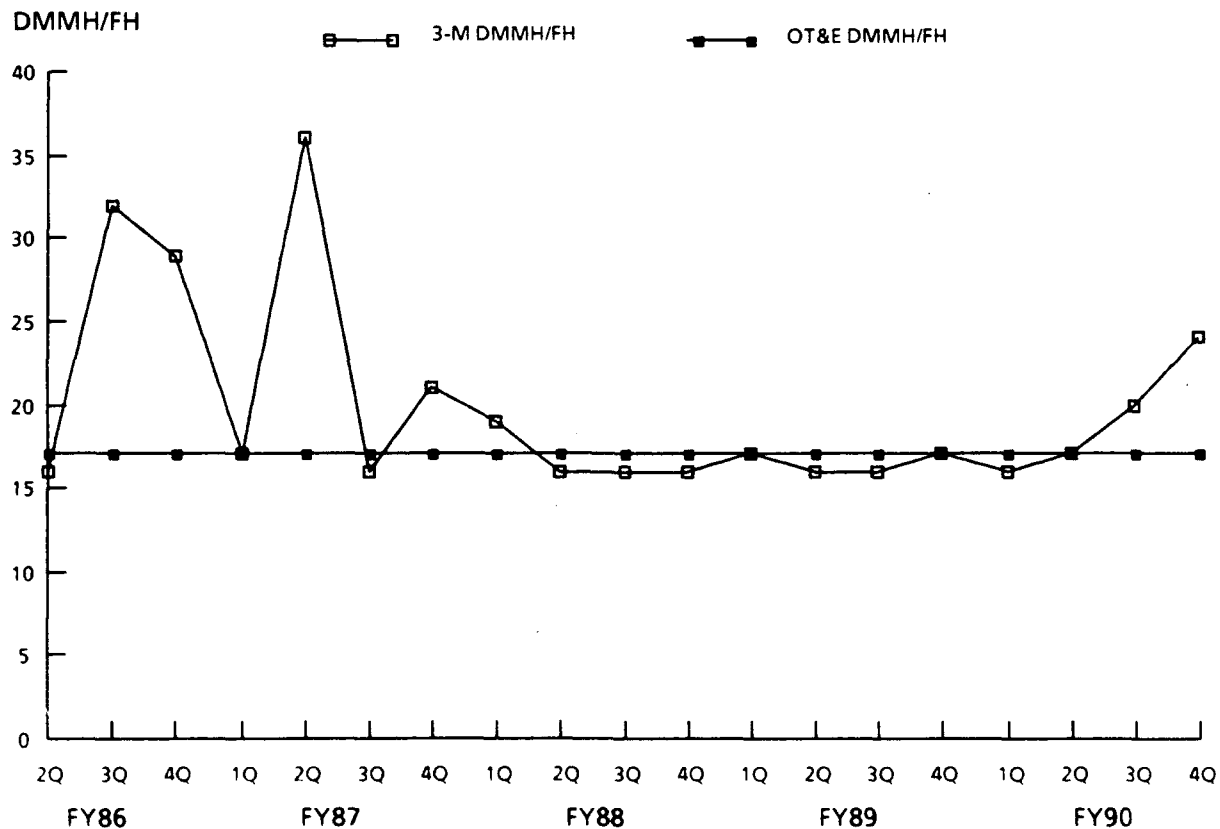


FIG. 6-2. AV-8B DIRECT MAINTENANCE MAN-HOURS PER FLIGHT HOUR

END-ITEM SUITABILITY ISSUES

Some specific suitability problems were identified during OT&E. They were not considered sufficiently large to render the aircraft not suitable, but they could prevent the program from achieving full potential. The specific items and their current field status are discussed below.

Reliability Issues

Air conditioning system: OPEVAL found the capacity of the air conditioning system and its reliability to be a problem. Currently, field personnel consider that the system's limitations originate from the desire for light weight. The system is not designed to cool the cockpit on the ground, but reliability is no longer a problem.

Gas Turbine Starter/APU: The GTS/APU is a continuing problem. One of the two GTS work unit codes has appeared on the "top 25 not mission capable list" 14 out of the last 15 quarters. (Navy 3-M Aviation SCIR Impact Ranking Summary [5]. In SWA, the I-level could not test the GTS/APU in theater, which contributed to the problem.

Generator: The VSCF Generator failed frequently during OPEVAL (6 times requiring replacement, 12 times experiencing transient failures.) It has continued to appear on the "top 25" list (11 of 15 reports), and it also ranks eleventh on the list³ of DMMH consumers, although the problems noted in OPEVAL have been fixed.

Communications system: The communications system experienced multiple problems during OPEVAL. There are still persistent problems with the radios, connectors, and wiring. The RT1250 radio, for instance, has been on 11 of 15 NMC reports and is the sixth largest DMMH consumer.

Mission computer/memory loader verifier: The difficulties with this system observed in OPEVAL have been fixed, and current maintainers do not find it a problem.

³September 1990 AV-8B *Top Twenty Mission Degraders* report [9] by the Program Support Directorate. Data are for the period July 1989 to June 1990.

Maintainability Issues

Weapon system troubleshooting: Weapon system troubleshooting is no longer perceived as a major problem in the field. There was a problem with Maverick documentation availability in the SWA theater.

Composite repair: Composite repair was flagged as a potential problem area in OPEVAL. It has not proven to be a major field problem, although problems with certain doors and the delamination of flaps made of composite material are still difficulties.

Horizontal stabilator – rivets and tips: These areas exhibited problems in OPEVAL following air combat maneuvering. The problems remain. Part of the maintenance burden results from the fact that the parts are not interchangeable between aircraft. We were told that this problem resulted from a decision made during contracting to save money by choosing not to buy interchangeability. The AV-8A did have interchangeable parts.

Table 6-3 summarizes the status of the above end-item issues, as well as some lesser ones noted in OPEVAL. As can be seen from Table 6-3, in many cases, the problems identified during OPEVAL have persisted. In addition, those problems that have been fixed were all real problems at one time. Therefore, it appears that OPEVAL was a good indicator for field experience.

Some problems that were not indicated in OPEVAL have been showing up in the field. Among these are aircraft heatshields, recurring inspections, the sealed lead-acid battery (SLAB), and the steering unit valve. The first two of these are examples of problems stemming from cumulative effects.

The heatshields have to be repaired frequently. To perform this repair, the rivets are drilled out and replaced with larger rivets. After repeated replacements, the rivet area has to be rebuilt. This process has led to the heatshield always being on the "top 25" NMC degraders list and on the "top 20" DMMH list.

Recurring inspections are the top DMMH user. This situation may not be atypical, but it is an area that the OPEVAL report did not discuss. Inspections may be taking longer as the system ages, although we were not able to document whether this is true for the AV-8B.

TABLE 6-3

COMPARISON OF OT&E AND CURRENT FIELD EXPERIENCE

Problems identified in OT&E	Current field observation	
	Fixed	Still problem
GTS/APU0		X
Generator		X
Communications systems		X
Mission computer/memory loader verifier	X	
Weapons system troubleshooting	X	
Composite repair – Doors 12L and 12R		X
Horizontal stabilator – rivets and tips		X
Spare fiber optic cable – position	X	
Pylon electrical connector jackscrew – broke, no spare		X
AN/URT-33A emergency radio beacon – on/off switch stepped on, broken	X	
External fuel panel assembly – position leads to breakage		X
Constant frequency generator – wire chafing, shorting	X	
Engine removal/installation – clearance, damage, fuel leaks		X
Coaxial connectors – easily damaged		X
Flap BIT low reliability	X	
Post-departure resistance BIT – transient failures	X	

The SLAB and the valve are problems stemming from the supply system. The SLAB has exhibited higher than expected failure rates. A replacement battery was procured, but it was even less reliable. Therefore, the expected life of the original SLAB was downgraded to 350 flight hours. It was reported to us that at some point the supply system neglected to stock the SLAB as a life-limited item, and consequently, a shortage developed at the field level. In response, the I-level started to remanufacture the batteries and the battery became the top consumer of I-level DMMH. As discussed in the following section, the ability of the organic supply system to support the AV-8B was not tested.

These examples are adduced to illustrate that some support problems may be difficult to observe during OT&E.

SUPPORT SYSTEM SUITABILITY ISSUES

The capability of the Marine Corps/Navy logistics system to support the AV-8B was not raised as a major issue in OPEVAL. This was partly because of test limitations and partly because most of the elements tested were satisfactory (e.g., O-level documentation and maintainer training). Test limitations of extensive contractor support and no Fleet Marine Force I-level support precluded testing major items of support equipment, much of the documentation, and I-level training.

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CHAPTER 7

LANTIRN NAV POD

INTRODUCTION

System Description

The Low Altitude Navigation and Targeting Infrared System for Night (LANTIRN) was developed to provide Tactical Air Force (TAF) a capability to conduct close air support, battlefield air interdiction, offensive counterair, and air interdiction missions at night and below weather. It is designed for use on the F-16C/D and F-15E aircraft.

The system has three major components: a wide-field-of-view head-up display (WFOV HUD), a targeting pod (TGT pod), and a Navigation (NAV) pod. Because the WFOV HUD development is assigned to the aircraft program offices and the targeting pod has not been fielded in quantity, this case study examines the NAV pod only.

The NAV pod contains a forward-looking infrared receiver (FLIR), a terrain-following radar (TFR), a pod control computer, a power supply, a servo-control, and environmental control subsystems. Figure 7-1 shows the major subsystems of the NAV pod. The pod is approximately 78 inches long, 12 inches in diameter, and weighs 430 pounds. The FLIR provides an unmagnified (one-to-one) thermal image of the external scene for display on the WFOV HUD. The TFR provides a signal to position a HUD terrain-following cue that the pilot uses for manual terrain following. In addition, an automatic terrain-following capability is included.

Acquisition History

Figure 7-2 summarizes LANTIRN's development history. The full-scale development contract award was made in late FY80. The NAV pod Milestone IIIA approval was obtained in April 1985, and the production contract was awarded 2 months later. The NAV pod received Milestone IIIB approval in February 1986. In

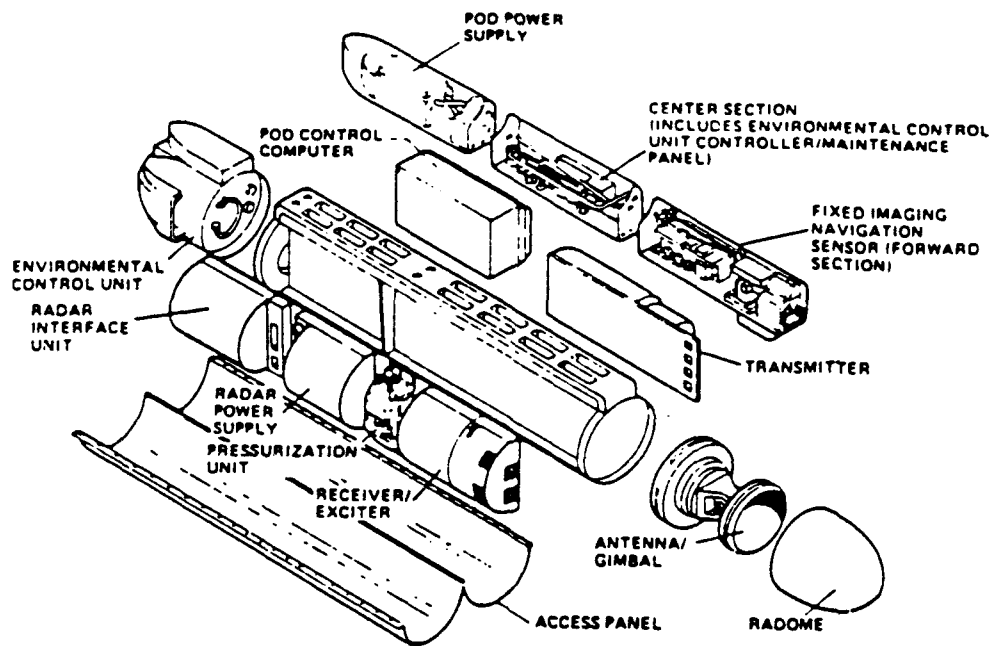


FIG. 7-1. MAJOR SUBSYSTEMS OF THE NAV POD

January 1987, the first production NAV pod was delivered. Production increased from 5 pods per month in May 1989 to the full rate of 18 pods per month in August of 1990. By the end of 1990, 275 pods had been produced. The total quantity of 561 pods is to be completed by May 1992.

There were three NAV pod production lots: Lot 1 – pods 1 and 2; Lot 2 – pods 3 through 9; Lot 3 – pods 10 and up. No additional lots are planned at this time. Lots 1 and 2 are being used for flight tests at Edwards AFB and for maintenance training at Lowry AFB. The system program office (SPO) plans to upgrade Lots 1 and 2 to the current configuration.

System Status

As of early 1991, NAV pods were deployed to three F-15E bases and five F-16 bases. Over 15,000 sorties and 30,000 operating hours have been accumulated on NAV pods.

LANTIRN INTEGRATED MIL

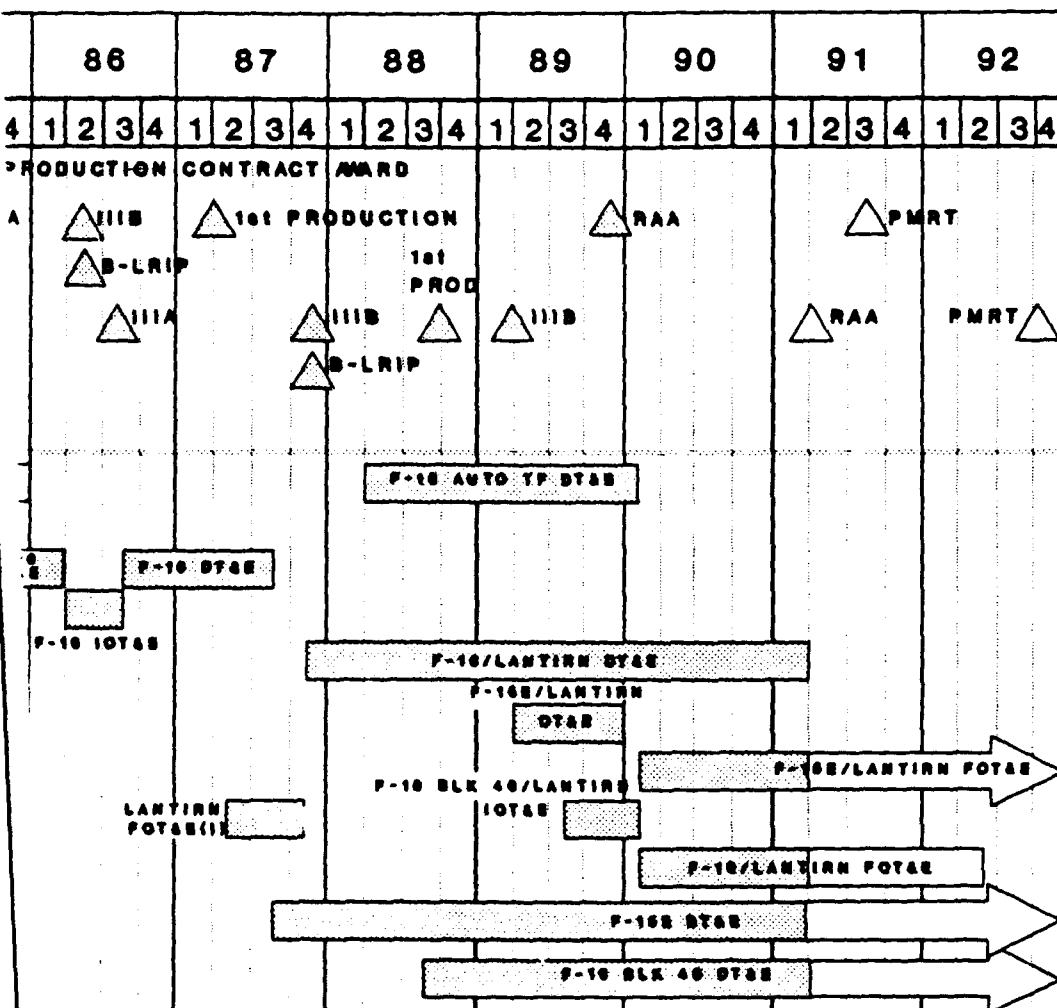
	FY 82				83				84				85			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PROGRAM MILESTONES	4th QTR: FY 82 F&D CONTRACT AWARD															
HEAD-UP DISPLAY/ NAVIGATION POD																△ P △ IIIA
TARGETING POD																
TEST MILESTONES																
HEAD-UP DISPLAY/ NAVIGATION POD																P-10 ST&E
TARGETING POD																P-10 ST&E
TOTAL SYSTEM INTEGRATION																P-10 ST&E

02-004

FIG. 7-2. LANTIRN DEVI

①

ESTONES AND TEST SCHEDULE



OPR:SMO-L

ELOPMENT HISTORY

2

SUITABILITY SUMMARY

The NAV pod progressed from "not operationally suitable" in its first OT to "operationally suitable" in follow-on OT&E (FOT&E). Field experience shows that the system is indeed suitable. In SWA, the NAV pod demonstrated MC rates and reliability that met or exceeded requirements without use of extraordinary support measures.

We found several suitability issues of particular interest. First, the OT&Es used reliability growth projections to estimate pod reliability at maturity (defined to be 10,000 cumulative operating hours). FOT&E(1) demonstrated a mean time between maintenance for inherent failures of 38 hours and a mission reliability of 0.93, figures that did not satisfy the respective requirements of 49.6 hours and 0.96. As late as 2 years after FOT&E(1), the pod did not meet the reliability requirements. Recent evidence from the field and the results of the contractor's reliability qualification test indicate that the pod now exceeds both requirements. One interpretation of this sequence is that OT&E was used as part of the system maturation process.

Maintainability evaluations are the second issue of interest. Contractor maintenance was used for all of the OTs. To evaluate the planned organic maintenance concept, the Air Force used a combination of judgment and modeling. Maintenance technicians made "over the shoulder" judgments of the time and difficulty of repair tasks by observing the contractor's efforts. These judgments were combined with projected failure rates in a computer simulation to compute maintenance measures. In addition, the modeling assumed high availability of spares and fully effective support equipment. The impact of the optimistic modeling assumptions was not addressed in the test reports. Field experience has not contradicted the model's estimates of system maintenance time.

Support equipment (SE) is the third suitability issue of interest. The OTs had no explicit criteria for SE [even though the System Operational Concept (SOC) contained detailed requirements], and SE was not available for the OTs. Operational units are able to maintain the pod with the SE, but the SE does have some problems that might have been avoided. These field problems with the SE have included excessive failures, difficulty in obtaining spare parts, and long test times attributable to the SE software.

END-ITEM SUITABILITY ISSUES

Availability

All of the OT&E reports rated NAV pod availability was rated as satisfactory. These ratings were judgments not based directly on test measurements. The only availability criterion was that the overall system be 80 percent fully mission capable (FMC) [1]. While the support concept called for organic maintenance, the OTs all used contractor maintenance. Accordingly, maintenance times were estimated by Air Force technicians. The availability ratings were based on Air Force Operational Test and Evaluation Center's (AFOTEC's) projection of the pod's mature reliability, organic maintenance times, and support system performance.

The initial OT&E [IOT&E(1)] report rated availability as satisfactory, even though mission reliability was marginal, logistics reliability was unsatisfactory, and maintainability was unsatisfactory.

In IOT&E(2), availability "was projected to meet the user's requirement of 80 percent FMC at maturity" [2]. Maturity was defined as 10,000 cumulative pod operating hours. The projection was obtained by exercising a LANTIRN version of a standard Air Force computer simulation, the Logistics Composite Model (LCOM), with projected reliability, projected maintenance times, an operational scenario, and logistic support assumptions. The last two inputs were provided by the Tactical Air Command (TAC). The scenario was one 24-aircraft squadron operating for 7 days at 3 sorties per aircraft per day. Key assumptions included full war readiness spares kit (WRSK); 100 percent manning; two spares each of line-replaceable units (LRUs), and unlimited shop-replaceable units (SRUs); and no maintenance downtime for the test station. Under all of the optimistic assumptions, LANTIRN's projected FMC rate system was 0.86 to 0.88, exceeding the 0.80 system requirement.

The FOT&E(1) report rating of "satisfactory" was predicated on achieving of the projected reliability growth. The NAV pod did not demonstrate the required availability level in OT&E. As in IOT&E(2), computer modeling was used to estimate LANTIRN's maintainability and availability. FOT&E(1) used the same model as IOT&E(2) - but more realistic LRU sparing assumptions - and projected that the availability of the mature system would be 0.87 to 0.92 [3].

LANTIRN system availability now exceeds the original goal of 80 percent. For most of the period from May 1989 through October 1990, the NAV pod FMC rate was higher than the current TAC standard of 85 percent [4]. Between August 1990 and April 1991, the NAV pod MC rate ranged from 85 percent to 90 percent and averaged over 87 percent [5]. The awaiting-parts rates during this period were in the range of 10 to 15 percent. In only a few cases were pods not mission capable because they were awaiting maintenance.

Reliability

Reliability of the NAV pod is measured in terms of mission reliability (weapon system reliability, WSR) and logistics impact (mean time between maintenance-inherent, MTBM-I). The original requirements for the NAV pod were $WSR = 0.96$ and $MTBM-I = 49.6$ hours [1].

In the first OT, neither reliability requirement was satisfied. Corrective actions were taken in response to observed failures. At the completion of FOT&E, AFOTEC projected that the mature NAV pod would have satisfactory reliability. While the pod did not meet its reliability requirements until over 2 years after completion of FOT&E, NAV pod reliability now exceeds the original requirements. The reliability drivers were accurately identified by OT&E, with one exception. The environmental cooling unit (ECU) failed over five times as often as predicted. The following paragraphs discuss the history and current status of NAV pod reliability.

Reliability evaluations for OTs are performed by AFOTEC, after the test data have been reviewed by a committee known as the Joint Reliability and Maintainability Evaluation Team (JRMET), whose purpose is to provide a common test data base for all interested parties. The LANTIRN JRMET members are AFOTEC, Air Force Flight Test Center (AFFTC), TAC, and the SPO. Typically, contractor representatives attend JRMET meetings as technical advisors. The JRMET codes failures as inherent (Type 1), induced (Type 2), cannot duplicate (CND)/re-test OK (RTOK) (Type 6), or test-unique (Type X or 9).

While the JRMET attempts to reach a consensus on failure coding, AFOTEC did not agree with all of the LANTIRN JRMET recommendations. In 1987, the JRMET stated that "it is unnecessary to code recurring events for which [the contractor] has a fix in-hand" [6]. The JRMET eliminated three types of recurring failure events: coolanol leaks due to faulty hose clamps, regenerator and bearing

failures in the cooler/detector assembly, and fixed imaging navigation sensor (FINS) video failures due to a broken motherboard. AFOTEC took the position that these events should be coded, since eliminating the events "would give an unrealistically optimistic picture of the LANTIRN system" [7].

In IOT&E(1), mission reliability was rated as marginal and logistics reliability as unsatisfactory. The NAV pod parts with excessive failures were the FLIR cooler/detector assembly, the terrain-following radar transmitter (TFR XMTR), and the NAV pod power supply. The contractor undertook corrective actions to improve the high-failure items.

In IOT&E(2), mission reliability was still rated marginal, but logistics reliability was judged satisfactory. The MTBM-I was measured to be 32 hours and was projected to be 55 to 89 hours at maturity, compared to the mature requirement of 49.6 hours. The current estimate of WSR was 0.92, and the projected mature result was 0.95 to 0.96, compared to the mature requirement of 0.957. The projections were based on (1) corrective actions incorporated and verified during flight test and (2) future corrective actions planned by the SPO. Notable NAV pod failures were coolanol leaks, water intrusion, and built-in test (BIT) problems.

In FOT&E(1), both reliability measures were rated as satisfactory. The ratings were based on reliability growth projections. Table 7-1 shows the FOT&E(1) observed and projected reliability values by subsystem versus the LANTIRN criteria.

The WSR results in Table 7-1 are higher than those observed during the test. Many erroneous BIT failure indications that could have resulted in needless mission aborts were known from previously reported deficiencies in the fault-reporting software. These BIT failure indications were omitted from the WSR calculations [3]. If they had been included, the WSR estimates would have been lower.

For both reliability measures, the NAV pod projections exceed the mature criteria. The growth projections were made according to the procedures in MIL-HDBK-189. However, none of the OT&E reports documented the specific assumptions or computations used.

A separate AFOTEC report [8] on the reliability growth projections was located. This report identified two key assumptions used: (1) system reliability will continue to grow at the same rate as demonstrated during test, and (2) all fixes incorporated in

TABLE 7-1

LANTIRN RELIABILITY

Reliability measure	FOT&E(1) observed	FOT&E(1) mature projection	Mature criterion
MTBM-I (hours)			
System	18	27 - 36	27
WFOV HUD	127	127	125
NAV pod	38	60 - 89	50
TGT pod	47	77 - 112	108
WSR			
System	0.85	0.90 - 0.92	0.92
WFOV HUD	0.98	0.98	0.98
NAV pod	0.93	0.95 - 0.97	0.96
TGT pod	0.93	0.96 - 0.97	0.98

production will be at least 70 percent effective. The report contains no justification for these two assumptions. In addition, it implicitly assumes that no new failure modes will occur in the field, and that the rate of fixes in the future will be the same as the rate prior to the report.

The reliability growth report [8] used several transformations of operating-time data. MTBM-I was computed using effective operating hours (OH_{ef}). The report provides equations showing OH_{ef} as a function of cumulative operating hours, pod-operating time, total pod sorties, a "ground equivalency factor" (8.4), reliability growth test time (i.e., laboratory time), and a "laboratory equivalency factor" (3.0).

No rationale for the time transformations was documented. We were told by an AFFTC analyst that the rationale was not clear at the time the report was written, and that the guidance to use them came from the SPO. Our interpretation is that the equations show OH_{ef} as equaling the sum of actual flight hours for the pods, 1/2 hour for each pod sortie, a fraction (1/8.4) of additional pod operating time on aircraft or support equipment, and a fraction (1/3) of laboratory operating time. This result is reasonable if the true failure rates during the various operating modes are in the proportions indicated by the fractions. If, on the other hand, virtually all of the

failures occur during actual flight time, then MTBM-I should be based only on flight time and on inherent failures that occur during flights. Using the reported transformations would inflate the MTBM-I estimate. The data necessary to resolve this issue could not be located.

The AFFTC performed flight tests on the F-16C/D Block 40 aircraft and Stage III avionics. Development test and evaluation (DT&E) of the Stage III avionics was performed between 1 December 1987 and 31 March 1989; IOT&E of the Block 40 F-16C/D aircraft was performed between 2 May 1989 and 2 November 1989. The reliability and maintainability (R&M) results, published in June 1990 [9], indicated that NAV pod reliability was unsatisfactory. In particular, AFFTC recorded 12 inherent failures in 181.2 flight hours for a demonstrated MTBM-I of 15.1 hours, a value far below the TAC goal of 49.6 hours. A joint message form in the appendix of [9] provided additional data. For the F-16C/D, the NAV pod experienced 30 failures in 581.1 flight hours for a demonstrated MTBM-I of 19.4 hours. For the F-15E, the pod experienced 11 inherent failures over 725.3 flight hours for a demonstrated MTBM-I of 65.9 hours. Combining the data from the two aircraft, the demonstrated MTBM-I is 31.9 hours.

Flight testing of Lots 1 and 2 has continued at AFFTC. Recent AFFTC results indicate significant improvement in NAV pod reliability [10]. Based on cumulative pod time since August 1987, the MTBM-I is 40.2 hours. The current instantaneous MTBM-I is over 56 hours, exceeding the TAC goal.

The current AFFTC estimate of the mean time between Type 6 failures (which are "cannot duplicates" and "re-test OKs") is approximately 105 hours. In other words, the pod has about one additional failure indication for every two inherent failures. Also, AFFTC's current estimate of the mean time between total corrective maintenance is about 21 hours. Combining these estimates indicates that the pod experiences one induced failure every 48 hours.

Field results indicate that NAV pod reliability currently exceeds the mature requirements. We could not perform an exact comparison, since available field data are inadequate to compute WSR and the MTBM for the various types of failures. The NAV pod data suffer from the usual problems in accurately recording maintenance events and determining the failure type (e.g., inherent, induced, cannot duplicate). However, a larger problem was locating data on pod operating times. The squadrons

equipped with the pods do not use them on all sorties. Also, the sorties vary in duration, and the pods may or may not be active for the entire sortie. The following paragraphs discuss the field data that were available.

According to TAC, NAV pod sortie effectiveness was about 97 percent through the first year of operation [11]. "Sortie effectiveness" is the probability that the NAV pod will work reliably long enough to accomplish the mission. The mission reliability goal was stated in terms of WSR, which is the probability that the pod will be reliable for an entire sortie (nominally of 1-hour's duration). Because a pod could fail after the mission objective is accomplished, sortie effectiveness is greater than or equal to WSR.

To compare sortie effectiveness of 0.97 to the WSR goal of 0.96, we hypothesized a 1-hour mission that requires the pod to operate for 40 minutes to accomplish the mission objective. Also, we assumed that the pod remains active for the final 20 minutes of the mission. Setting the 40-minute reliability equal to 0.97, and assuming an exponential failure distribution, will derive an imputed failure rate of 0.0457 failures per hour. The corresponding 1-hour reliability is 0.955, quite close to the WSR goal.

The production contract included a reliability incentive of \$14 million. The amount awarded to the contractor is a function of the number of relevant failures during a reliability qualification test (RQT) in which two pods are operated under specified environmental conditions for specified times. The first RQT was held in 1989. The pod failed. The second RQT, which accumulated 1,100 hours on two pods from November 1990 through May 1991, was successful. (While four relevant failures were observed, up to seven were allowed with no decrement of the incentive.)

Reliability and maintainability data for LANTIRN are collected by TAC. The SPO and the contractor classify the failures as inherent, induced, or CND/RTOK. Figure 7-3 shows the MTBM-I results for the first 10 months of 1990 [12]. Those data represent over 12,000 flight hours of Lot 3 pods. The figure shows that MTBM-I of the total population exceeds the required value of 49.6 hours. Most of the data points below the requirements are from Luke AFB, which is a training base.

We received some comments and data on pod reliability during Operation Desert Storm. LANTIRN maintenance personnel from Hill AFB and Seymour Johnson AFB, as well as TAC personnel, were strongly satisfied with the reliability.

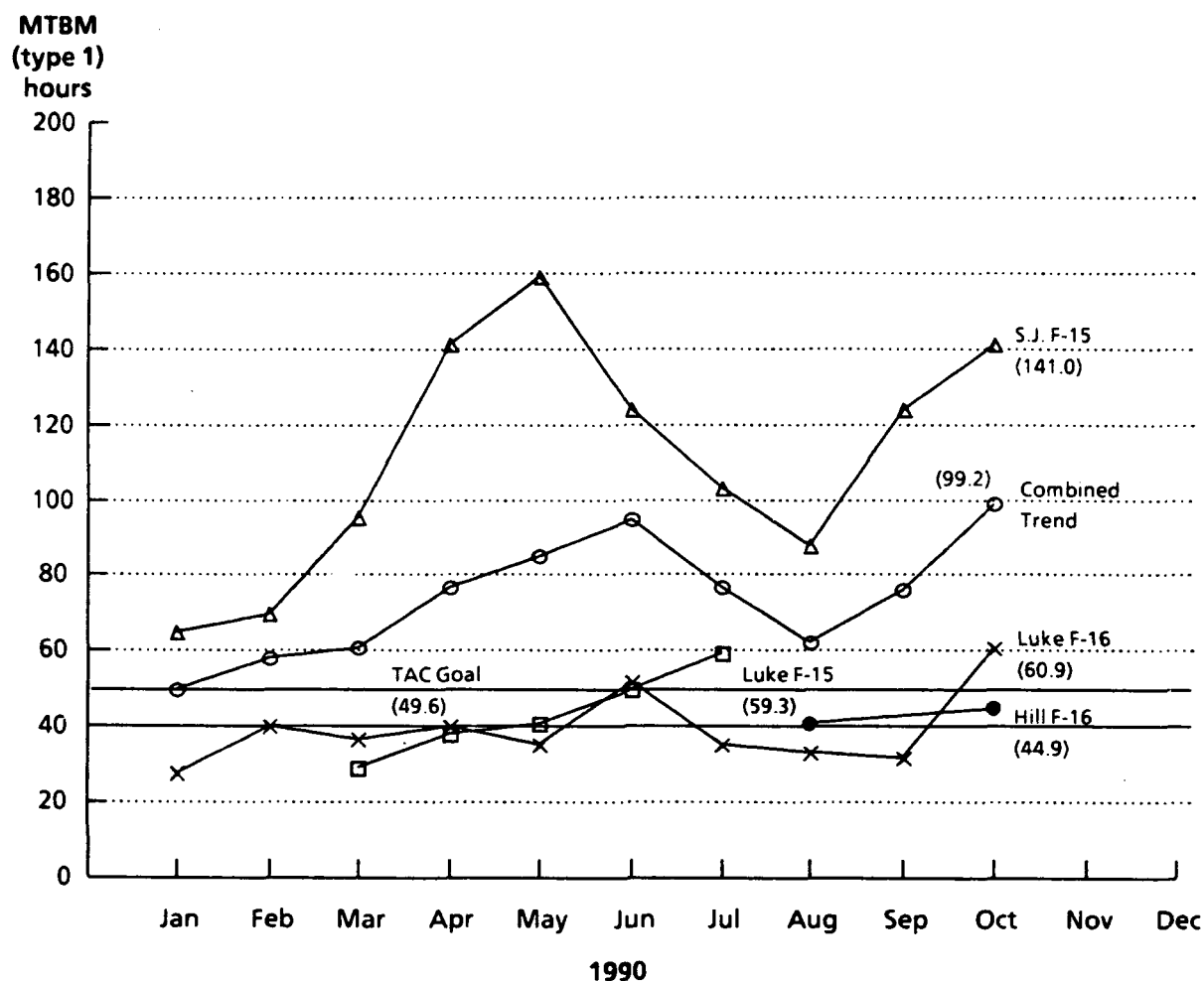


FIG. 7-3. THREE-MONTH MOVING AVERAGE OF MTBM-I FOR THE LANTIRN NAV POD
(BASED ON TAC DATA SCORED BY THE SPO AND THE PRIME CONTRACTOR [12])

During March 1991, the NAV pods on the F-15Es from Seymour Johnson AFB were operated for 2,900 hours and 797 sorties. There were 761 sorties with no pod failures. In 28 of the sorties, the pods had failures that reduced capability but did not prevent the mission from being accomplished. Only 8 sorties had pod failures that caused the pod to be unable to perform its mission. This performance corresponds to a mean time between mission failure of 362 hours. The NAV pod reliability was 0.954, and the sortie effectiveness was 0.989.

We investigated part demand data as another indication of the rates at which parts were failing in the field. Data were obtained from the depot – Warner Robins Air Logistics Center (WRALC) – and the LANTIRN prime contractor – Martin

Marietta Electronic Systems (MMES). Given demand rates based 50 percent on predictions and 50 percent on actual experience, the total demand rate for spares is 0.0226 demands per hour (computation based on the MMES briefing on the subject [13]). The corresponding probability of one or more demands in a 1-hour mission is 0.978. Because some failures do not result in demands, and multiple demands can occur for a single pod failure, this figure is not equivalent to WSR – but it should be approximately the same as WSR, which had a mature criterion of 0.96. Table 7-2 summarizes these reliability findings.

TABLE 7-2
NAV POD MISSION RELIABILITY

Source/basis	Sortie effectiveness	WSR	MTBM-I (hours)
Goal	None	0.96	49.6
FOT&E(1) – observed		0.93	38.0
FOT&E(1) – projected		0.95 – 0.97	60 – 89
AFFTC – F-16 tests			31.9
AFFTC – current			56.0
TAC/SMO-L	0.97	~0.96	
F-15E (1991)	0.99	0.95	80.6
WRALC-MMES		~0.98	
SPO/Contractor			79.8

Figure 7-4 shows the inherent (Type 1) failures of Lot 3 NAV pods for the first 10 months of 1990. The number of observed failures is less than two-thirds of the number predicted by the contractor. Furthermore, the figure for mean flight hours between inherent failure is 79.8, which exceeds the MTBM-I requirement of 49.6 operating hours.

The major reliability problems today are the FINS, the environmental control unit (ECU), the power supplies, the TFR XMTR, the receiver/exciter (R/E), and the antenna/gimbal (A/G) assembly. These components account for about 90 percent of the pod failures shown in Figure 7-4. Most of these components now fail less

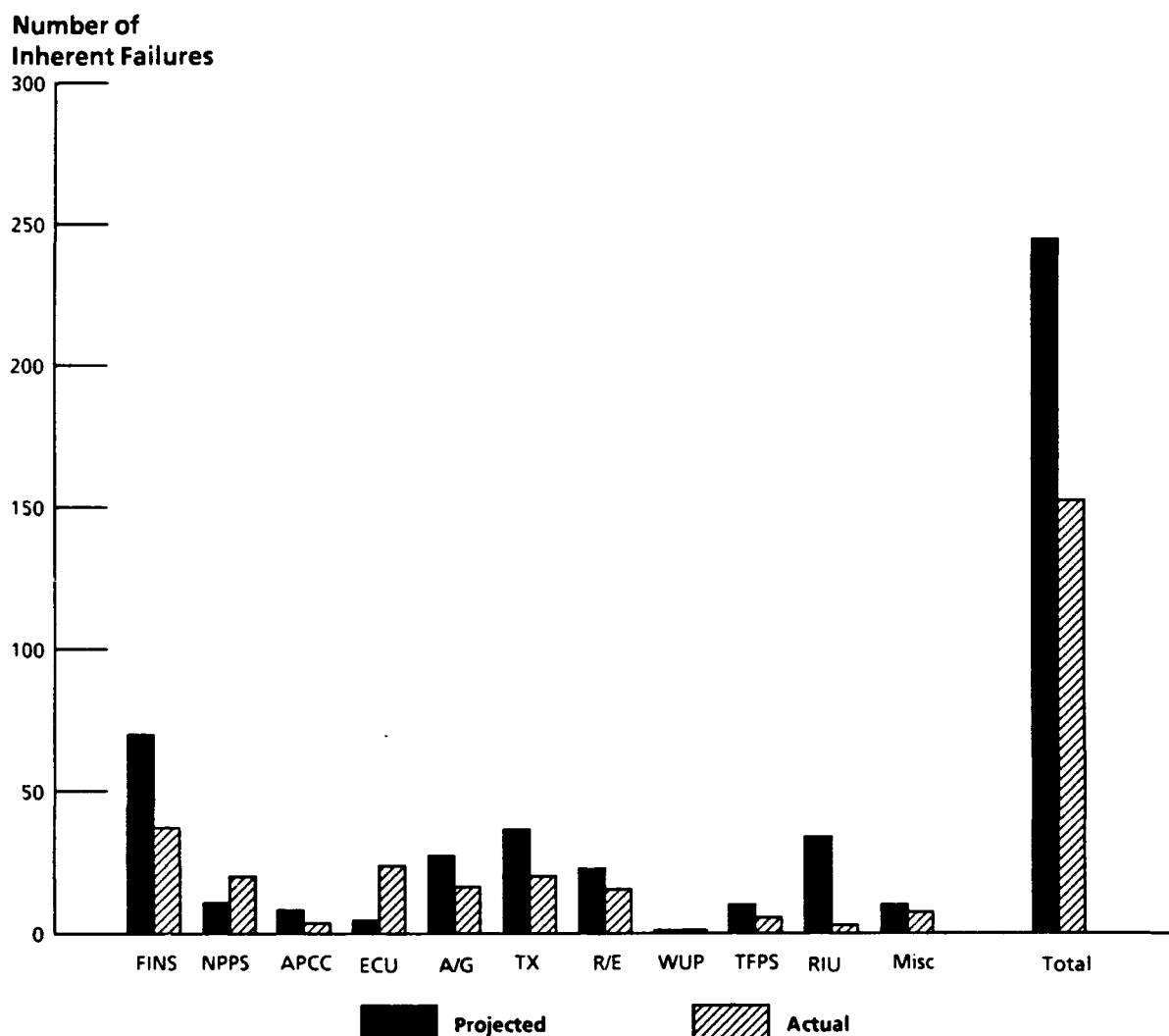


FIG. 7-4. COMPARISON OF PROJECTED AND ACTUAL FAILURES FOR NAV POD LRUs (LOT 3; 1 JAN – 30 OCT, 1990; 12,127 HOURS; TAC DATA SCORED BY THE SPO AND THE PRIME CONTRACTOR [12])

frequently than predicted. The major exception is the ECU, which has failed about four to five times more frequently than predicted.

Water intrusion occurs when an aircraft with a pod goes through a wash rack [12] and during normal rainfall. While water intrusion has not been a major failure cause, it is a continuing concern. An engineering change proposal, ECP LTE 103, "NAV Pod Water Intrusion Modification," is being processed by the SPO. In the

meantime, most squadrons are using locally procured covers to protect the pod-aircraft interface between sorties.

The TFR XMTR began to exhibit an increased failure rate in late 1990. The increase, which occurred at both CONUS and SWA sites, exceeds predictions based on testing. Attempts by TAC, the SPO, the prime contractor, and the subcontractor to identify the cause of the failures have not been successful. The leading hypothesis is that the problem is caused by quality control problems in production.

The FLIR windows suffered from sand erosion in SWA. This phenomenon was not noted in OT&E. However, a memorandum from TAC [14] noted that the problem had been encountered at Luke, Nellis, and Edwards AFBs. The erosion causes visible pitting of the window, but the impact is primarily cosmetic. Video degradation requires prolonged operation in the sand environment and is gradual. In SWA, 24 windows were replaced for the 52 pods deployed through 26 December 1990. WRALC purchased additional spares. A carbon-coated window is being developed; initial results are promising [14].

In summary, NAV pod reliability was poor in early tests, improved gradually as the early and full production phases proceeded, and now satisfies the original requirements. AFOTEC's "satisfactory" ratings were based on reliability growth predictions. While we found evidence that pod reliability did increase, we did not find sufficient data to evaluate the assumptions used in the growth predictions. Operational tests correctly identified the high-failure-rate items.

Maintainability

The LANTIRN SOC [15] specified a number of maintainability requirements, which are summarized in Table 7-3. In addition, the SOC addressed skill levels of maintenance personnel, the three-level maintenance structure, and the role of support equipment. These requirements were not tested by the OTs. In each LANTIRN OT, maintenance was performed by the contractor. Air Force maintenance personnel observed the contractor's efforts. The OT&E maintainability ratings were based on the observations and on modeling. As noted in the discussion of availability, the modeling assumed reliability values that were projected to maturity.

TABLE 7-3

MAINTENANCE CRITERIA FROM THE SYSTEM OPERATIONAL CONCEPT

Measure	Criterion
O-level mean corrective time (MCT)	20 minutes
O-level max corrective time (95 percentile not-to-exceed time)	30 minutes
LRU failures detected at I-level SE	96%
LRU failures fault-isolated to 3 or fewer SRUs	99%
LRU failures fault-isolated to a single SRU	92%
I-level pod MCRT	1.5 hours
I-level Mmax CT	3.5 hours
I-level LRU repair time (average)	0.5 hours
I-level LRU repair time (95th percentile not-to-exceed time)	1.5 hours
I-level SRU repair time (90th percentile)	2.0 hours
O-level fault-detection/isolation for prime and support equipment	100% (g)
LRU replacement	1.5 hours
SRU replacement	3.5 hours (g)

Note: (g) indicates a goal rather than a requirement.

In IOT&E(1), NAV pod maintainability was rated as unsatisfactory. The major deficiencies were accessibility of the pod center section, immaturity and inadequacy of BIT functions, and ECU servicing functions [2].

In IOT&E(2), LANTIRN system maintainability was rated as marginal, but the report did not comment on the NAV pod specifically. Table 7-4 summarizes the IOT&E(2) results for the system. We could not find a source for the maintenance man-hours per operating hour (MMH/OH) and maintenance downtime (MDT) requirements. They were not given in the SOC, statement of need (SON), System Operational Requirements Document (SORD), or TEMP. AFOTEC could not identify the source. We suspect that the MMH/OH and MDT requirements were derived by combining the detailed maintainability requirements with a hypothesized scenario.

In FOT&E(1), system maintainability was judged to be satisfactory. The NAV pod was not separately rated. The rating was based on MMH/OH and MDT derived from a computer simulation that used the reliability values projected to maturity.

TABLE 7-4
LANTIRN MAINTAINABILITY IN IOT&E(2)

Maintainability measure	Test estimate	Mature estimate	Mature requirement
MMH/OH (hours)	0.91	0.54 - 0.61	0.60
MDT (hours)	2.09	1.86 - 2.01	1.55

Table 7-5 shows the FOT&E(1) results. We note that the mature estimate of MMH/OH is almost identical for FOT&E(1) and IOT&E(2), even though the test estimates differ significantly from each other. The estimated FOT&E(1) result for MMH/OH was 0.77 hours, and the mature projection was 0.58 to 0.54 hours. The FOT&E(1) report stated the mature requirement as 0.60 MMH/OH.

TABLE 7-5
LANTIRN MAINTAINABILITY IN FOT&E(1)

Maintainability measure	Test estimate	Mature estimate	Mature requirement
MMH/OH (hours)	0.77	0.54 - 0.58	0.60
MDT (hours)	2.00	1.89 - 2.00	1.55

BIT has been a problem from IOT&E through today. Both IOT&E phases cited BIT immaturity and inadequacy as maintainability problems. FOT&E(1) found that BIT mechanization was not capable of supporting fault isolation and troubleshooting [3]. The Air Force stated that "Under the FSD BIT design, many failure modes were grouped under one fault code, making severity of the fault condition unclear to both the pilot and maintenance personnel. The LANTIRN system fault-reporting software is being redesigned for production to eliminate erroneous fault indications and improve fault nomenclature to directly identify failures" [16].

False alarms (CNDs) were reported by TAC to be a driver of direct maintenance man-hours. This view is in accord with the estimate by Hill AFB that CNDs add about 50 percent to 100 percent to the maintenance man-hours.

BIT performance in the field is not measured, so comparisons with the original requirements could not be made. BIT performance was not scored in the OT&Es, but some deficiencies were noted and corrective actions were taken.

On the basis of DT&E and OT&E flight tests on the F-16C/D Block 40 aircraft, AFFTC [9] states that NAV pod maintainability is unsatisfactory. The AFFTC estimates are MTTR = 2.24 hours, mean repair time (MRT) = 1.01 hours, and MMH/FH = 0.79 hours. Five deficiencies were noted: (1) high wear of threaded fasteners and their threaded receptacles on the center section panels, (2) chafing of the wiring harness, (3) water intrusion, (4) navigation set mounting (several hardpoints had to be tapped and threaded), and (5) nonstandardization of bolt torquing. Service reports were referenced for each of these discrepancies.

Comments on these five deficiencies were offered by TAC [17]. Operational experience confirms that four of them were actual field problems. The fastener and bolt torquing issues are still open items. The wire chafing problem was solved by rerouting and protecting selected wires. Water intrusion is addressed in the field by placing locally procured covers over the pod-aircraft interface. An engineering change order for an improved interface "boot" is being developed. The remaining deficiency, pod mounting, has not been reported as a recurring problem.

We were informed by TAC personnel that they do not track MMH/OH. They expressed satisfaction with the personnel requirements associated with NAV pod maintenance. Their perception is that the MMH/OH may have been lower in SWA than in normal peacetime operations. One possible explanation is that the pods were handled less per sortie in the SWA theater than in normal peacetime operations and that handling is stressful.

Manpower Supportability

The original LANTIRN requirements [1, 15, 18] specified that direct support manpower requirements not exceed 1.125 persons per pod set (based on peacetime manning of a 5-day, 40-hour-per-week, 2-shift operation). Current manpower requirements are below that level. LANTIRN I-level shops are authorized 51 persons

to support 72 pod sets, or 0.71 persons per pod set. The O-level requirement is estimated to be between 0.1 and 0.2 persons per pod set. The combination of I-level and O-level manning is well below the requirement. The OT&Es did not explicitly evaluate manpower supportability.

Training Requirements

The LANTIRN shops at Hill and Seymour Johnson AFBs are satisfied with the training that their personnel have received. TAC/LGMA does not have any particular concerns about the amount of training required for the NAV pod or about the availability of maintenance personnel. FOT&E(1) did not evaluate training but did review plans for training. No concerns were cited.

Safety

No safety issues were identified in the OT&E reports. One safety issue was reported in the field. Both Hill AFB and TAC/LGMA mentioned the issue. The LANTIRN Mobile Shelter Set (LMSS) has a hoist used for transporting pods between carts and the LMSS interior. A hoist fell on a pod when the "A-legs" at the end of the hoist collapsed. No injuries were reported. The fix was to replace quick-release pins that connect the pod to the hoist with nuts and bolts. There have been no subsequent incidents.

SUPPORT SYSTEM SUITABILITY ISSUES

Logistics Supportability

The AFOTEC reports use a broad interpretation of the term "supportability." For example: "Supportability. Air Force personnel must be able to support the LANTIRN system within the framework of the Air Force support system" [11]. In general, AFOTEC considers logistics supportability to encompass the elements of Integrated Logistics Support (ILS).

In IOT&E(1) and IOT&E(2), logistics supportability was rated "incomplete," because the ILS elements were not available during test. The ILS elements also were unavailable for FOT&E(1). AFOTEC reviewed the plans for ILS. The plans for supply support, support equipment, training, and facilities were judged to be satisfactory. Some concern was noted about the tight schedule for production of technical manuals.

We learned of no major problems with the support equipment, technical manuals, or training. However, minor support equipment problems were found, they are discussed below.

Support Equipment

For diagnosing and repairing both the NAV and TGT pods, the LANTIRN intermediate shops have a range of SE. Almost all of the hardware is commonly used equipment. The SE includes the LANTIRN intermediate automatic test equipment (LIATE), the power supply test station, the ECU test station, the electro-optical test set, cooling and servicing units (CSUs), fluid conditioners, air conditioners, 400-hertz converters, generators, and a portable calibrator. The executive software is based on the Air Force's Modular Automatic Test Equipment (MATE) program. The application software for the pods and their components was developed by the prime contractor. The SE contract reportedly contained no warranty provisions.

The SE is housed in the LMSS, which consists of two adjoining transportable shelters. The LMSS requires one C-141 for deployment. Each LANTIRN wing of 72 aircraft is assigned three LMSS units. External to the LMSS is a CSU that provides cooling for tests of the infrared sensors.

The SE was not evaluated in any of the LANTIRN operational tests. We found no evidence to indicate when the SE could have been available. As part of FOT&E(1), AFOTEC did review the plans for development and fielding of the SE. No deficiencies were cited. A special demonstration of the SE was conducted in late 1990 at Seymour Johnson AFB to assess the SE, technical orders, maintenance training, and the capability of U.S. Air Force technicians to support LANTIRN [3]. The test was conducted by the Tactical Air Warfare Center under the guidance of HQ TAC and AFOTEC. Successful completion of the test was the final step in the transition from contractor support to organic support.

We found the SE to be suitable in the field. Delivery of SE has been well coordinated with the delivery of pods to field units and has been relatively easy to activate. For instance, at one F-15E base, the SE was operational within 3 days of its arrival. (In contrast, SE for other systems has taken months for initial set-up.) The LMSS has been reliable and deployable. The SE has exhibited a number of minor

problems that degrade maintenance efficiency, but the overall performance has been satisfactory. The following paragraphs discuss the observed SE problems.

We found that the SE has exhibited a number of minor problems in the field. Maintenance personnel are able to perform the necessary functions with the SE, but their efficiency is degraded. Over 200 service reports have been submitted on the SE. The deficiencies include hardware failures and software problems. TAC/LGMA considers SE to be a prime concern of the LANTIRN system. TAC noted that the SE has no warranty. When some SE components had unexpected failures, the intermediate shops had difficulty in obtaining replacement parts and technical support. Another issue is the lack of accuracy in fault identification.

The LMSS has experienced some minor problems after being transported. The typical time required to unpack and set up an LMSS upon arrival at a deployed site is about 1 day.

The CSU has experienced problems with temperature control. In SWA, the maintenance personnel occasionally resorted to placing a heater in front of the CSU air intake to obtain output at the correct temperature. Also, some relays have exhibited low reliability, and replacements have been difficult to obtain.

One difficulty with the SE software is the inability to enter test routines from intermediate points. When a test is being run and stops before completion, it must be restarted. When a part has been repaired and is to be checked out, the entire test must be run, even if the repair action dealt with only a subset of the part. Since many of the tests require several hours of run time, the need to run the entire test can be quite inefficient. Service reports have been submitted for specific cases, and software modifications are being considered.

Personnel from TAC/LGMA now track the LMSS status at each LANTIRN site. They measure LMSS capability by the percentage of LANTIRN LRUs that can be tested. Most bases are reporting capability rates of 80 percent to 100 percent. An exception is Hill AFB, where one of the three LMSSs is only about 20 percent capable. The other two are almost 100 percent capable. The "bad actor" LMSS was the first unit at Hill AFB but the fourteenth unit overall. It has not been reliable. It is now being used to provide spare parts for the other two units at the base.

Problems with SE may have been exacerbated by an accelerated fielding plan. While the original plan was to activate three sites in the first year, seven sites were actually activated.

Also, SE fault diagnostics showed early problems. TAC/LGMA noted that the SE software is updated every several months. Version 14 is now being fielded. The SPO stated that the SE software changes are motivated primarily by configuration changes to the LANTIRN pods and not by errors.

Software Suitability

Software suitability was judged to be satisfactory. The judgment was based on subjective evaluation of documentation, coding practices, and software support resources. We found no evidence of field experience to contradict the judgment.

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CHAPTER 8

F-16 BLOCK 40

INTRODUCTION

System Description

The F-16 was originally designed as a lightweight air-to-air day fighter. Its requirements subsequently were expanded to give equal emphasis to night, all-weather, and air-to-surface missions. The F-16C/D Multinational Staged Improvement Program (MSIP) was designed to modernize the U.S. Air Force and allied tactical fighter forces with minimum investment in operating and maintenance costs. The requirement to develop and implement the F-16C/D MSIP was contained in the July 1985 F-16 configuration plan (which provided guidelines by block for subsystem integration) and an October 1988 program management directive.

The MSIP was a systematic upgrade of the F-16 weaponry, communications, avionics, navigation, and sensors. The program was divided into three stages: Stage I, from late 1981 through early 1985, which provided minimum essential structural, wiring, and cooling system changes to support future growth; Stage II, which supported future growth stage subsystems in Block 25/30 aircraft (evaluation of Stage II modifications was accomplished during the January to April 1985 IOT&E); and Stage III, which involved integration of separately developed and tested subsystems supporting F-16C/D Block 40/50 production aircraft, as well as a retrofit program. Stage III included integration of the Airborne Self-Protection Jammer (ASPJ), LANTIRN (Block 40 only), Advanced Medium-Range Air-to-Air Missile (AMRAAM), the Global Positioning System (GPS), the advanced radar warning receiver, the combined altitude radar altimeter, and AN/APG-68(V) [1].

This case study concerns the F-16 Block 40. With a 42,300-pound maximum gross weight, it is a single-seat, integrated weapon system tailored for first-pass weapon delivery. LANTIRN provided automatic terrain-following (auto TF), fixed imaging navigation sensor, forward-looking infrared (FLIR) video, and weapons delivery at night under the weather. The APG-68V radar provided target

information for all-weather weapon deliveries and also provided LANTIRN targeting pod cuing.

The cockpit provided air-to-surface and air-to-air mission capability. Two multifunction displays (MFDs) provided display for new weapons and sensors, increased flexibility in presenting other required information, and permitted programmable pilot interface. Information displayed on the MFDs included radar, LANTIRN targeting pod video, electro-optical weapon sensors video, stores management functions, and built-in test (BIT)/fault-isolation results. The 20-degree by 30-degree wide-angle raster holographic head-up display added the ability to display LANTIRN FLIR video.

The F-16C Block 40 incorporates a general avionics computer (GAC), to replace the F-16C Block 30 fire control computer. The GAC performs weapon delivery, navigation, and energy management functions, and provides serial/digital bus control of up to four multiplex buses. The digital flight-control subsystem (DFLCS) replaces the analog flight-control subsystem with a quad-redundant digital computer. The GAC supports the DFLCS with fault reporting and bus control. Additionally, the DFLCS is integrated with the LANTIRN NAV pod to provide auto TF capabilities.

Airframe structural changes were incorporated to maintain the F-16's 9 G capability. Landing gear, brakes, struts, tires, and doors were enlarged to accommodate the increased takeoff gross weight. The APG-68V fire control radar was a lower cost, multimode, digital sensor designed to provide all-weather air-to-air and air-to-ground modes with superior dogfight and weapon delivery capabilities. An improvement over the preceding version of the APG-68 radar was the incorporation of the situation awareness mode.

The F-16C Block 40 also employs the GPS, a passive, all-weather, jam-resistant navigation system that receives and processes radar frequency (RF) transmissions from orbiting satellites. The GPS receives and processes the navigation messages to determine the propagation time of the message.

Acquisition History and System Status

As Figure 8-1 [2] shows, delivery of production Block 40 F-16s began in early 1989 and was scheduled to continue into 1992, at least as of May 1990. (Force

downsizing plans developed since then involve some reductions in the number of F-16 buys in FY92 and beyond.) Through the second quarter of FY91, 228 Block 40 F-16Cs (the single-seaters) were in the hands of the Tactical Air Force (TAF), along with another 40 F-16Ds (the two-seaters) [3].

Operational Testing History

The F-16C Block 40 IOT&E sorties were flown from May through October 1989 using three production Block 40 F-16Cs. A total of 222 sorties were flown during the test (110 at Edwards AFB; 74 at Nellis AFB; and 38 at Eglin AFB). The testing focused on the equipment and capabilities that distinguished the Block 40 from the earlier block designs.

The following test limitations were noted [1]:

- Maintenance training: "Due to manning problems, only three maintenance individuals received Type 1 training. This precluded accurate troubleshooting time measurements."
- Support element availability: "Complete assessment of logistics supportability could not be accomplished due to limited availability of integrated logistics support elements."

OVERALL SUITABILITY

The Air Force Operational Test and Evaluation Command (AFOTEC) [1] concluded as a result of the 1989 IOT&E that "F-16 suitability performance was not significantly affected by Block 40 enhancements." The aircraft met the user requirements for sortie-generation rate, mission capable (MC) rate, fix rate (percentage of discrepancies fixed by maintenance within established time standards), and mean time between maintenance. It did not meet the user's break rate (percentage of sorties experiencing one or more discrepancies) requirement because of the GAC's poor reliability. When the aircraft was configured with wing tanks and LANTIRN pods, the gun could not be loaded using the universal ammunition loading system.

Field data from Tactical Air Command (TAC) [4], the F-16 System Program Office (SPO) [2], and Air Force Logistics Command (AFLC) [5] indicate that the F-16C Block 40 is an operationally suitable system. It achieves high MC rates: in the first quarter of 1991, the average MC rate for Block 40 F-16s was 91.8 percent, with

91.3 percent fully mission capable (FMC) and 0.5 percent partially mission capable (PMC). These rates are being achieved without making extra demands on support resources. The field suitability problems noted by TAC, the SPO, and AFLC and as a result of a visit to an F-16 wing at Hill AFB [6, 7] are not major suitability issues. Only a few of the issues were unknown by the end of OT, and these issues are minor.

END-ITEM SUITABILITY ISSUES

Availability

Block 40 IOT&E (combined with experience from preceding blocks) indicated that the aircraft's availability would exceed minimum TAF thresholds (85 percent MC rate). That expectation has been borne out in field experience; as indicated in Figure 8-2 [2], MC rates for Block 40 F-16s have consistently exceeded those for earlier F-16s and, currently, are among the highest ever experienced for tactical aircraft.

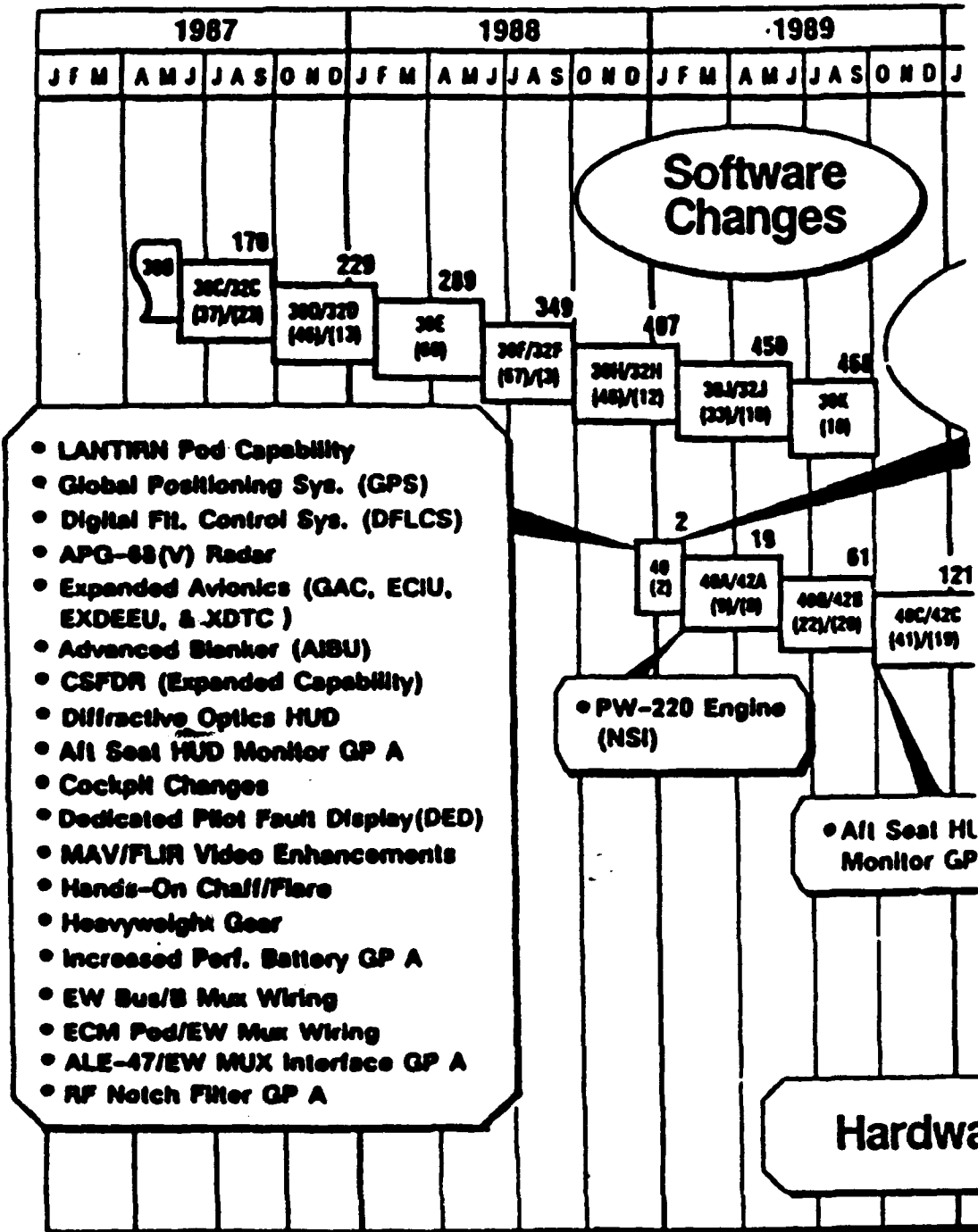
The field experience recorded in Figure 8-2 includes the wartime experience during the SWA campaign. Block 40 F-16s had very high MC rates during Operation Desert Shield/Desert Storm (for example, the 388 Tactical Fighter Wing (TFW) had FMC values of 94 percent [8]). These high rates, coupled with the fact that CONUS-based units were not "robbed" to support the deployment, allowed the overall MC rates shown in Figure 8-2 to remain steady throughout the deployment period.

In IOT&E, "system availability" was measured by the sortie abort rate during the test period. During the test, the abort rate for Block 40 F-16s was 3.5 percent [9], compared to the TAF standard that abort rates be no greater than 6 percent. The small numbers of end items generally involved in IOT&E make direct measurement of MC and FMC rates difficult, forcing IOT&E to rely on other measures (such as abort rate) that generally can be expected to be indicators of MC and FMC rates, if not explicitly equal to them definitionally.

Thus, the overall DOT&E evaluation [10] following IOT&E of the Block 40 F-16s – namely, that "Overall F-16 operational suitability is satisfactory in most areas" – has been borne out as being correct, if perhaps somewhat understated.

That is not to say that individual suitability issues did not surface during OT&E or that F-16 Block 40 aircraft have no suitability problems at all. Reliability

USAF F-16C/D Cc Block



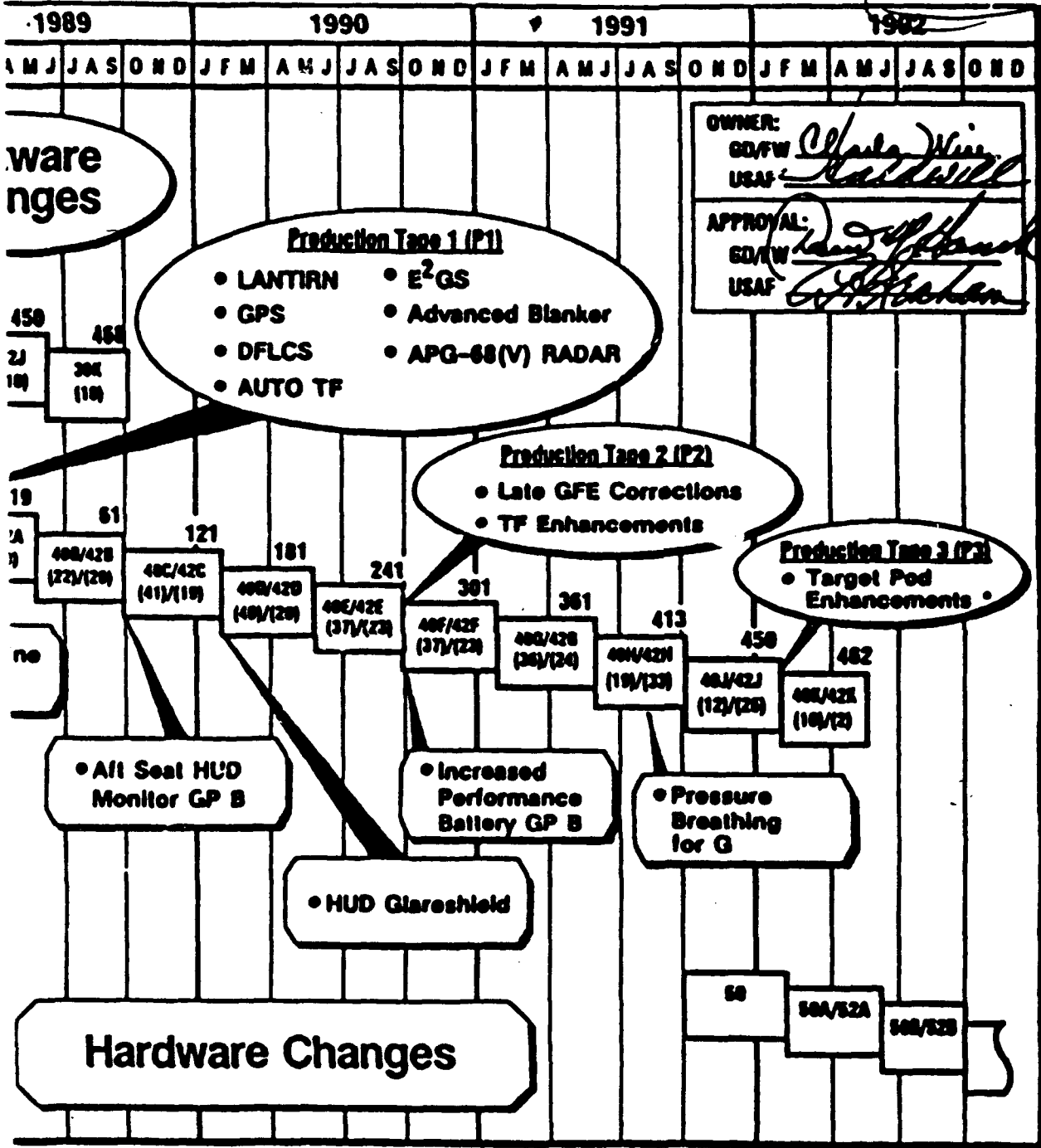
*** Not Currently Authorized; Anticipated Incorporation Date**

FIG. 8-1. U.S. AIR FORCE F-16C/D

6C/D Configuration Plan

Block 40

4 May 1990



AC1659W 17

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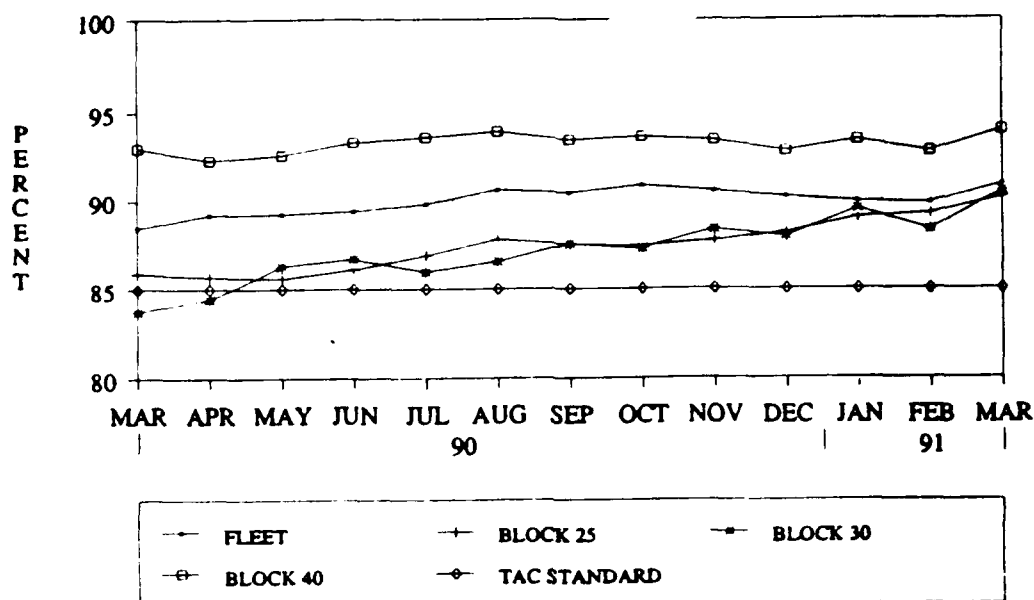


FIG. 8-2. MISSION CAPABILITY RATES - USAF F-16 C/Ds

problems for new LRUs and subsystems that characterize Block 40 F-16s were observed in IOT&E and exist in the field today.

Reliability

System reliability for the F-16C Block 40 was measured by mean time between maintenance – for inherent failure (MTBM-I) value of 2.9 hours in IOT&E [9]. Today, in the field, the Block 40 aircraft are experiencing slightly more than 4 hours in MTBM-I [11] – indicating at least rough accuracy in IOT&E on system reliability.

Most current reliability problems at the LRU level were also identified by OT. Table 8-1 shows MSIP Stage III LRUs that received “unsatisfactory” or “marginal” reliability ratings in OT and compares their MTBM-I with current (August 1990 – February 1991) values.

The “Total” in Table 8-1 refers to the MTBM-I for the collection of LRUs taken together and compares it to the MTBM-I in general for the F-16C aircraft. The F-16 SPO identified the Digital Flight Control Computer (DFLCC), the HUD, and the GAC as being among the LRU “drivers” for current R&M problems [3]. It is interesting that these “drivers” have substantially improved MTBM-I values over what they had in OT – reflecting not only OT’s correct identification of problem

TABLE 8-1

F-16C AVIONICS RELIABILITY COMPARISON

Unit	MTBM-I (hours)		
	Test	Field (GD)	Field (SPO)
DFLCC	80	265	485
GPS	122	(200) ^a	(200) ^a
HUD	102	235	480 – 560
GAC	13	223	135
LANTIRN NAV pod	32	(70) ^a	(70) ^a
Total	7.2	31.5	32.4
Aircraft	2.9	4.1	4.5

Sources: Air Force Flight Test Center [9].
 General Dynamics (GD) [12].
 F-16 System Program Office [11].

^a Estimated from other sources.

LRUs but also the fact that these problem LRUs have been improved since OT (e.g., GAC software updates) in order to reduce the size of the problem they cause.

During a visit to an operational unit, we were told of several reliability problems that had not been reported in OT [7]. The problems have only minor impacts on mission and logistics reliability. One example is cold weather problems with the GAC batteries. The batteries were supposed to be qualified for below-zero temperatures. Field experience of one unit is that the batteries fail with exposure to near-zero temperatures. Another example is the effect of high humidity. Two LRUs (the DMT and the MLPRF) have been observed by one wing to more than double their demand rates when the unit deploys to a humid environment.

Maintainability

Table 8-2 [1, 4, 9] shows system-level maintenance values from both OT and the field for the Block 40 F-16C. The table suggests that (1) maintenance man-hours per flying hour (MMH/FH) have been successfully reduced since OT&E and (2) maintenance still can fix roughly 90 percent of broken aircraft in 8 hours or less (even though the “breaks” may have changed somewhat).

TABLE 8-2
F-16C BLOCK 40 MAINTENANCE MEASURES

Measure	Test	Field
MMH/FH 8-hour fix rate (percentage fixed within 8 hours)	10.6 90%	<6.0 89 - 94%

At the LRU level, the GPS, GAC, and LANTIRN NAV pod set were the only major Block 40 MSIP III LRUs that received "unsatisfactory" maintainability ratings in OT. The digital flight control system, the air data system, the fire control radar, the hud, the radar altimeter set, and the stores management system all received "satisfactory" ratings [9].

The GPS problems were not "hi-tech" but rather "connector" deficiencies having to do with plugs and mounting screws. Problems exist in the field today with the GPS, but they involve fault-isolation problems.

Maintainability problems with the GAC in OT related to batteries and fault-isolation, which caused the GAC to "dump" its programs, requiring time-consuming reloading of software. Problems still exist with GAC batteries leading to the "dump" phenomena (cold-weather problems mentioned earlier), so OT at least pointed reasonably closely to a current suitability problem for this key LRU.

LANTIRN NAV set maintainability problems in OT derived from "mechanical" problems: stripped fastening screws, wire harness chafing, nonstandard and confusing bolt-torquing requirements, and water intrusion in the set during rain. Today in the field, a Tactical Interim CAMS and REMIS Reporting System (TICARRS) report provided by the F-16 SPO [4] showed the *LANTIRN NAV set* topping the list of LRUs ranked by maintenance man-hours consumed (473 maintenance man-hours consumed fleetwide over the January to March 1991 period).

The OT also indicated fault-identification problems for the AIBU (an LRU with multiplexing functions) and BIT problems for the AN/APG-68 radar. Both of these issues are present in the field today. At one wing, the AIBUs give several fault

indications per day, of which 40 to 50 percent are false alarms. In addition, the AIBU has had several configuration changes. The configurations are not interchangeable, so spares availability is sometimes a problem. For the AN/APG-68 radar, one avionics technician estimated that the BIT fault-isolation is about 50 to 60 percent accurate. The field reported that fault-isolation is easy for the HUD. However, 60 to 70 percent of the fault indications are cannot duplicates (CNDs), and about 2/3 of the CND units show a fault again when returned to the aircraft.

A general conclusion from the comparison of OT maintainability results compared to current field experience is that OT did not detect or emphasize problems in the area of CND, bench check serviceable (BCS), and retest OK (RTOK). These are problems of importance today, however, to the SPO. The SPO has a Bad Actor Program [13] and a RACAT program [14] (Rtok/bcs/cnd, Analyze for cause, take Corrective Actions, user/support Team) expressly aimed at reducing the BCS/CND/RTOK "problem." Some increased consideration of this problem, which is widespread for hi-tech avionics equipment, would seem to be in order for future OT.

SUPPORT SYSTEM SUITABILITY ISSUES

Suitability elements relating to the support system external to the Block 40 F-16 weapon system – i.e., logistics supportability, transportability, technical documentation, manpower supportability, training requirements, wartime usage, safety, and human factors – did not receive any focused or specific attention in OT. The focus in the AFFTC test was on the Block 40 weapon system itself (availability, reliability, and maintainability of the system and its components).

This may be in part because the Block 40 F-16 was an evolutionary step in an ongoing development program deliberately designed to allow for changes without causing major disruption to the external support system for the aircraft. As noted in the introduction to this case study, the F-16C/D MSIP was designed to modernize the U. S. Air Force and allied tactical fighter forces *with minimum investment in operating and maintenance costs*.

It is interesting that even though this was a stated goal of the F-16 MSIP program, the Air Force did not feel it necessary to try to test whether that goal was being achieved – by looking at the potential demands that the new Block 40 aircraft might place on the external support system. Having said that, we must also note that field reports do not suggest that any extra or extraordinary external support

requirements have accompanied the fielding of Block 40 F-16s. The few instances in which external support suitability issues have been raised are summarized in the following subsections.

Logistics Supportability

Supply support for on-aircraft parts was not an issue in OT, and supply support generally has been quite good for the Block 40 F-16s. One problem noted by the avionics shop at Hill AFB is the main cable for the multiple load verifier (MLV), which is used to load software into LRUs that are being installed on aircraft. One end of the cable uses a male cannon plug that is unique to the F-16 application. Plug failures are not rare. Replacement plugs have been difficult to acquire. Since there are only two MLVs per squadron, there is a chance that both could be out of service and that replacement LRUs could not be programmed.

Regarding avionics test equipment, we know that appropriately configured test sets for the MSIP III GAC and DFLCC were not available during IOT&E because they were still not available after fielding.

Technical Documentation

Technical documentation was not explicitly evaluated in OT, and avionics shop personnel at Hill AFB report that technical documentation for the Block 40 aircraft is "good."

At the time of OT, the DOT&E did note in his evaluation that some technical data were lacking, but that the problem should improve "as the system matures."

Training Requirements

The classified Air Force Flight Test Center (AFFTC) report on the results of testing indicates that AFFTC felt that some pilot "training upgrade" would be needed in conjunction with the GAC.

No issues surfaced either in OT or in current field experience relating to the suitability elements of transportability, manpower supportability, wartime utilization, safety, or human factors.

F-16 BLOCK 40 SUMMARY

IOT&E for the Block 40 F-16C/D aircraft focused on availability, maintainability, and reliability of the weapon system itself and its defining components; it did not attempt to explicitly address support system questions.

IOT&E was generally quite successful in identifying areas where end-item suitability (availability, reliability, maintainability) problems existed. Problems in many of those areas still exist, but their severity has diminished across the board – suggesting that, for this system, the Air Force has acted on problems identified (and recommended for attention) in OT&E.

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