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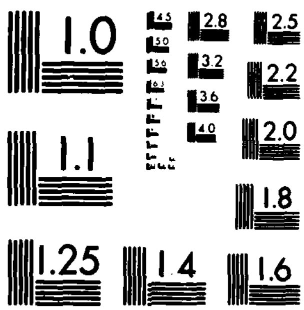

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A CASE STUDY OF RELIABILITY AND MAINTAINABILITY OF THE F-16 APG-66 FIRE CONTROL RADAR

Daniel DeMarchi, Captain, USAF

LSSR 99-81

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One cannot overstate the importance of acquiring weapon systems that are reliable and maintainable. During the development and test phase of weapon system acquisition, program management and design emphasis must be directed to producing a system that achieves these goals in the field. This research investigated these development and test efforts and the demonstrated operational performance of a major weapon subsystem in the form of a case study analysis of the F-16 fire control radar. Comparisons of predicted, test-demonstrated and operational APG-66 reliability and maintainability parameters constitute the significant portion of the analyses. In addition, the reliability and maintainability programs and selected performance indicators of the APG-66 and APQ-120 are compared in order to examine the results of differing test-program acquisition policies. This thesis effort determined that the APG-66 has not yet attained a constant failure rate indicative of an equipment's useful life. The research also determined that increased efforts in the test function of an acquisition produces significant benefits in operational results. A summary analysis of the entire program found the predictions based upon the critical design review and intermediate level maintainability demonstration to be somewhat optimistic.

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A CASE STUDY OF RELIABILITY AND MAINTAINABILITY OF THE F-16 APG-66 FIRE CONTROL RADAR

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

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CHAPTER I

INTRODUCTION

Background

Recent Fighter Aircraft Experience

U.S. Air Force tactical aircraft of the 1960s and early 1970s proved their worth and capabilities during the Southeast Asian conflict. The experience gained in this actual combat setting proved valuable in discriminating between those characteristics desirable in a tactical fighter and those factors which degraded overall mission effectiveness. Although for the most part they had been designed to perform specific missions, Vietnam-era fighter aircraft were employed in a variety of roles. The natural progression in design of these aircraft from earlier variants had seen them grow heavier, faster (normally), and more complex than their predecessors. The rapid advance of technology was most evident in the avionics and fire control radars of these aircraft.

The F-4, as a multi-role aircraft, represented an excellent compromise of the mission demands placed upon it. To maintain its combat effectiveness, the Air Force enhanced its capabilities through evolutionary modification in the form of increased thrust, improved fire control radar, and electro-optical ordinance delivery systems. The F-4, however, became less effective in some aspects of its mission demands due to its age, increased gross weight and declining relative performance characteristics. It became apparent that there was a need for a multi-role combat fighter in the 1970s to replace the existing fleet. Air Force requirements at this time envisioned an aircraft that could perform conventional weapons delivery in addition to fulfilling the tactical nuclear and air defense postures.

Evolution and Development of the Air Combat Fighter

The U.S. Air Force lightweight fighter program that began in 1972 had the initial purpose of investigating new technology that might be appropriate to future U.S. fighter aircraft requirements (6:34). In addition to demonstrating advanced technology, the lightweight fighter program aimed to reduce technical and cost uncertainties involved in the development of fighter aircraft. In an attempt to motivate contractor innovation through competition, the USAF selected two companies, General Dynamics and Northrop, to design and build two prototypes. When the USAF determined that such a concept was feasible and readily functional, officials accelerated the prototype program to a competitive flyoff (15:126).

The program exhibited a central change from conventional management approaches in that the contract set only desired performance goals without the rigidity of contractual specifications (17:50). USAF philosophy, then, was to manage the program only by exception and to allocate the routine decisions to the contractors. In fact, USAF officials gave full design responsibility to the contractors, a measure which was meant to convey the government's willingness to accept and evaluate new ideas, to recognize the risk associated with technological advance, and to free the contractors from unnecessary constraints (17:50).

The lightweight fighter program, under which the General Dynamics YF-16 and Northrop YF-17 developed, took on greater significance when in April 1974 the Secretary of Defense announced that the Pentagon was considering full-scale development of an air combat fighter (ACF) derivative of either the YF-16 or YF-17 (17:51). The lightweight fighter was an obvious choice for the air combat fighter because of the increasing complexity and resulting costs associated with more sophisticated weapon systems.

During this period, the forecast Soviet threat depicted the USSR overtaking the U.S. in quality as well as quantity of fighter aircraft. It was important then, that the USAF maintain a force large enough to meet its current commitments in addition to modernizing the fighter fleet. The philosophy at the time advocated that the simplest weapon system possible which could accomplish a mission should be procured in order to insure the lowest acquisition cost along with the lowest operating and support costs (18:89).

Each prototype was designed for the visual air combat environment only, a move that was to minimize life-cycle costs by requiring less avionics (18:77). Both prototype aircraft had been designed to a target cost of $3,000,000 per unit in fiscal year 1972 dollars, based on an assumed production run of 300 aircraft consisting of the airframe, engine, heads-up display, gun and simple ranging device (17:50).

As a result of the competitive flyoff, cost and mission considerations, the USAF selected the General Dynamics YF-16 as the winner of the air combat fighter competition, and the corporation was awarded the full-scale development contract in January 1975.

Fire Control System for the F-16

Evolution. In 1975, when full-scale development began, the Tactical Air Command (TAC) did not have a required operational capability (ROC) prepared for the F-16 (19:7). Although the F-16 was conceived as a replacement for the F-4, it originally, as the ACF, was forecast to perform in the visual air combat arena alone. TAC revised the F-16 mission employment roles, however, which dictated that a more complex and comprehensive fire control radar (FCR) be developed, a system which would have radar-missile, ground mapping and electro-optical weapons delivery capabilities.

The Air Force decided that the enhanced F-16 fire control radar could be built as contractor-furnished equipment (CFE) in accordance with TAC requirements. One of the fire control radars submitted as a subcontractor proposal, the Westinghouse WX-200, was an indirect descendant of the F-4 APQ-120 radar. In November 1975, General Dynamics announced the selection of Westinghouse as subcontractor for the F-16 radar (18:77).

The newly designated APG-66 radar pressed the DSARC IIIB (full production decision) deadline of September 1977 when pre-production testing fell behind schedule. Prior to the full production decision, the subcontractor had to successfully demonstrate all radar functions and the integration of the radar with the other F-16 avionics subsystems. A flight model of the F-16 radar had demonstrated its capability to perform most of the required functions while flown in an F-4 testbed; however, the set was 20 percent larger than the one to be used in the production aircraft (19:7). The ensuing technical, reliability and maintainability development of the system is discussed in detail and analyzed in Chapter IV.

APG-66 System Description. The APG-66 fire control radar for the F-16 is a coherent, multi-mode, digital fire control sensor designed to complement the air superiority and strike roles of the aircraft (23:vii). The system was designed with digital technology and sophisticated software to enable ease of maintenance and to provide a more reliable product.

The design features several maintainability considerations including the absence of blind connectors and the fact that no flightline adjustments or special tools are required. Six functional line replaceable units (LRU) which are organized for autonomy, function, minimum interconnection, and ease of maintenance compose the system (23:vii). The six line replaceable units are the antenna, transmitter, low-power radio frequency unit (LPRF), digital signal processor (DSP), the radar computer, and a radar control panel. A rack assembly is mounted to the aircraft which retains the transmitter, DSP, computer, LPRF and associated cabling and waveguide. All of the radar LRUs are mounted in the nose of the aircraft and are accessible from ground level, except for the radar control panel mounted in the cockpit.

The system has built-in-test (BIT) and self-test capabilities that both alert the user of degraded system functions and provide maintenance personnel with a detailed history and description of fire control radar failures.

The built-in tests require maintenance personnel or pilot participation in order to detect or isolate a system fault to a particular LRU (23:vii). Self-tests are characterized as automatic noninterferring performance testing in which either continuous or iterative monitoring techniques may be applied. A fire control computer operational flight program is integrated to collect and store faults from the radar, to command avionic equipments to perform detailed self-tests, and to provide a display of the results of the self-tests to the pilot or maintenance personnel (23:vii).

Statement and Scope of the Problem

Problem Statement

The armed services strive to optimize the acquisition of weapon systems in order to provide the most effective national defense for the appropriated defense budget. One of the paramount factors in any major weapon system acquisition is the minimization of future system life-cycle costs. The reliability and maintainability that the system exhibits in its deployed phase directly determines the amount of these costs. In addition, reliability and maintainability determines the effectiveness of several critical measures of defense readiness including system availability, unit/individual combat readiness, and mission effectiveness. Although the defense services place a great deal of emphasis on reliability and maintainability during weapon systems acquisition, an optimal approach has not been found. As a recent major acquisition, the APG-66 development displayed various management and design measures indicative of a concentrated reliability and maintainability effort. This thesis will examine reliability and maintainability of the F-16 APG-66 fire control radar in comparison with its contractual requirements and the operational results of the APQ-120 radar which was its predecessor.

Scope

This thesis analyzes the APG-66 reliability management history in the critical design review and reliability qualification test phases of development. No attempt will be made to determine the applicability of test specifications or MIL-STD 781B procedures. Operational field reliability data used to ascertain reliability growth and other measures of reliability comparison are gathered via AFM 66-1 (Aircraft Maintenance Management) maintenance data reports on USAF-owned continental-U.S. based aircraft only. This data is assumed to be valid. No attempt is made to analyze the European consortium aircraft procurement or their reliability performance.

Analysis of the APG-66 maintainability management history is limited to an examination of the critical design review and the intermediate level maintainability demonstration in comparison with a twenty-month window of operational results.

A major consideration in this effort is the phase of APG-66 system maturity in comparison with the APQ-120 fire control radar. In some analyses, the data presented for the prior generation system represents a period that is three years-plus from the completion of reliability qualification testing. Although the data management of system failure reporting has changed since the 1973 study of APQ-120 reliability, this effort attempts to present both data sources on a common normalized base.

Objectives

The main objective of this thesis effort is to determine the effectiveness of the APG-66 subcontractor's reliability test program and maintainability plan in producing a reliable and maintainable weapon subsystem. A major subobjective is to determine the relative increase in fire control radar reliability in comparison with a representative prior generation radar.

As a case study, the thesis will attempt to aid systems program office personnel in the acquisition of future weapon systems.

CHAPTER II

LITERATURE REVIEW

Reliability and Maintainability

Definition and Relationship to Life-Cycle Cost

Igor Bazovsky in 1961 noted the impact of reliability with respect to production, waste, technology, and safety:

> The lack of reliability wastes billions of dollars and has slowed technological progress in many vital areas. There is perhaps no engineering field today where the need for improvement is greater than in the field of reliability [3:vii].

Reliability is not a theoretical notion without practical application; rather it ". . . is quantitive in concept, predictable in design, measureable in test, assurable in production, and maintainable in the field [14:4.6]." Reliability, in general terms, can be defined as: ". . . the probability that a system can meet an operational requirement for a given period when the system operates under certain conditions [14:4.3]." The importance of reliability in weapon systems cannot be overstated. Greater reliability provides for greater availability of necessary weapon systems and, more importantly, it provides an increased probability that these weapon systems can successfully complete their missions.

The most direct method, theoretically and practically, to achieve reliability in weapon systems is to design and produce simple systems. While desirable, simplicity in design is not a feasible approach in the development of some defense hardware. A prime example is aircraft avionics, where improved capability is usually accomplished through technological advances which require more complex systems. Inherently then, mission requirements for improved technical performance in avionics and fire control radars often result in reduced reliability.

The fact that a declining defense procurement budget buys fewer increasingly complex systems emphasizes the role of system reliability in the determination of weapon system life-cycle costs. A weapon system experiences three distinct phases of failure during its life cycle:

1. <u>Burn-in (early life) period</u>. During this time manufacturing practices are refined, product tolerances are reduced, and improvement in designs are made. Testing during this period improves system performance so that the burn-in period diminishes rapidly and reaches the design level (14:4.10).

2. <u>Useful life period</u>. During this period, systems experience chance failures according to one of several probability distributions, normally the exponential. In addition, during this period, systems reach their lowest

failure rate, and thus they can be utilized to the greatest advantage (3:33).

3. Wearout period. During this period, systems experience increased failure over that experienced during useful life. High system reliabilities for extended periods of time can be achieved by periodic replacement of components before they fail and periodic inspections at specific intervals (3:36).

The relationship of reliability to weapon system life-cycle cost is a direct one. Bazovsky (3:171) determined that improvements in system reliability can best be made, and at the lowest cost, in the design of the weapon system through tradeoffs in system performance. Total acquisition costs increase as the reliability improvement decision is delayed until later phases of the system life cycle. When a weapon system is operationally deployed and requires reliability modifications, not only are costs higher, but the system experiences lower availability. Thus, it is desirable to have intensive research and reliability engineering in the design phases rather than after a weapon system is in the operational inventory.

Department of Defense Reliability Experience and Emphasis

The high financial costs of unreliable systems are not of recent discovery. In the mid-1960s a pioneer effort was made to estimate these costs to the Royal Air Force (RAF). The report estimated that failure of equipment to live up to its expected performance cost the RAF approximately 40 percent of its annual budget (13:23).

U.S. Department of Defense (DOD) officials recognized the effects reliability and maintainability have on system life-cycle costs (LCC), mission effectiveness and defense readiness. In order to emphasize DOD complicity, DOD Directive 5000.40 (Policy Statement on Reliability) officially issued guidelines that all DOD program managers must follow to ensure that reliability and maintainability factors are included in all design efforts (5:56).

Defense efforts to introduce lower cost weapon systems that are more reliable, available, and maintainable have, however, been less than fully successful. A report on the implications of highly sophisticated weapon systems on military capabilities was performed in June 1980 by the U.S. General Accounting Office (GAO). The review was requested by the Chairman of the Senate Committee on Foreign Relations as the result of a 1979 study on impediments to reducing the costs of weapon systems. The GAO report concluded that despite increased DOD efforts in reliability and maintainability, the results fell short of desired goals. The report also predicted that weapon systems designed in the mid-1970s are likely to experience many of the same problems that occurred in high performance weapons deployed at the time of the study (18:Abstract). The review recommended that personnel involved with the acquisition of costly systems must be fervently concerned with the deployed equipment's field capability, and also suggested that increased emphasis should be made in the early design of weapon systems in order to obtain an optimum mix of high performance and support characteristics (18:Abstract).

Current Department of Defense directives require that LCC estimates be formulated in the validation phase and reviewed at each Defense System Acquisition Review Council (DSARC) milestone. With 700 different LCC models to choose from, the cost estimating process is not a simple one. Compounding the estimating problem is the fact that equipment hardware as well as the acquisition plan goes through metamorphosis in this phase. In an attempt to balance mission performance requirements against the costs of unreliable systems, some recent acquisition strategies favored acquiring those systems that performed acceptably and had the lowest life-cycle cost (4:99).

Focusing attention on the reliability variable of a life-cycle cost model does not necessarily result in lower acquisition and operational and support costs, however. Air Force Systems Command personnel in a 1976 interview determined several drawbacks of the reliability-oriented approach (9:22):

1. If technically and operationally feasible, high-spares/maintenance cost subsystems or components should be eliminated which would result in more savings than improving their reliability would accomplish. (The key to this approach is the fact that Warsaw Pact state-of-the-art technology in deployed weapons is rapidly approaching that of the U.S. This makes it necessary for the U.S. to incorporate their newest technology in the design and production of their aircraft. The inherent reliability associated with this new technology will be somewhat less than if tried and proven components were utilized.)

2. Reliability and maintainability improvement must be coordinated with an effort to reduce manpower when that system is deployed. If the operating commander does not have the option of reducing his maintenance personnel roster, the costs will still exist.

Reliability Test Program

The contractor's reliability test program is one of three reliability elements considered basic to the achievement of equipment reliability. This element is comprised of three phases; environmental screening, evaluation testing, and qualification testing (8:7).

Environmental screening is conducted at the equipment level during system development in order to remove infant or early mortality failures from the equipment.

This phase serves several purposes; it removes failures normally associated with poor workmanship by parts vendors, and it determines if the equipment is capable of meeting its predicted performance parameters when subjected to simulated field use environments.

The second phase of the test program, evaluation testing, has the intended purpose of revealing design and manufacturing deficiencies that cannot be detected during the design of the equipment. The tests are characterized by a test-and-fix atmosphere where equipment failures are analyzed, corrective actions are implemented, and the effectiveness of the actions are evaluated during the remainder of the test. Evaluation testing is normally conducted at the equipment level of development where it is subjected to temperature cycling and periodic vibration patterned after MIL-STD-781. There is considerable evidence that equipment reliability grows exponentially with accumulated test time during a properly conducted evaluation test (8:8).

The reliability qualification test phase is the final system demonstration prior to production. In this phase, the equipment is subjected to an environment dictated by MIL-STD-781 in order to measure the mean time between failure (MTBF) achieved as a result of the reliability engineering program. The reliability qualification test affects the final reliability of the product in two ways (8:8): it motivates the contractor to properly conduct the developmental reliability program, and it allows an assessment of corrective action effectiveness prior to full-scale production.

Reliability Studies

The problem of unreliable weapon systems hardware has been the subject of intense research and analysis, particularly in the defense community. This section will summarize the important findings of those studies and, in addition, one of the projects, a study of APQ-113,-114,-120, and -144 radar reliability, will provide a basis for a comparative analysis developed in Chapters IV and V.

Air Force experience with reliability in aircraft avionics has not been promising. HQ USAF recognized the inherent unreliability of aircraft radars and began an effort to solve the problem. A 1973 report, funded by the USAF, was performed by the General Electric Aerospace Electronic Systems Department in a study of APQ-113,-114,-144 and APQ-120 radar reliability. The objective of the study was to correlate differences in radar reliability performance compared to the equipment reliability requirements and program structures. The study, which used reported field reliability data, took considerable interest in those factors identified as major contributors of equipment reliability: reliability evaluation testing, parts screening, and equipment burn-in (7:iii).

Two significant results of the study were among those found to be very important in other reliability research efforts. First, the report emphasized the importance of uncompromising contractual incorporation of MIL-STD-781 at applicable airborne stress levels as the principal driving force in establishing and executing effective reliability development efforts (7:iii). Second, the study agreed with current acquisition philosophy that properly developed and directed reliability program investment can produce significant cost savings leverage when compared against the projected equipment life-cycle maintenance costs for unreliable equipment (7:iii).

Also in 1973, USAF contracted a study of avionics equipment acquisition in order to develop basic relationships capable of determining and predicting the acquisition costs attributable to equipment reliability. The results of the study provided insight into the relationship between reliability development cost and resulting reliability (8:4). An analysis of ten contractors' reliability design, parts and test programs revealed interesting statistics reflecting the incremental gain in reliability MTBF due to the various phases of the contractors' programs. Incremental gains in MTBF due to investment in the reliability design program ranged from 1.4 to 2.9 times (1.8

times average) the initial off-the-board MTBF; the gains resulting from investment in the reliability parts program ranged from 2.5 to 4.8 times (3.4 times average) the design gain; while the most noteworthy results were attained during the reliability test program where the gains ranged from 2.3 to 35.3 times (12.8 times average) the parts gain (8:18).

A 1976 Defense Management Journal review concluded that three important factors emerged from various reliability studies: the user and contractor must maintain a close planning and management interface; complex multiple contractual incentives can be counterproductive; and contractors must be involved in the life-cycle of the product (16:52). A panacea does not exist which could resolve the reliability problems involved in weapon system acquisition; rather, most experts advocate tailoring acquisition strategies to each new system as it enters the conceptual phase (16:53). Findings also revealed that although the first incentive to improve reliability should be exploited in requests for design concept proposals, the effort must continue through full-scale development, where in addition to incentives, emphasis can be placed on tradeoffs between reliability, operational performance and costs.

The disparity between predicted laboratory reliability and operational field reliability is a problem that is frequently encountered in weapon system acquisition.

The USAF Rome Air Development Center (RADC) sponsored a survey by Hughes Aircraft Company in an effort to gain insight into the factors that affect the field reliability of avionics equipment. In an analysis of sixteen different avionics systems, Hughes reached several conclusions which emphasized the need for clear contract term definition, close contractor/USAF interaction, and realistic contractor reliability estimates (5:56).

The study determined that the reliability experienced was found to be influenced by the maintenance personnel skill levels, maintenance procedures, and geographic/climatic differences of geographically separated bases.

Contractually negotiated definitions of system failure were found to conflict with the Air Force maintenance data management system; the fact that a significant portion (44 percent) of reported field maintenance actions did not involve relevant equipment failures emphasized the disparity (5:56). An analysis of the contractor predicted reliability of the equipment compared to a reassessed relevant failure rate indicated that some contractor estimates were optimistic. To underscore the importance of properly trained and motivated avionics maintenance personnel, the Hughes study noted that

> . . . fairly large differences in field MTBF can and do occur even though the same equipment is used on the same aircraft flying a virtually identical training syllabus at different bases [5:58].

CHAPTER III

METHODOLOGY

General Approach to the Problem

In order to place the field reliability and maintainability performance of the APG-66 in perspective, it was necessary to research those events leading up to the radar's production that significantly affected the equipment development. As such, those planning and testing documents relating to APG-66 development milestones were considered the logical point of departure for further study. Among these were the critical design review of the radar, and the development progress demonstrated in the reliability qualification test and the intermediate level maintainability demonstration.

The APG-66 demonstrated field reliability and maintainability experience constituted the principal portion of the analysis. AFM 66-1 reported field reliability and maintainability results were used as the supporting data in the calculation of a variety of performance indicator parameters. These parameters were used to judge system effectiveness and also provided a basis of comparison with an earlier generation radar, the APQ-120.

Management Documents

This analysis of the APG-66 reliability and maintainability history begins with an examination and summary of those program management documents considered crucial to the development of the production radar.

The Critical Design Review (CDR) of the F-16 Fire Control Radar, Volumes I through III, presented that information necessary to ascertain the emphasis that program management placed on the reliability and maintainability aspects of the radar development. The review summarized the subcontractor's conduct of the entire acquisition, including system design, parts control, system performance predictions, test programs and contractual compliance. The summary is an important foundation for future analyses since it provides a baseline for comparison of operational results.

The final report of the conduct and results of the formal Reliability Qualification Test (RQT) demonstrated the radar's ability to meet contractual MTBF requirements and also provided a baseline of comparison for APG-66 operational reliability performance. In this analysis, the emphasis is placed on the test results in comparison with the critical design review predictions.

It was considered essential at the RQT point to begin comparison with the APQ-120 in terms of qualification test programs, measureable reliability performance, and failure distributions. This analysis provides a baseline for further operational comparisons of the two radars in Chapter V.

The final analysis of pre-production radar testing and development is performed in the scrutiny of the contractual requirements and test results of the formal Intermediate Level Maintainability Demonstration. This report provides a foundation of final pre-production testing results to be used in the analysis of operational APG-66 maintainability. A significant amount of emphasis is placed on the conduct of the demonstration as it relates to operational maintenance procedures. The maintainability demonstration results are used in Chapter V in comparison with APG-66 maintainability experience to provide insight into the applicability of the radar maintainability program and the demonstration itself.

Comparison of Field Data

Data Sources

In order to properly analyze and compare the APG-66 field reliability performance, it was necessary to obtain as much of the system's reliability and maintainability history as possible. The necessary data, in the form of RCS LOG-MMO(AR) 7170 maintenance action summaries, was obtained for a twenty-month operational period from the Reliability Management section of the F-16 Systems Program

Office (SPO), located at Aeronautical Systems Division, Wright-Patterson AFB. This report provides on- and off-equipment historical information on the maintenance actions, man-hours, and aborts for a six-month period by month on every work unit code included in the master record. In addition, the report provides a series of summary line entries for each subsystem of the APG-66. Since the primary use of the report is for reliability and maintainability studies, the data provides the capability to plot trend and performance analyses in the areas of system and component failures, maintenance actions, manpower resource expenditure and aborts (1:1).

In conjunction with RCS LOG-MMO(AR) 7170, RCS LOG-MMO(AR) 7179 titled "Summarized Maintenance Actions for Selected Work Unit Codes," was used to analyze and compare the maintainability performance of the APG-66. The report, obtained from Headquarters Air Force Logistics Command (AFLC) located at Wright-Patterson AFB, provides six months of summarized detail maintenance information segregated by on-equipment and shop repair actions. The report is primarily used to conduct detailed analysis on work unit codes to determine reasons for substandard performance, to determine if maintenance actions are evenly distributed geographically, and to identify causes of high unscheduled maintenance rates (2:2).

The final source of data, used in comparison with APG-66 reliability development and field experience, was a 1973 radar reliability study titled "Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120 and -144 Radars." The document, available from the Defense Technical Information Center, is a comprehensive comparison of the radars' reliability activities and their impacts on life-cycle costs. This thesis effort uses some of the methodologies and comparative analyses employed in that study as a basis of comparison for the APG-66.

Field Analyses

The analysis of APG-66 field reliability begins with a comparison of experienced field reliability with those figures predicted during the critical design review and reliability qualification test. In order to shed light on the radar's predicted reliability performance, the derivation of these numbers from the critical design review reliability growth model is presented. Comparisons of field reliability performance, unadjusted and adjusted for MTBF definitional variability, with those pre-production radar predictions concludes this analysis.

The second analysis calculates the classic measureable reliability parameters exhibited in the APG-66's relatively short operational deployment. An analysis of the radar's failure rate (λ) characteristics is performed in order to determine whether the system has achieved those properties identified by components in useful life.

The reliability growth of the APG-66 discussed earlier is further analyzed in this section using reported field data. The final analysis in this discussion researches the effect of increased system use versus the system's MTBF.

The analysis of field repair times begins the examination of APG-66 maintainability. The section specifically establishes those classical parameters that are characteristic of and indicative of equipment maintainability. The focus of the analysis in this discussion is in determining the existence of a learning curve effect in the maintainability of the APG-66. The analysis concludes with an examination of the effect on maintainability as increasing numbers of radars are introduced into operational use.

The next section employs data gained from RCS LOG-MMO(AR) 7179 in order to determine the field flight-line fault diagnostic capability of the APG-66 maintenance concept. The APG-66 maintainability section is concluded with a comparison of predicted versus field line-replaceable unit (LRU) mean-time-to-repair (MTTR) figures.

Chapter V is concluded with a comparison of the APG-66 and APQ-120. These radars' capabilities and qualification test programs are presented in order to establish a baseline for further system comparison. This section uses the field reliability and maintainability figures calculated earlier in this thesis effort to judge the relative worth of the reliability and maintainability activities employed during the APG-66 development.

CHAPTER IV

APG-66 RELIABILITY/MAINTAINABILITY DEVELOPMENT

Reliability and Maintainability Overview

The focus of this chapter is an examination of the reliability and maintainability historical development of the APG-66 fire control radar. The analysis begins with the examination of the state of APG-66 design during the critical design review where the reliability and maintainability performance figures are used as a baseline for future system development. Formal reliability qualification testing (RQT), performed to demonstrate final APG-66 design MTBF, is the second subject of analysis. The emphasis in this section is placed on the achieved testing results in comparison with the F-4 APQ-120 at a similar stage of development. The final analysis examines the requirements and demonstrated results of the APG-66 formal intermediate level maintainability demonstration.

In summary, the underlying objective of this chapter is to gain insight into the progression in the reliability and maintainability design of the APG-66 fire control radar. This information, in combination with the operational field performance data analysis in Chapter V, will be used to assess the overall system reliability and maintainability program.

Pre-production Reliability and Maintainability Development

Critical Design Review

Reliability Emphasis and Predictions. The critical design review (CDR) of the APG-66, conducted in June 1976, placed a great deal of emphasis on the reliability performance of the system. Four measures developed to assure APG-66 reliability were evident in the reliability program proposed during the review. The first measure considered was the inherent strengths of the system's full-scale development design which had been subjected to electrical/thermal derating, design and thermal analysis, failure mode effects analysis and predicted reliability analysis (20:p.3-4). The second measure involved selection of only high quality/reliability component parts for inclusion in the system. General Dynamics, as the prime contractor, required that major vendors use preferred parts, source control nonstandard parts, burn-in and temperature-cycle final assemblies and improve upon the radar design to meet the contracted MTBF (20:p.3-24). The third measure, the test-and-fix phase, involved environmental screening and thermal verification, test and evaluation, and reliability growth measures. Finally, Westinghouse as the APG-66 subcontractor, was required to demonstrate both in formal testing and operational use the contractual MTBFs. As a full-scale development design, the system was required to meet a formal reliability qualification test (discussed later in this chapter) MTBF of sixty hours for the entire radar and seventy hours for the radar less the ground-mapping elements (20:p.3-4). Once full-scale production began, the radar was required to exhibit 100/125 hours in production acceptance testing and maintain a warrantied guaranteed mean-time-between-failure of seventy hours during operational use (20:p.3-4).

The F-16 radar reliability test program was forecast to be very comprehensive in that it included various environmental screenings in addition to three formal reliability demonstrations. Table 1 depicts the test program matrix annotated with the originating requirement, sample sizes and appropriate test comments. It should be noted that a 100 percent sample of all pre-production and production radar comp ·ent modules (SRUs) and first-line units (LRUs) are exposed to burn-in and random vibration.

The inherent reliability predictions calculated during the critical design review were very optimistic about projected field performance. Table 2 presents the inherent reliability predictions for the air-to-air and combined air-to-air and air-to-ground modes during the full-scale development and production phases. Table 2 will be used in Chapter V to compare predicted reliability with operational results in order to gain further insight into the reliability program.

TABLE 1

F-16 RADAR RELIABILITY TEST PROGRAM

Test	Comment	General Dynamics	West-inghouse	Full Scale Develop-ment	Pro-duction	Sample
Module Burn-In	Temperature Shock		X	X	X	ALL
First Line Unit (FLU) Burn-In	Temperature Random Vibration		X	X	X	ALL
Reliabil-ity Quali-fication Test	MIL-STD-781B, Test Plan III, Modified Test Level F	X		X	X	3,5
Thermal Verifica-tion Test	Two Tempera-ture Bakes	X		X		1
Reliabil-ity Accept-ance Test	MIL-STD-781B, Test Plan IVA Modified Test Level F	X			X	8
Transmitter Waveguide-RQT at Vendor	MIL-STD-781B, Modified Test Level F, 3000 HR, One Failure Permitted	X		X		3
Reliabil-ity Growth	Temperature Cycle, Random Vibration, Humidity-2,000 Hours	X	X	X		2

SOURCE: Critical Design Review F-16 Fire Control Radar, p. 3-5.

TABLE 2

INHERENT RELIABILITY PREDICTIONS

	Full-Scale Development		Production	
	Combined Modes	Air-to-Air	Combined Modes	Air-to-Air
LRU	MTBF (hours)	MTBF (hours)	MTBF (hours)	MTBF (hours)
Antenna	1,764	1,764	1,764	1,764
LPRF	651	651	651	651
Transmitter	1,366	1,366	1,366	1,366
DSP	491	548	576	693
Computer	1,259	1,259	2,008	2,008
RCP	12,048	12,048	12,048	12,048
System	168	174	187	197

SOURCE: Critical Design Review (U) F-16 Fire Control Radar, p. 3-7.

Maintainability Emphasis and Predictions. Westinghouse placed a great deal of emphasis on the maintainability features of the APG-66 system prior to and during the critical design review of June 1976. The maintainability program milestones developed by Westinghouse proved to be somewhat optimistic, however, as is discussed later in this chapter. The original milestone plan, as presented at the critical design review, is reflected in Figure 1.

The culmination of the maintainability program, the intermediate maintainability demonstration, was forecast to have two problem areas, one of scheduling Avionics Intermediate Shop (AIS) test equipment that might delay the demonstration itself. The second problem was a matter of normalizing diverse maintenance repair-time data to a common base for contractual interpretation of mean-time-to-repair (MTTR). The latter was a result of performing APG-66 fault diagnosis during the test by different methods: manually, using factor test equipment and automatically, using AIS equipment (20:p.10-4).

The basic parameter to measure system maintainability, mean-time-to-repair, and its prediction was the foundation of the APG-66 maintainability program. The subcontractor utilized the guidelines of MIL-HDBK-472 in generating a computer program that could provide MTTR predictions on a periodic and timely (bi-monthly) basis. The basic data used in the MTTR predictions came from four

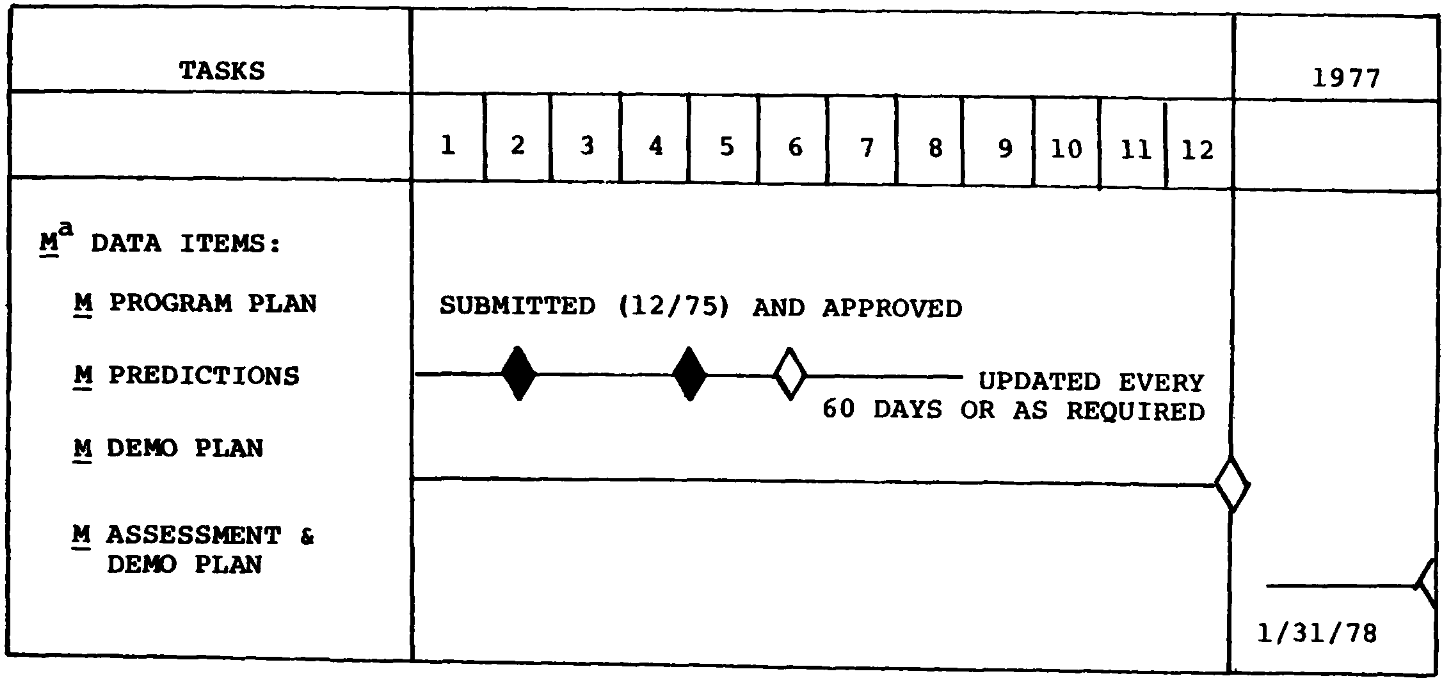

Fig. 1. Maintainability Program Milestones

[a]Maintainability

SOURCE: Critical Design Review (U) F-16 Fire Control Radar, p. 10-6.

sources (20:p.10-8): (a) the inherent failure rates of the SRUs, (b) the test times achieved in isolating faults to specific SRUs, (c) the remove and replace times for the SRUs, and (d) the retest times for a repaired LRU. The predicted MTTR, to be compared with the contractual requirements, was computed in the following manner (20:p.10-8):

$$\frac{\Sigma(\lambda M_{ct})}{\Sigma\lambda}$$

where,

λ = failure rate (number of failures per 10^6 hours), and

M_{ct} = corrective maintenance time to repair an LRU.

The MTTR predictions shown in Table 3 were calculated in May 1976 and are presented as a basis for comparative analysis in Chapter V.

The APG-66 was designed to require no adjustment or calibration of the SRUs once the system was installed in an operational aircraft. The critical design review noted, however, that the radar transmitter would require adjustments in two instances, a not unfavorable situation that still related the subcontractor's desire to conform to the maintainability requirements (20:p.10-14).

Inherent in the maintainability problem was the complexity of the APG-66. In order to enable a high percentage of fault isolation and to reduce components to a lesser number of functional modules, the six LRUs of the

TABLE 3

INTERMEDIATE LEVEL MTTR PREDICTIONS

LRU	MTTR (Minutes)	Maximum Corrective Time (Minutes)
Antenna	20.44	23.90
LPRF	42.64	49.14
Transmitter	86.31	182.30
DSP	30.64	34.70
Computer	30.21	37.35
RCP	28.26	44.41
System	42.05	67.15

SOURCE: Critical Design Review (U) F-16 Fire Control Radar, p. 10-10.

fire control radar were designed as eighty-seven shop-replaceable units (SRUs). During the critical design review this maintenance concept was instituted. Analysis revealed that 85 percent of detected system faults could be isolated to a single component during depot level maintenance. In addition, at the same maintenance level, a system fault could be isolated to three components 99 percent of the time (20:p.10-15).

Fault isolation at the field level of maintenance was also considered important. As was discussed in Chapter I, the self-test and built-in-test features of the APG-66 were important facets in the overall maintenance concept for fault isolation. At the time of the critical design review, these two subsystems were exhibiting impressive accuracy in the fault isolation process; in fact, each had in excess of 98 percent of correct system diagnosis (20:p.10-88).

In summary, the APG-66 maintenance concept, maintainability design and maintainability predictions presented during the critical design review were very optimistic of projected field results. Later sections of this chapter present further analysis and test results during the APG-66 maintainability development.

Reliability Qualification Test

Introduction. Westinghouse Electric Corporation, in conjunction with General Dynamics, conducted a reliability qualification test of the full-scale development F-16 fire control radar during the period 15 April through 30 June 1978. The objective of the reliability qualification test, which was performed in accordance with General Dynamics Specification 16ZE009 and MIL-STD-781B Test Plan III, was to verify the hypothesis that the true MTBF of the FSD F-16 fire control radar configuration met the minimum acceptable contractual MTBF (21:p.1-1). An additional requirement during the reliability qualification test was that the fire control radar pass the contractually mandated sixty-hour MTBF for the entire radar and the seventy-hour MTBF requirement for the radar less the elements unique to the ground map modes (21:p.1-1). The APG-66 was subjected to two reliability qualification tests, failing the first after thirty-three hours of relevant operating time, and passing the second in which a total of 740 relevant operating hours were accumulated (21:p.2-3).

Results of APG-66 Reliability Qualification Testing. The initial reliability qualification testing begun on the two FSD APG-66 radars resulted in a test reject decision when three relevant failures were incurred after thirty-three hours of relevant testing (21:p.2-1). In addition, twenty-two discrepancies were discovered during pretest setup and nonrelevant troubleshooting time. In order to prevent recurrence of the noted deficiencies in subsequent formal testing and operational use, proposed corrective actions were submitted to the prime contractor and thereafter incorporated into the radar design. Of the twenty-five total deficiencies, thirteen were corrected by design specification changes, five were corrected at component vendors' facilities, four were workmanship problems that precipitated procedural changes, and no cause could be identified for three (21:p.2-2). The measures implemented to correct the pretest deficiencies were thought to have accelerated the radar environmental design maturity such that the contractor exhibited a high level of confidence in immediately resuming formal reliability qualification testing.

As a result, the second formal reliability qualification test was conducted between 15 April and 30 June 1978 during which time the two systems achieved 721 relevant hours of operation while incurring thirteen relevant failures (21:p.2-3). The point estimate of fifty-seven hours used as the final qualification test achieved MTBF was derived by extending the test past the 721-hour test-plan truncation point to 740 hours (21:p.2-3). Figure 2 depicts the plot made of the progress of the test in time based on the accept/reject curves of MIL-STD-781B test plan III. Each point on the step curve represents one failure occurrence in either of the two radars tested, plotted against the combined test time of both radars at the time of failure (21:p.2-10). The graph clearly depicts the sixty-hour MTBF acceptance decision after the eleventh failure and the seventy-hour acceptance decision after the thirteenth failure.

Table 4 portrays the thirteen relevant failures observed during the second qualification test, each allocated to the particular LRU in which the deficiency was detected. In analysis, when the observed MTBF for each specific LRU is compared with the predicted MTBF, it becomes obvious that the low-power radio frequency (LPRF) and transmitter (XMTR) LRUs performed well below what was expected.

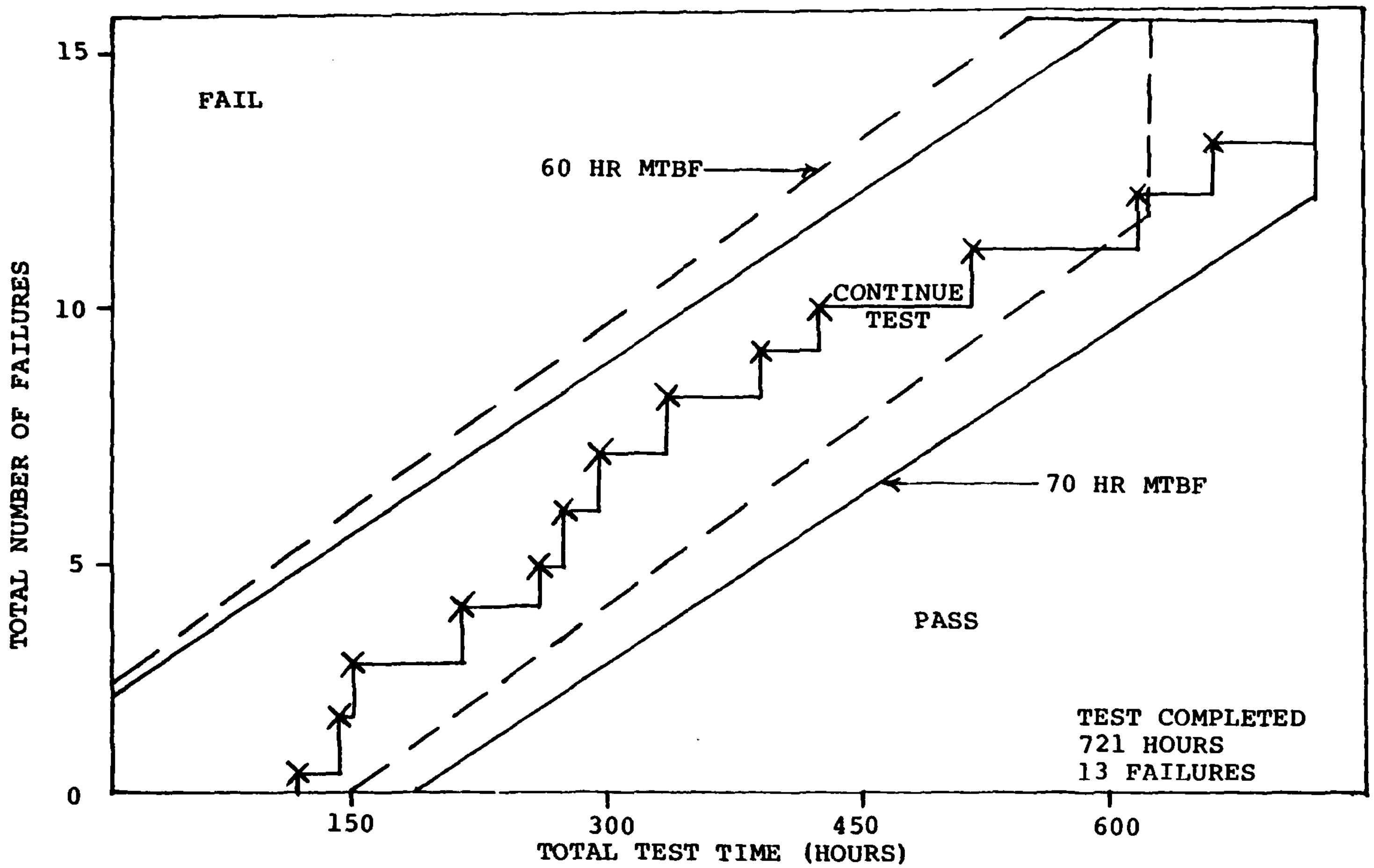

Fig. 2. Reliability Qualification Test

SOURCE: Final Report on the Reliability Qualification Test of the F-16 Fire Control Radar (FSD), p. 2-11.

TABLE 4

RELEVANT FAILURES, RELIABILITY QUALIFICATION TEST

LRU	Failures	Observed MTBF (Hours)	Predicted MTBF (Hours)
Antenna	2	370	360
LPRF	5	148	360
XMTR	4	185	300
DSP	0	Indeterminate	800
Computer	1	738	480
RCP	1	738	480
System	13	57	70

SOURCE: Final Report on the Reliability Qualification Test of the F-16 Fire Control Radar, p. 2-4.

The figures in Table 4 will also be used in Chapter V as a basis for comparison of reliability qualification test performance versus field experience.

In order to correct the deficiencies identified by the thirteen relevant failures, the subcontractor proposed design and procedural changes along with engineering investigation to General Dynamics to be implemented in the production fire control radars. The contractor predicted that these improvements, gained from qualification test experience, would significantly improve the overall system reliability.

Reliability Qualification Comparison with APQ-120. Since reliability qualification testing is the formal measure of achieved system MTBF, the APQ-120 RQT No. 5 and the APG-66 RQT No. 2 tests were compared as shown in Table 5. The complexity (parts count) of the systems were similar, APQ - 120 and 13,500 versus APG-66 with 15,100; however, the APG-66 contract MTBF was nearly seven times more demanding than that for the APQ-120 (sixty hours versus nine hours). In addition, the APG-66 demonstrated 95 percent of its contractual MTBF, while the APQ-120 fell short of its contractual requirement by more than 50 percent. The overall effect of the advancements in component technology, system design and equipment reliability programs is nowhere more revealing than in the measureable reliability performance (MTBF) differential where the ratio is 13:1 in the favor of the APG-66.

While only two APG-66 radars were evaluated during the test, the fact that each APG-66 unit achieved significantly more test exposure hours per unit of equipment (369 hours versus 32 hours) results in a greater chance of detecting workmanship-related defects whose manifestation is environmentally or time dependent (7:168). Nevertheless, the opportunity to subject a greater sample to formal reliability qualification testing should be enforced in order to determine if subtle defects in component parts lots exist.

TABLE 5

APG-66 VERSUS APQ-120 RELIABILITY QUALIFICATION TEST COMPARISON

		APQ-120[a]	APG-66
Requirements	Contract MTBF	9 hours	60/70 hours
Results	Demonstrated MTBF	4.3 hours	57 hours
Test Conditions	Chamber Test Levels	-54°C to 49°C	-54°C to 71°C
	Vibration	2.2 g	2.96 g
	Relevant Hours	96	738
Resources	Number of Equipments	3	2
Test Duration Efficiency	Elapsed Months	3	2.5
	Average Relevant Hours/Month	32	295
Incidents	Part Design	0	1
	Part Workmanship	43	5
	Design	0	2
	Workmanship	25	4
	Undetermined	7	11 (10 non-relevant)
	Total Incidents	75	23
Incident Categories by Percent of Total Incidents	Part	57	26
	Design	0	9
	Workmanship	33	17
	Undetermined	10	52 (48 non-relevant)
Incident Classification	Relevant Failures	16	13

[a]SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120, and -144 Radars, p. 169.

The reliability qualification test failure distributions for both systems were segregated into three groups according to the determination of the cause of the failure--parts (design and workmanship), equipment design and equipment workmanship. Table 5 depicts these failure classifications and the associated percentage of failures. Several items of interest are apparent from the data; most noteworthy is the fact that only 4 percent of the APG-66 relevant failures had an undetermined cause. It can be assumed that the test equipment employed did in fact perform its function to a high degree. Another significant revelation is the fact that parts workmanship and equipment workmanship incidents accounted for 70 percent of the relevant failures. Taking into consideration the low absolute number of relevant failures, this may be attributed to poor component vendor parts control and a lapse in the LRU environmental screening program. Further examination of the table reveals that the APG-66 system design appears to be quite mature in its early stage of development in that only two relevant failures could be assigned an equipment design cause.

Table 6 portrays a comparison of the two fire control radars' qualification test failures distributed according to the system environment when the deficiency was discovered. In the case of the APQ-120, more failures were observed in the cold environment than in the hot by a

TABLE 6

FAILURES OBSERVED AT COLD VERSUS OTHER TEMPERATURES APG-66 VERSUS APQ-120, RQT

TEMPERATURE	APQ-120 RQT[a]								RATIO FAIL/100 HRS AT COLD VS OTHER TEMP
	NUMBER OF FAILURES					TOTAL FAILURES	TOTAL EXPOSURE HOURS	FAILURES PER 100 HRS	
	RQT-1	RQT-2	RQT-3	RQT-4	RQT-5				
COLD	3	3	3	17	13	39	88	44	2.4
OTHER	-	-	-	17	3	20	100	20	

APQ-120 RQT cycle = 9.6 HRS   APG-66 RQT cycle = 8 HRS

ENVIRONMENT WHEN FOUND	APG-66 RQT					RATIO FAIL/100 HRS AT COLD VS OTHER (VS VIBRATION)
	NUMBER OF FAILURES		TOTAL FAILURES	TOTAL EXPOSURE HOURS	FAILURES PER 100 HRS	
	RQT-1	RQT-2				
COLD	10	3	13	330	4	
OTHER	3 (11)	9 (10)	12 (21)	893	1 (2)	
VIBRATION	8	1	9	285	3	1.7

[a]SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120, and -144 Radars, p. 176.

factor of 3:1. In determining the cause for each relevant failure, however, the final report of APG-66 RQT ascertained that only one failure was due to the test thermal (hot) environment. This demonstrates the importance and effectiveness of a thorough system environmental screening program.

One significant fact is that five of the total relevant APG-66 failures were found to be caused by the vibration employed during the testing. This can be attributed to the extensive employment of this environment (2.96 g's for fourteen minutes of every hour of system operation).

One important result of reliability qualification testing is the fact that better quality and more reliable equipment will be produced when the test cycle used closely simulates field conditions. The test-and-fix atmosphere of the formal testing ensures a major contribution will be made to the future reliability growth of the equipment.

Intermediate Level Maintainability Demonstration

Contractual Requirements. As part of the effort to deliver a fire control radar that was field maintainable, General Dynamics required that the radar subcontractor, Westinghouse, demonstrate intermediate level maintenance capability to fault isolate the radar LRUs to a shop replaceable unit (SRU), within specific accessibility, adjustment, skill level and mean-time-to-repair (MTTR) parameters (22:1). The tests were conducted on the radar LRUs that are the focus of this thesis effort: antenna, radar computer, radar control panel, transmitter, digital signal processor and low-power radio frequency. In order that the maintainability demonstration duplicate field conditions as nearly as possible, the test attempted to utilize diagnostic equipment (Avionics Intermediate Shop) actually deployed with operational units; however, in some instances Westinghouse factory test equipment and manual testing were used.

The intermediate level maintainability demonstration consisted of inserting 150 faults into the six LRU shop replaceable units (SRU) and computing the time parameters required by General Dynamics: fault isolation, LRU retest, and remove/replace and alignment (22:3). The fault isolation parameter was the time required to isolate a fault in a defective SRU utilizing factory test equipment or AIS; the remove and replace time was the time required to remove an SRU that had been determined to be defective; the total repair time was the sum of the two aforementioned parameters plus a baseline test time, a measure which determined that a corrected SRU functioned properly (22:32). General Dynamics Prime Item Development Specification 16ZE009H required that the values measured during the tests be used to determine the intermediate level maintainability parameters to ascertain progress of the maintainability development program. These parameters and requirements, in accordance with the specification, were as depicted in Table 7.

TABLE 7

INTERMEDIATE LEVEL MAINTAINABILITY REQUIREMENTS

Parameter	Requirement
1. Maintenance Time	1.0 hour
Mean (M_{ct})	1.0 hour
Max (M_{maxct})	2.0 hours
2. Skill level	AFM 39-1, Level 5
3. Intermediate Level Testability	97 percent
4. Adjustments	No Adjustments at Intermediate Level (Except as approved)
5. Accessibility	Direct Access to each SRU (Except as approved)

SOURCE: Intermediate Level Maintainability Assessment and Demonstration Report for the F-16 Fire Control Radar, p. 5.

Intermediate Level Results. The computation of the final results of the intermediate level maintainability demonstration was based on the actual repair times recorded on the isolation and repair of 138 faults. The calculations revealed, with no normalization adjustment for manual test mode, repair time results that were outside the General Dynamics specification requirements of:

Mean (M_{ct}) 1.0 hour

Max (M_{maxct}) 2.0 hour

In order to present these parameters in terms of the specification requirements that were based on the use of automatic test equipment, a decision was made to modify the recorded data for the low-power radio frequency, transmitter, and antenna test times which were diagnosed with nonautomatic equipment. The modified final results of

Mean (M_{ct}) = [illegible]8' 07"

Max (M_{maxct}) = 1 hour 48' 13"

demonstrated the APG-66 system's capability to meet the contractual specifications of repair time.

The requirements of AFM 39-1, Skill Level 5 for Air Force Specialty Code (AFSC) 32550, Fire Control Systems Mechanic, and AFSC 32551 were demonstrated by inspection during the test to be more rigorous than the requirements placed on the operator during the test demonstration.

The unabridged requirement for parameter number three, intermediate level testability, read in full:

> Each LRU shall contain sufficient test points in external SE connectors, internal test connectors (DSP) only and normal LRU interface connectors to permit connection of the required test equipment to allow positive fault isolation to an SRU for a minimum of 97% of all failures attributable to the system's SRU total failure rate [22:35].

The initial calculations of fault isolation yielded a poor testability of 68 percent; however, after corrective action and retest a 94 percent testability was achieved (22:36). The radar subcontractor considered this diagnostic figure to be sufficient and recommended to General Dynamics that the 97 percent requirement be changed to 94 percent (22:37).

The demonstration met the requirements of parameter number four, adjustments, except for two SRUs that were exempted by prior approval from General Dynamics. The last parameter, SRU accessibility, was verified for each LRU by demonstration during the test (22:38).

In summary, maintainability in the design of the radar produced satisfactory results during the intermediate level maintainability demonstration. Chapter V will compare operational repair times and diagnostic success with the outcomes of this demonstration in order to provide insight into the radar maintainability program.

CHAPTER V

FIELD RELIABILITY AND MAINTAINABILITY DATA ANALYSIS

Introduction

The general focus of this chapter is an examination of the field reliability and maintainability of the APG-66 fire control radar. The reliability analysis begins in the next section with a comparison of reported field reliability performance data as opposed to the contractual equipment reliability requirements of the last chapter. The second analysis determines those classical reliability measures exhibited by the APG-66 in its deployed phase.

The following section of this chapter concentrates on the reported field maintainability of the APG-66. In addition to researching the indicators of field maintainability, the section compares the operational maintainability results with the critical design review and demonstration test predictions in order to determine the results of the dedicated maintainability program.

The final section integrates the reliability and maintainability discussion by comparing the APG-66 with the performance of an earlier generation radar, the APQ-120. In this comparison, it should be kept in mind that equipment technical capabilities are an important facet of equipment mission performance but are not the focus of this effort.

APG-66 Field Reliability

Objective

The primary objective of this section is to correlate differences in reported field reliability performance data for the APG-66 in comparison with equipment reliability requirements. A second objective is to determine the reliability parameters experienced by the system in its deployed phase.

The data used in the analysis comes from several sources. The performance characteristics of reliability qualification testing used in Tables 8, 9 and Figure 3 (shown later in this chapter are derived from the "Final Report on the Reliability Qualification Test of the F-16 Fire Control Radar (FSD)," a document prepared by the Westinghouse Defense and Electronic Systems Center. Reliability predictions for the production radar used in Tables 8, 9 and Figure 3 are extracted from the "Critical Design Review of the F-16 Fire Control Radar," a document also prepared by Westinghouse. The data used to calculate the radar's field reliability results in Tables 8 and 9 were obtained for a six-month reporting period (August 1980 to January 1981) from RCS LOG-MMO(AR) 7170, titled

"Maintenance Actions, Manhours, and Aborts by Work Unit Code," an output provided by the Air Force Logistics Command management information system.

Data Analysis

Requirements and Field Results Comparison. This analysis of APG-66 field reliability performance begins with an examination of the reliability growth model (Figure 3) which was presented at the critical design review as part of the Westinghouse reliability management program. The reliability growth model is a graphic representation that can be used to ascertain the amount of reliability testing hours necessary to achieve a target MTBF. Conversely, it can also be used during development to determine whether a system's reliability is growing at the projected rate.

The subcontractor's selected growth rate for the APG-66 radar, $\alpha=0.5$, was based on the radar's inherent design, the component inherent failure rates and the system's parts complement. An examination of Figure 3 reveals that in order to achieve a target sixty hours MTBF, a minimum of 1500 hours of evaluation testing would be required at the selected growth rate of $\alpha=0.5$. It is significant that although the reliability qualification test results were less than that contractually specified

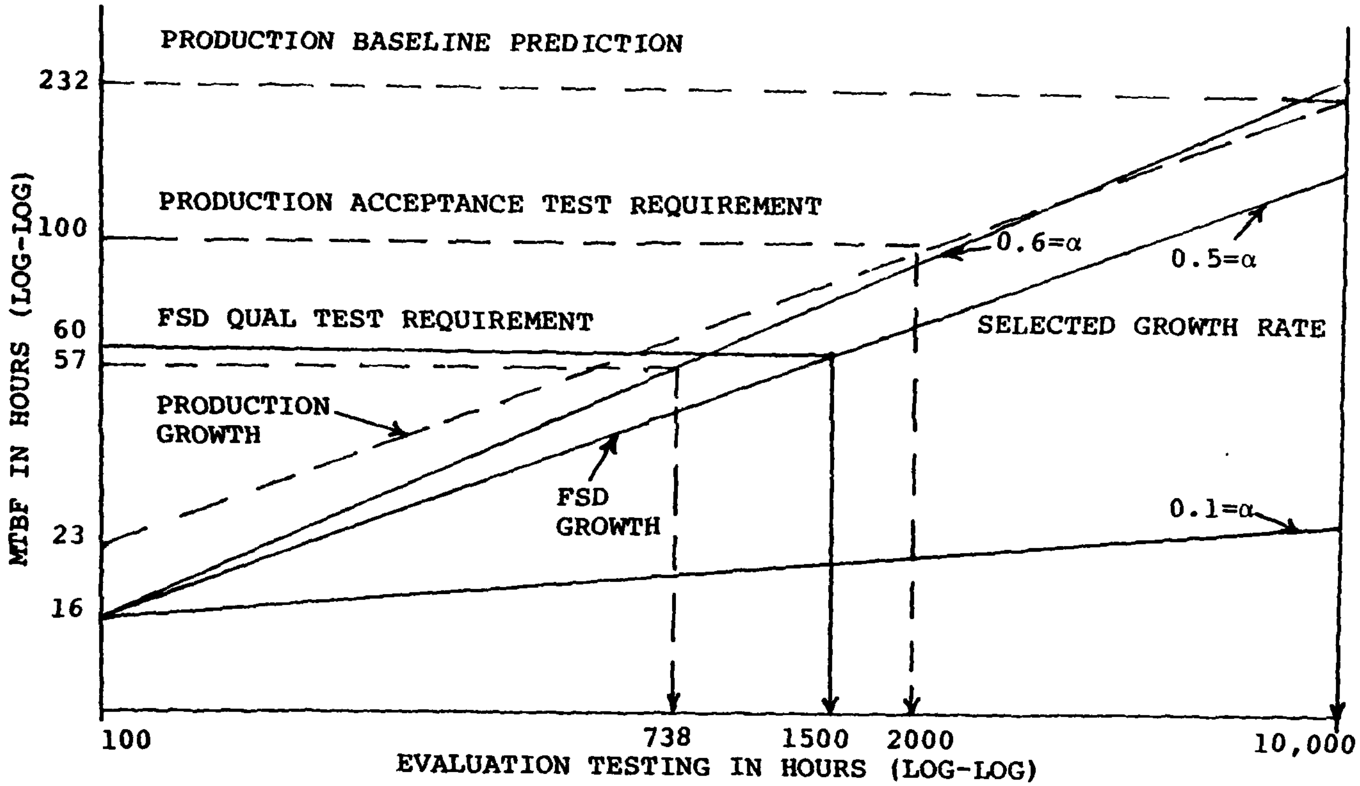

Fig. 3. Reliability Growth Model, APG-66

SOURCE: Final Report on the Reliability Qualification Test of the F-16 Fire Control Radar, p. 2-11.

(fifty-seven hours MTBF versus sixty hours MTBF), the radar experienced a greater reliability growth rate (α=0.6) than that required.

The reliability growth model is also used to establish the testing hours necessary to achieve the production baseline and production acceptance test requirements. The test consists of a 2000-hour test-and-fix development conducted in accordance with test plan IV-A of MIL-STD-781B, where a minimum MTBF of 100 hours at a growth rate of α=0.5 is required. Although the production acceptance tests are not yet complete, the minimum and baseline production reliability figures of 100 and 232 hours MTBF, respectively, constitute a basis for comparison with the field reliability performance data experienced to date.

Table 8 provides reliability figures that can be used to judge the accuracy of the program's reliability design and testing predictions in comparison with the field results. The figures in column one represent the subcontractor's predicted MTBFs, which were based primarily on the radar's inherent design, presented during the critical design review of the radar. The data in column 2, RQT Results, are reliability performance figures obtained during formal reliability qualification testing. Column 3 presents the reliability experienced by the radar during a six-month operational period.

TABLE 8

COMPARISON OF PREDICTED RELIABILITY VERSUS OPERATIONAL RESULTS, APG-66[a]

LRU	Production[b] Prediction	RQT[c] Results	Field[d] Results
Antenna	1764	370	138
LPRF	651	148	150
Transmitter	1366	185	202
DSP	576	Indeterminate	399
Computer	2008	738	300
System	187	57	35

[a]Hours MTBF.

[b]SOURCE: Critical Design Review (U) F-16 Fire Control Radar, p. 3-7.

[c]SOURCE: Final report on the Reliability Qualification Test of the F-16 Fire Control Radar (FSD), p. 2-4.

[d]Reporting Period: August 1980 to January 1981.

The significant observation of Table 8 is the difference between the system MTBF in the RQT results (57) and that experienced in the field (35). This can be explained by the different definitions of MTBF employed in the two phases. In the reliability qualification testing phase, MTBF was defined as: ". . . equal to the total operating time of the equipment divided by the number of failures. The Mean Time Between Failure is also the reciprocal of the failure rate [21:p.1-2]."

The determination of MTBF in operational radars is calculated using reported flight hours, which in most instances is somewhat less than the total radar operating time. A modifier factor (k=1.5), applied to the MTBF, is used to correct for the difference. Table 9 presents the same comparison with the field results adjusted by the modifier factor, now defined R rate adjusted. It can be seen that the field results for the radar are now 92 percent of that demonstrated during reliability qualification testing.

TABLE 9

COMPARISON OF PREDICTED RELIABILITY VERSUS ADJUSTED OPERATIONAL RESULTS, APG-66[a]

LRU	Production Prediction	RQT Results	Field Results
Antenna	1764	370	182
LPRF	651	148	225
Transmitter	1366	185	303
DSP	576	Indeterminate	599
Computer	2008	738	449
System	187	57	52

[a] R Rate Adjusted, defined as Field MTBF multiplied by 1.5.

SOURCE: see Table 8.

Analysis of Field Reliability Parameters. The analysis in this section deals with measureable reliability parameters experienced by the APG-66 during its deployed phase. The reported system failure occurrences and aircraft flight times are extracted from data reported in the RCS LOG-MMO(AR) 7170 computerized output. Table 15 (Appendix A) presents the APG-66 reported field data used in the analysis.

The first analysis performed was a determination of the failure rate (λ) characteristics exhibited by the radar during its deployed period ending January 1981. The failure rate, λ, is defined to be the inverse of the Mean-Time-Between-Failure, or $(\frac{1}{MTBF})$.

It is generally accepted that complex avionics, such as radar, exhibit a failure rate which, when plotted as a function of time, portray a bathtub shaped curve (Figure 4). The curve represents three theoretical divisions of an equipment's life. In reference to Figure 4 these three divisions are the burn-in period, where failures occur usually as a result of poor manufacturing and quality-control techniques during the production process; useful life, where the failures are usually due to chance (as a result of sudden stress accumulations); the final period is wearout, where failures occur due to component aging. At some period of component life, the early failure rate of a system will decrease and approach the constant failure rate representative of the useful life

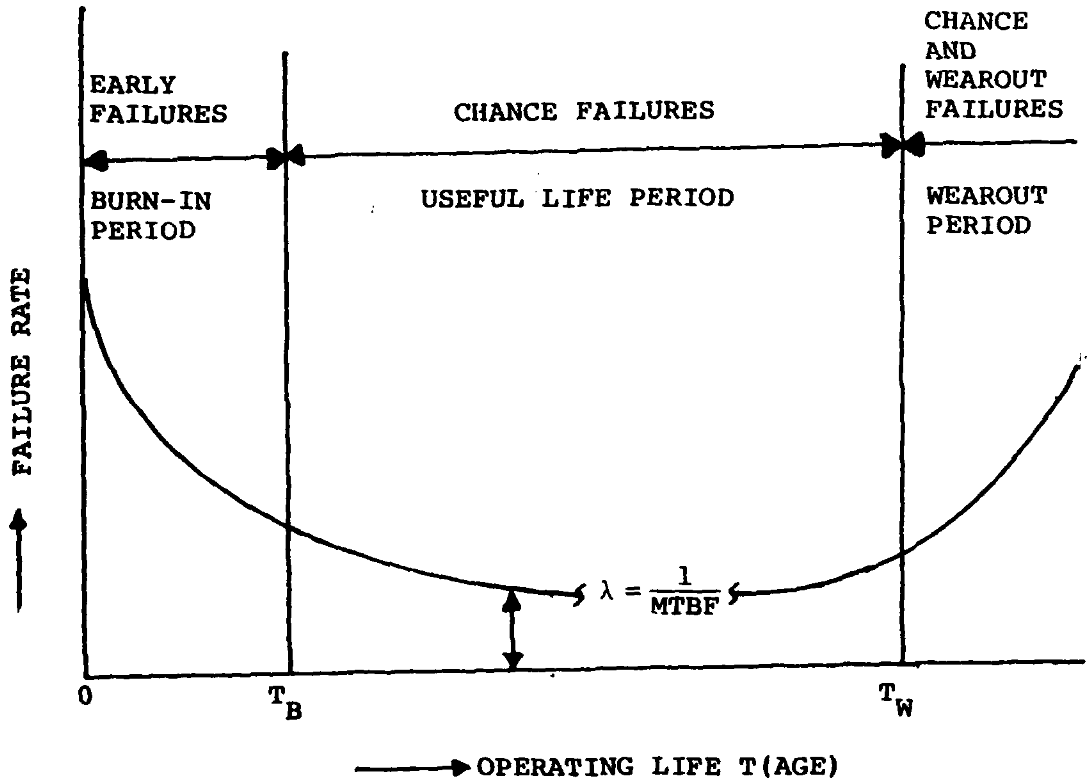

Fig. 4. Component Failure Rate as a Function of Age

SOURCE: Bazovsky, <u>Reliability Theory and Practice</u>, p. 33.

period. In that the APG-66 radar is a relatively new system, it is not improbable that its failure rate characteristics are representative of the early life/normal life juncture.

Table 16 (Appendix A) presents the data used to examine this hypothesis. This failure rate data, presented as a scatter plot in Figure 5, clearly depicts the exponential curve characteristics identified with "early life" in Figure 4. The data does not allow an assessment of whether a constant failure rate has been achieved; however, it appears that the upward swing in the curve near the end of the data cycle may be due to imperfect repair of substandard components (3:71).

Further analysis of the APG-66 failure distribution is depicted in Figure 6, a graph which shows cumulative failures plotted against cumulative flying time. The non-linearity of the plot is indicative of a non-constant failure rate. The slope of this curve at any one point is, in fact, the failure rate.

In order to gain insight into the reliability growth of the system during its deployed phase, the cumulative AFM 66-1 R Rate (reported flight hours divided by failure occurrences) was plotted against the cumulative flying time incurred during the same period. A scatter-plot of the data in Figure 7 reveals a tendency towards linearity. As such, a linear least squares regression

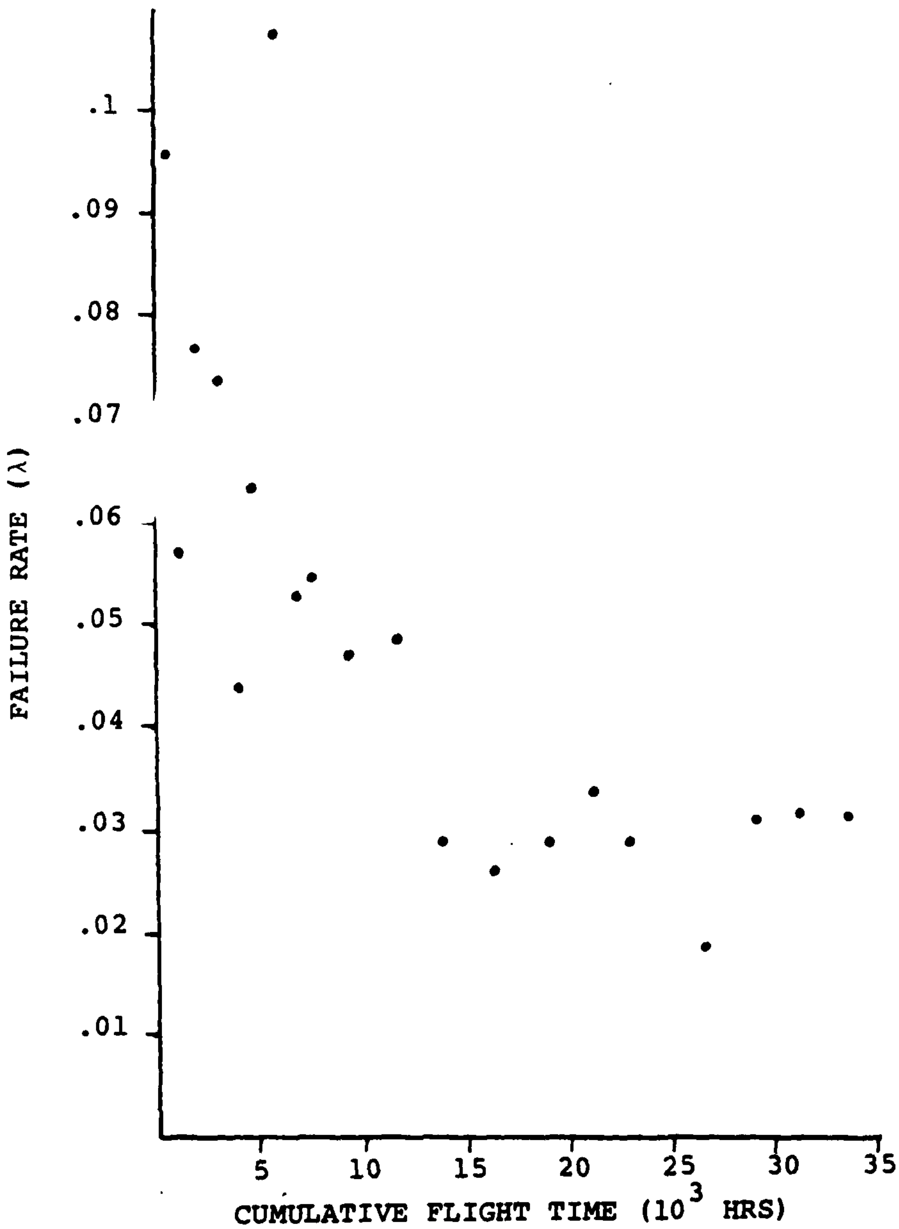

Fig. 5. APG-66 Failure Rate vs Cumulative Flight Time (Reporting Period: June 1979 to January 1981)

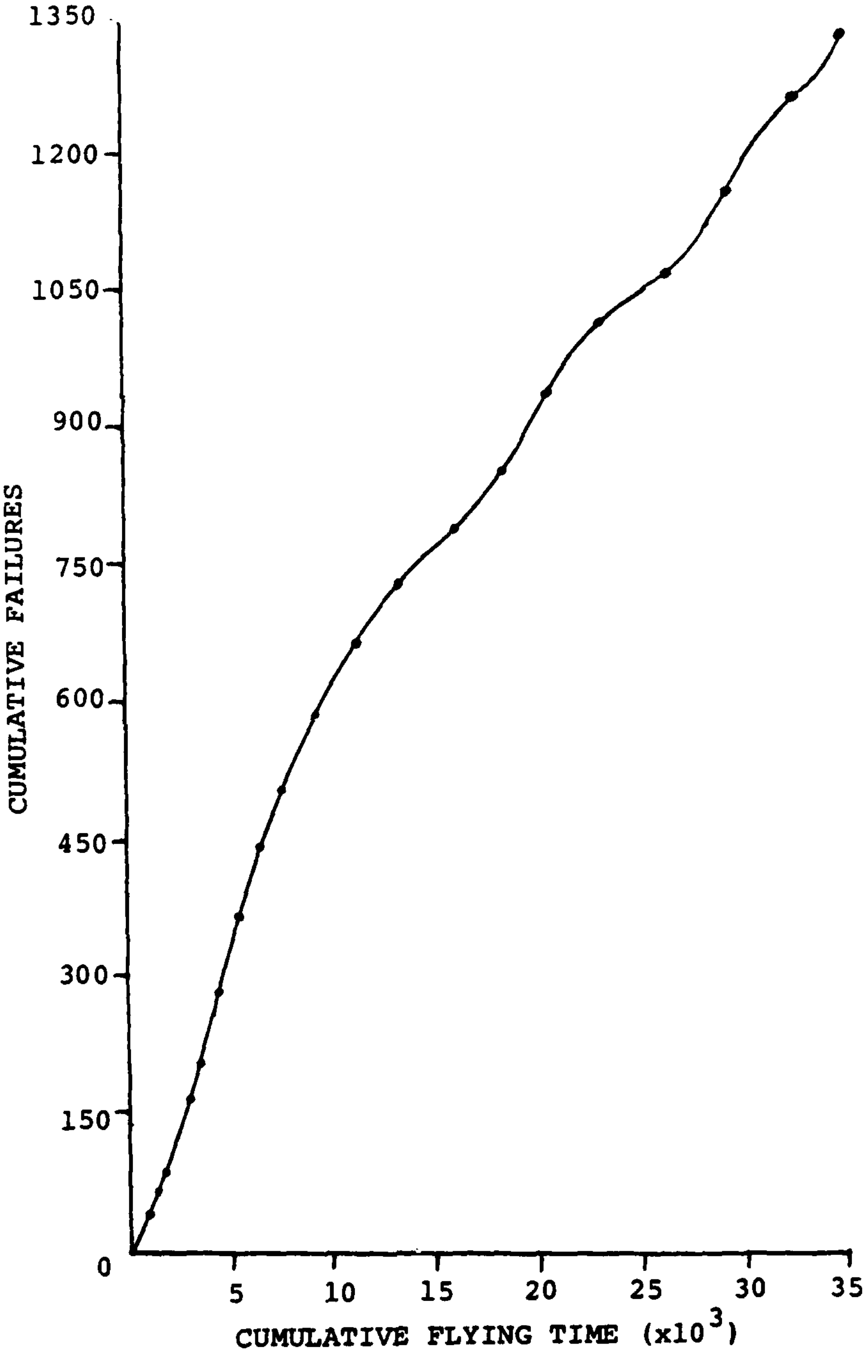

Fig. 6. Graph of APG-66 Cumulative Failures vs Cumulative Flying Time (Reporting Period: June 1979 to January 1981)

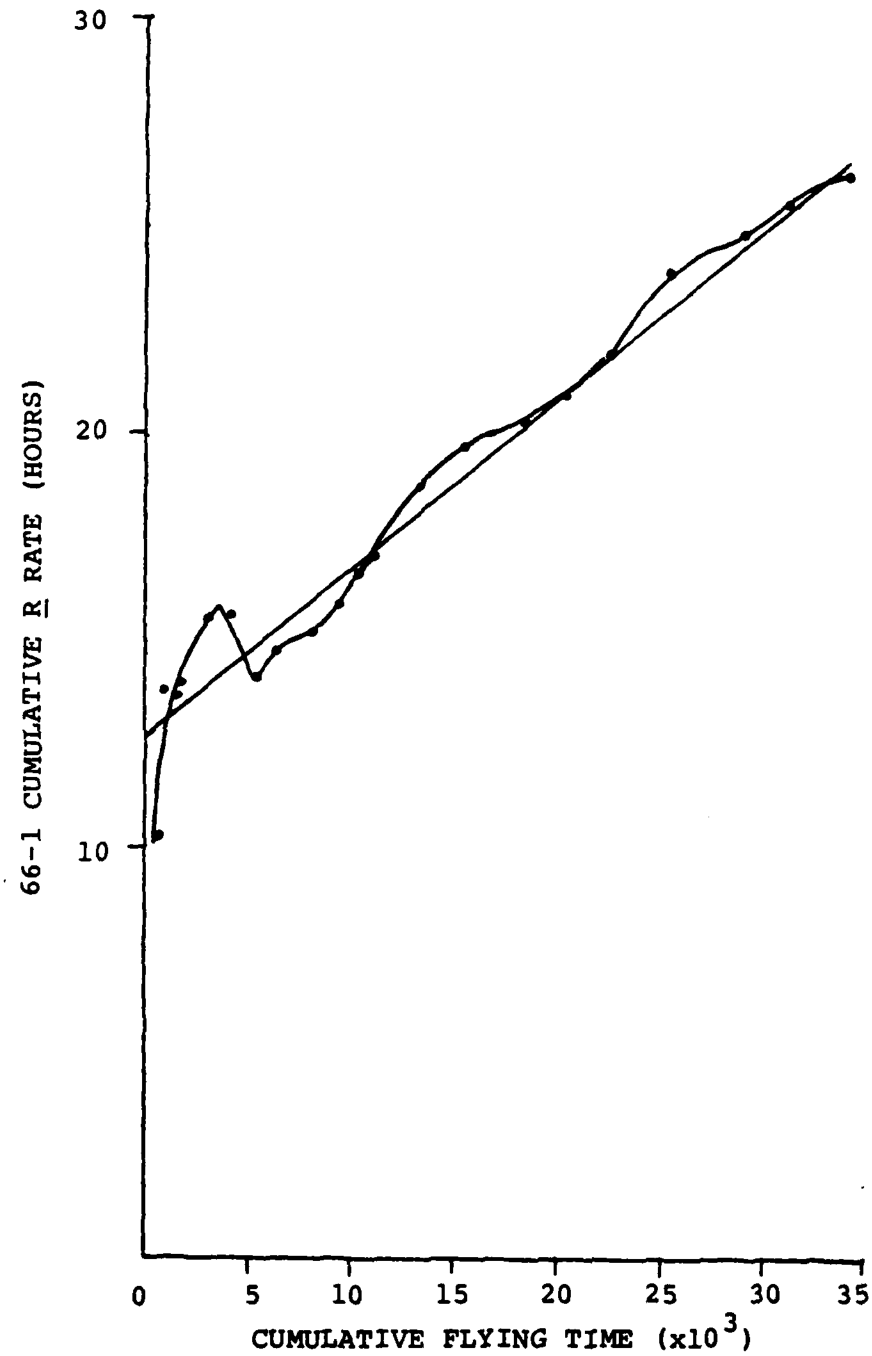

Fig. 7. Graph of APG-66 Cumulative MTBF (R Rate) vs Cumulative Flying Time (Linear Equation, by regression, $\hat{y}=12.552 + 0.00042x$; correlation coefficient = 0.981) (Reporting Period: June 1979 to January 1981)

model was fit to the data yielding a predictive equation of $\hat{y} = 12.552 + 0.00042x$ and a correlation coefficient equal to 0.981. The slope of the regression equation, 0.00042, is in fact the reliability growth experienced by the radar in operational use. That is, the radar reliability is increasing by 0.4 hours between failures for every 1,000 hours of operational flying.

A final analysis was performed to determine if increased operational use of the system would increase the system's reliability. A more effective time to analyze this hypothesis would be after the system had entered its useful life period referred to earlier. A scatter plot in Figure 8 of monthly MTBF versus monthly flying time again shows a trend toward linearity. A least squares linear regression model of the data yields a predictive equation of $\hat{y} = 6.347 + 0.011x$ with a correlation coefficient of 0.888. The positive slope, though it is contaminated by a decreasing failure rate and learning curve effects, does seem to indicate that increased frequency of system use has a positive effect on MTBF.

APG-66 Field Maintainability

Introduction

This section examines the maintainability parameters experienced by the APG-66 in its deployed phase. The analysis begins with an examination of the distribution

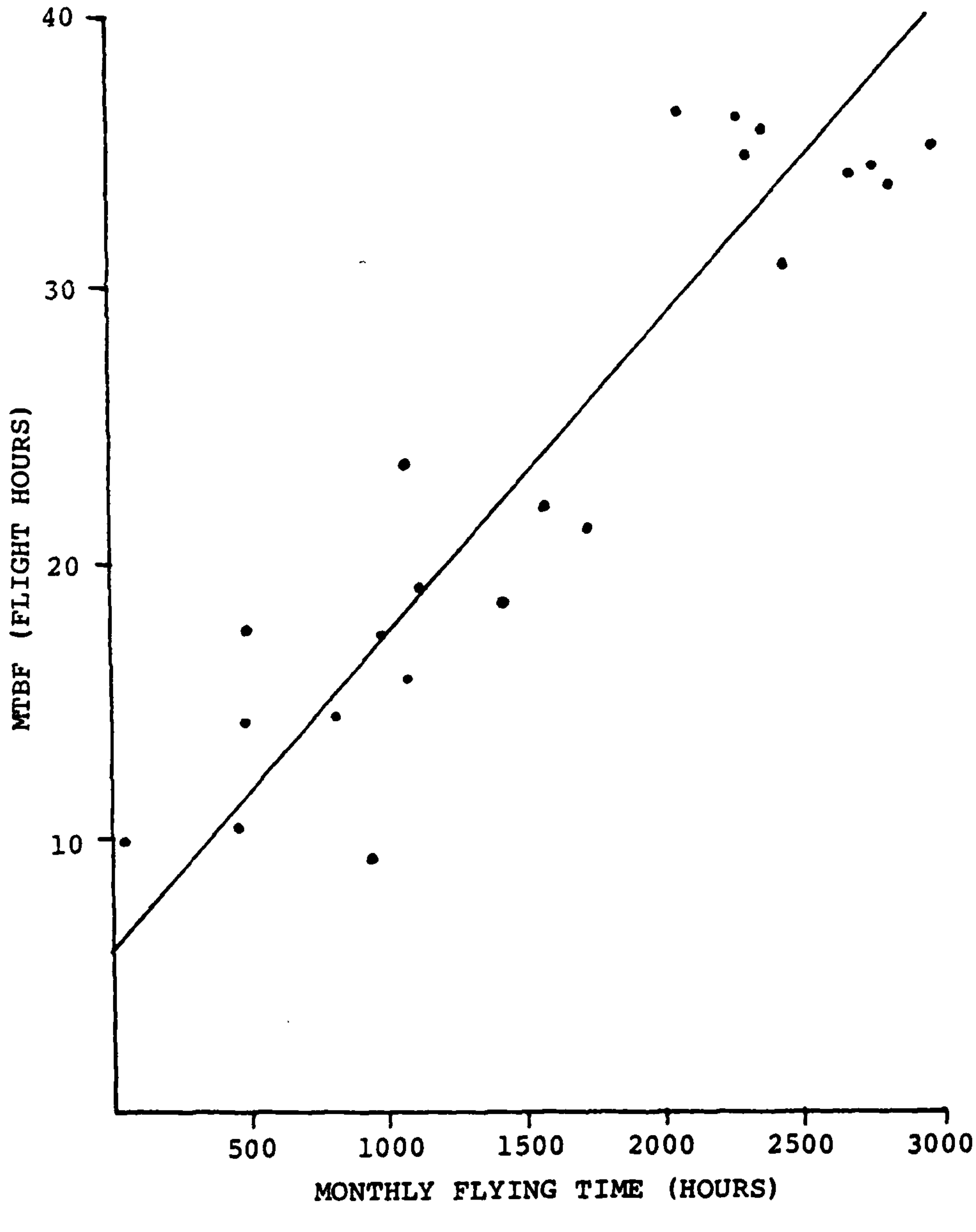

Fig. 8. Graph of APG-66 Monthly MTBF vs Monthly Flying Time (Linear Equation, by regression y=6.347 + 0.011x; correlation coefficient = 0.888) (Reporting Period: June 1979 to January 1981)

of the ratio of maintenance-man-hours (MMH) per failure occurrence (OCC) data points and closes with a scrutiny of field maintainability experience. APG-66 field maintainability is compared with the predictions forecast at the critical design review and also with the results attained during the intermediate level maintainability demonstration. The data used in these analyses was obtained from RCS-MMO (AR) 7179, titled "Summarized Maintenance Actions for Selected Work Unit Codes," which is a computer product generated by the Air Force Logistics Command management information system. In particular, the APG-66 maintenance data extracted was valid for a twenty-month reporting period (June 1979 through January 1981) and included both "on-equipment" (scheduled plus unscheduled) and "off-equipment" (shop repair) maintenance repair times and actions.

The two main objectives of this section are to first determine if a learning curve effect exists in the maintainability of the APG-66, and then to determine the applicability of critical design review predictions and maintenance demonstrations in forecasting expected system mean-time-to-repair (MTTR).

Data Analysis

Examination of Maintenance-Man-Hour Distribution.

In order to determine the possible existence of a learning curve effect in the maintainability of the APG-66, field flight line repair data (scheduled plus unscheduled on-equipment maintenance repair actions and man-hours) was analyzed for a twenty-month period of operational experience. Table 17 (Appendix A) depicts the information extracted from RCS LOG-MMO(AR) 7179, including radar units in the operational inventory (INV), maintenance-man-hours (MMH) allocated during the calendar month, total maintenance occurrences (as opposed to failures) during each calendar month, and a final column reflecting a maintenance-man-hour/occurrence ratio (MMH/OCC).

Each MMH/OCC data point was plotted against the respective cumulative flight time figure in order to determine if the increase in system familiarity due to the passage of time (learning curve effect of the form $y=ax^n$ where $n = \log b/\log 2$) might cause a decrease in the MMH required to correct a system deficiency. The scatter plot of the MMH/OCC data points shown in Figure 9 clearly depicts the opposite of that hypothesized; in fact, the data reflects a tendency towards linearity with a positive slope. The slope can be interpreted as representing an average increase in maintenance-man-hours devoted to each maintenance action when there is a corresponding increase in the cumulative system flight time. A possible explanation for this unexpected result is the unfamiliarity with the system on the part of maintenance personnel due to new radar units

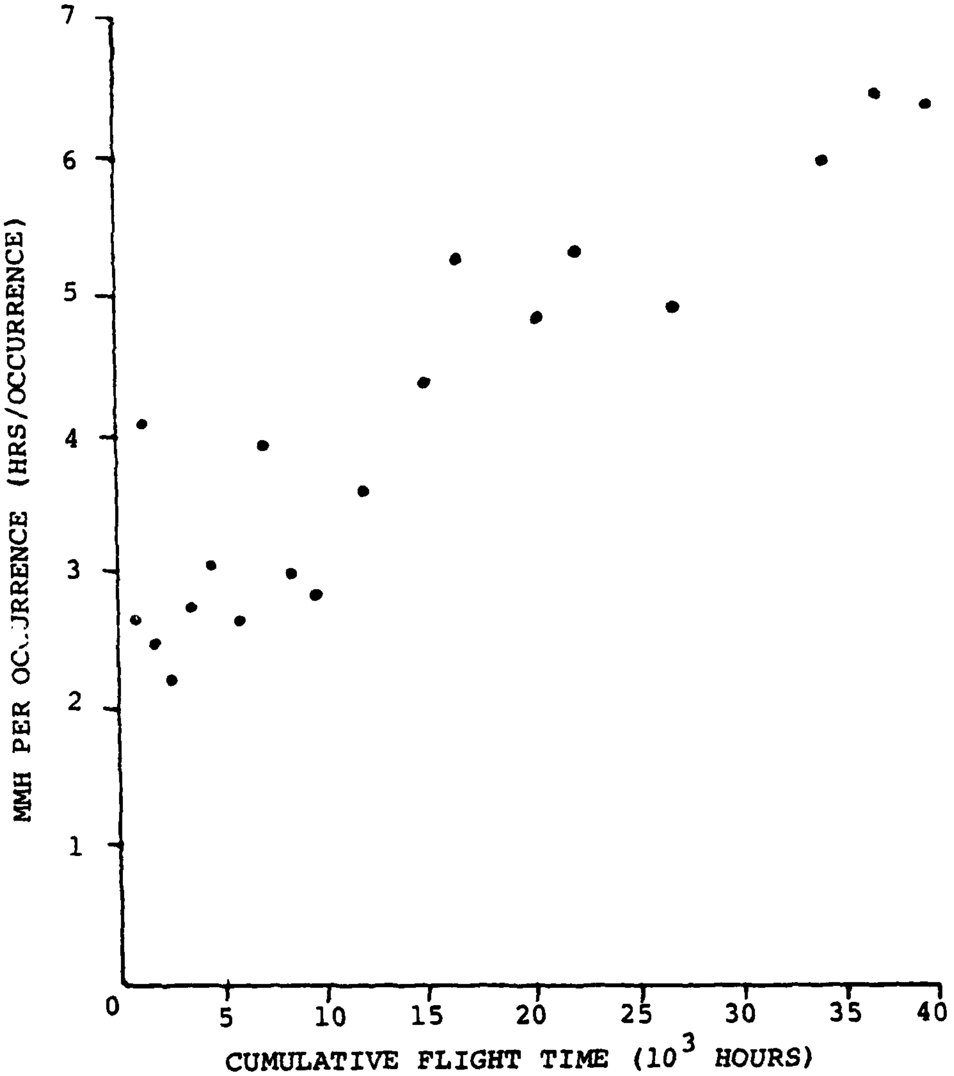

Fig. 9. Graph of Maintenance Man-Hours per Failure Occurrence vs Cumulative Flight Time (Reporting Period: June 1979 to January 1981)

being deployed in the field. A definite increasing MMH/OCC trend can be seen occurring at the 9500 flight hour point that corresponds to March 1980.

Figure 10, a graph of MMH/OCC plotted against APG-66 inventory, more clearly emphasizes this trend. The rapidly increasing slope occurs at the eighty-nine-unit point which, assuming a seventy-two-unit equipment (UE) wing, might indicate the activation of a new squadron at a geographically separated location.

A possible conclusion, based on the preceding discussion, is that the training of new personnel in the diagnosis and maintenance of the APG-66 appears to be somewhat deficient. A second possible explanation for the anomaly is that APG-66 diagnostic equipment may be lagging the radar inventory, thus requiring a greater use of time-consuming manual system testing.

Predicted versus Field APG-66 Maintainability. This section analyzes the field maintainability of the APG-66 in comparison with the predictions of the critical design review and the test results of the maintainability demonstration. The field data used in the analyses were extracted from RCS LOG-MMO(AR) 7179 for a six-month reporting period (June 1979 through January 1980).

The first analysis examines the field flight-line fault diagnostic capability of the maintenance personnel,

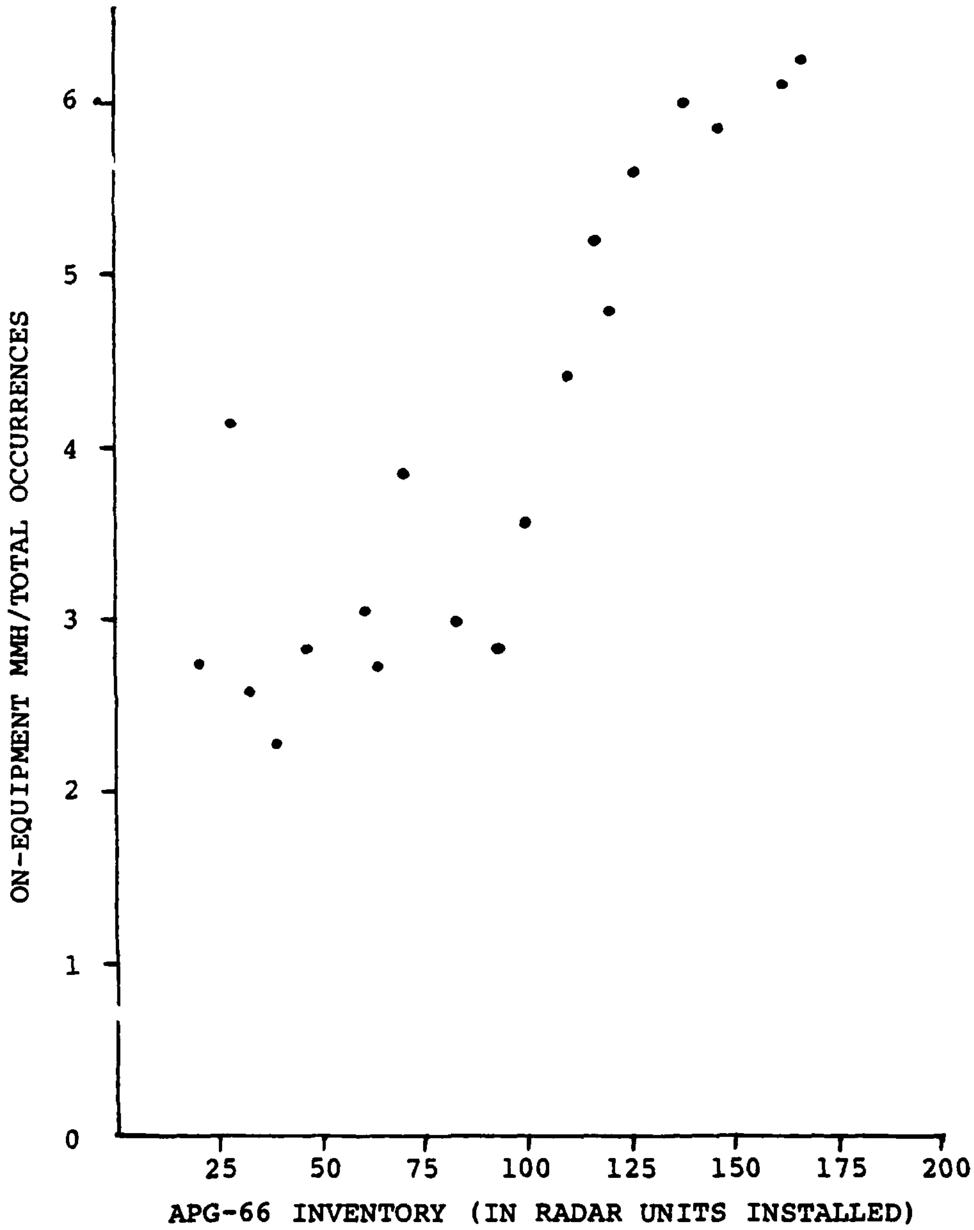

Fig. 10. Graph of On-Equipment Mean Maintenance Hours per Occurrence vs APG-66 Inventory (Reporting Period: June 1979 to January 1981)

the associated test equipment, and the built-in-test self-test features of the F-16 aircraft. To perform this analysis, it was necessary to determine the number of the total maintenance occurrences that were classified as Type 6 (no defect) how-malfunction codes for "on-equipment" maintenance. Table 10 displays the percentage of unverified failures by LRU.

TABLE 10

FLIGHT-LINE DIAGNOSTIC RESULTS, APG-66

LRU	Total Occurrences	Unverified Failures	Percent Unverified Failures	Total Complexity (Parts Count)
Antenna	169	14	8.28	1653
LPRF	172	21	12.21	3172
Transmitter	128	10	7.81	2150
DSP	76	13	17.11	4588
Computer	104	18	17.30	2700
Control Panel	32	7	21.88	245
System	681	83	12.18	-

Reporting Period: June 1979 to January 1981.

Maintainability experience usually dictates that as equipment complexity increases, failure diagnostic accuracy decreases (3:219). Such is not the case in this analysis; in fact, the least complex LRU, the radar control panel, exhibited the highest rate of serviceable diagnosis. It also appears that fault isolation in the digital signal processor and computer LRUs is somewhat deficient.

As was noted in Chapter IV, the radar subcontractor was very optimistic during the critical design review of the predicted maintainability of the APG-66. Although not achieving the predicted MTTR, the APG-66 intermediate level maintainability demonstration achieved impressive results in minimizing system total repair time (consisting of fault isolation time, remove and replace time and baseline test time).

The APG-66 maintainability experienced in the field, however, has to this point not achieved the predicted results. In order to determine the extent to which pre-production predictions were satisfied, it was necessary to determine the maintenance-man-hours expended for on-equipment repair for the total maintenance actions recorded. This data was available in RCS LOG-MMO(AR) 7179 for the six-month period of concern, August 1980 to January 1981.
The MTTR was calculated for each APG-66 LRU by summing the respective total on-equipment MMHs expended and dividing by the total number of repair actions allocated to system deficiency occurrences. Table 11 presents these field results in comparison with the predictions of the critical design review and demonstration test.

TABLE 11

COMPARISON OF ON-EQUIPMENT MTTR, CRITICAL DESIGN REVIEW PREDICTIONS AND MAINTAINABILITY DEMONSTRATION VERSUS OPERATIONAL RESULTS, APG-66

LRU	CDR Predicted[a] MTTR (Minutes)	Demonstration[b] MTTR (Hrs/Min)	Field[c] MTTR (Hrs)
Antenna	20.44	2 hrs 24 min	4 hrs 48 min
LPRF	42.64	1 hr 54 min	4 hrs 12 min
Transmitter	86.31	51 min	4 hrs 6 min
DSP	30.64	29 min	4 hrs 12 min
Radar Computer	30.21	32 min	3 hrs 30 min
RCP	28.26	10 min	2 hrs 24 min
System	42.05	1 hr 12 min/ 0 hrs 58 min (adjusted)	3 hrs 52 min

[a]SOURCE: Critical Design Review (U) F-16 Fire Control Radar, p. 10-10.

[b]SOURCE: Intermediate Level Maintainability Assessment and Demonstration Report for the F-16 Fire Control Radar.

[c]Reporting Period: August 1980 to January 1981.

Reliability Comparison, APG-66 versus APQ-120

Objective

This section uses a 1973 radar reliability study, "Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120 and -144 Radars," as a foundation of reliability and maintainability comparison of the APG-66 and APQ-120 radars. Some of the methodologies and comparative analyses used in that study are employed in this effort to standardize the results. In addition, all data pertaining to the APQ-120 radar is extracted from this report and is assumed to be valid.

This analysis focuses on the relative equipment capabilities, a comparison of the reliability qualification test programs, and a generalized look at the experienced field reliabilities. The major objective of this section is to determine what, if any, progress has been made in complex avionics reliability development.

Equipment Capabilities and Reliability Program Comparison

It is important to realize in any comparative analysis that different equipment, even though performing similar functions, may have different functional capabilities, and that those capabilities may differ in the degree of technical performance. This effort does not attempt to measure this relative technical equipment performance, but rather focuses on the predicted and achieved reliability maintainability results. A comparison of these functional complexities and capabilities is presented in Figure 11. Although the APQ-120 and APG-66 are not of similar design vintage, their functional capabilities, system complexities and field application are very similar.

Table 12 presents a dramatic contrast between the two radars in the manner in which the reliability qualification test programs were conducted. Whereas the APQ-120 achieved a demonstrated MTBF of only 4.3 hours based on a contractually required forty-five hours, the APG-66 achieved a fifty-seven-hour MTBF of a seventy-hour requirement. This contrast can be attributed to several factors, foremost among them is the overall conduct of the reliability program. Specifically, while the APQ-120 was subjected to only ninety-six relevant hours of reliability qualification test time, the APG-66 underwent 738 hours. Strict enforcement of the contractual MTBF at this stage is also important. This facet is most evident considering that the APG-66 achieved 82 percent of its reliability qualification test MTBF requirement, whereas the APQ-120 was notably deficient, achieving only 47 percent of its requirement.

Field Reliability/Maintainability Comparison

Table 13 compares the APQ-120 to the APG-66 in field reliability expressed in mean-flight-hours-between

RADAR	APQ-120[a]	APG-66[b]
COMPLEXITY (ELECTRICAL PARTS)	13,553	8,721
ELECTRICAL LRUs	19	6
Search	X	X
Detection	X	X
LCOSS Display	X	X
Tracking	X	X
Missile Illumination	X	X
AOJ	X	X
Air Combat Mode		X
Mapping	X	X
Ranging	X	X
Expanded Display		X
Freeze Mode		X
DBS		X
CRT Display	X	X
BITE	X	X
Self-Test		X
Computation	X	X
Beacon Capability	X	X
Auto Photography		X
ECM Features	X	X
EO Mode	X	X
Fault List		X
Sea Mode		X
Target History		X

Fig. 11. Equipment Capability Comparison, APQ-120 vs APG-66

[a]SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120, and -144 Radars, p. 12.

[b]SOURCE: User's Manual (Computer Program) for the F-16 FCR.

TABLE 12

RELIABILITY PROGRAM COMPARISON

	APG-66[a]	APQ-120[b]
Equipment Complexity (parts count)	15,200	13,500
Reliability Test Specification	MIL-STD-781B, Test Plan III, Level F	MIL-STD-781A, Level A
Reliability Test Timing	Late	Late
Relevant Reliability Qualification Test Hours	738 Hours	96 Hours
LRU Environmental Screening	100 Percent	0 Percent
MTBF Required	70 Hours	9 Hours
MTBF Predicted	187 Hours	45 Hours
MTBF Demonstrated	57 Hours	4.3 Hours

[a]SOURCE: Final Report on the Reliability Qualification Test of the F-16 Fire Control Radar.

[b]SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120, and -144 Radars.

TABLE 13

AFM 66-1 DATA, APG-66 VERSUS APQ-120

Parameter	APQ-120[a]	APG-66[b]	APG-66/APQ-120 Ratio
R Rate (hours)	11	35	3.18
M Rate (hours)	4	11	2.75
Flight Hours/MMH[c]	0.4	1.36	3.4

[a]SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120 and -144 Radars, p. 2-11. (Reporting Period: June to November 1971).

[b]SOURCE: RCS LOG-MMO(AR) 7170. (Reporting Period: August 1980 to January 1981).

[c]MMH includes scheduled/unscheduled maintenance in the field, shop and depot.

failures (R rate) and in field maintainability expressed in mean-flight-hours-between-maintenance-actions (M rate). The column headed Ratio to APQ-120 clearly shows the APG-66 to be a superior radar in the reliability sense.

It has previously been noted that reliability growth was considered an important facet of the APG-66 program. Figure 12 presents a comparison of reliability history of the APQ-120 (reporting period 1967 to 1971) versus the APG-66 (reporting period June 1979 to January 1981). It's evident from the slope of the older generation radar's curve that little, if any, reliability growth occurred. In contrast, as noted earlier in this chapter, the APG-66 is experiencing an aggressive reliability growth.

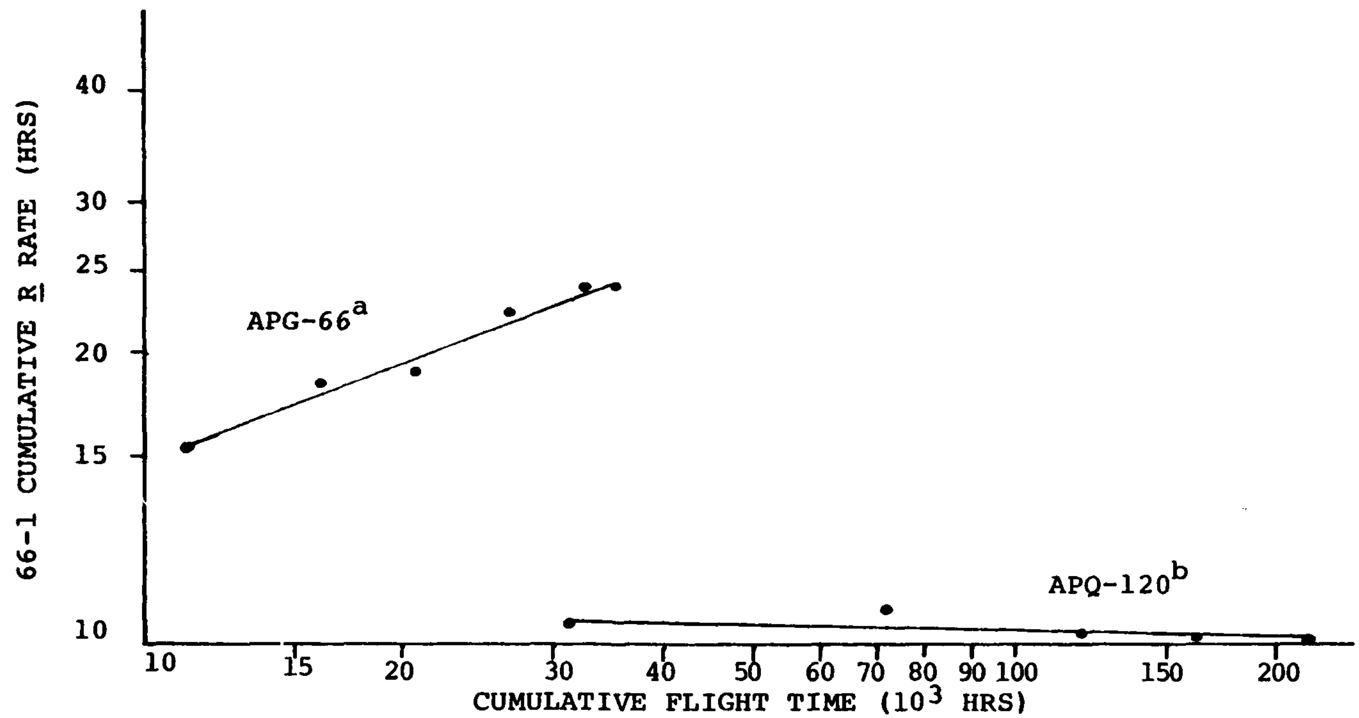

Fig. 12. Adjusted Field Reliability vs Flight Time, APG-66[a] vs APQ-120[b]

[a]Reporting Period: June 1979 to January 1981.
[b]Reporting Period: 1967 to 1971.

SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113,-114,-120, and -144 Radars, p. 225.

Table 14 compares the maintainability aspects of the fire control radars in terms of maintenance-man-hours per maintenance action (MMH/MA), a figure that reflects greatly on a weapon system's availability. Clearly, again, the APG-66 is a superior radar in this sense with a low average 6.0 MMH/MA. This contradicts the indication that a maintenance learning curve for the APG-66 did not exist. A possible explanation may be that the APG-66 is extensively partitioned into six line-replaceable units (LRUs) and eighty-seven shop-replaceable units (SRUs). As noted in Chapter IV, considerable effort was devoted to LRU and SRU accessibility and testability, and it appears the effort has met with considerable success.

TABLE 14

UNSCHEDULED MAINTENANCE MAN-HOURS (FLIGHT-LINE) PER MAINTENANCE ACTION, APG-66 VERSUS APQ-120

Radar	Unscheduled Maintenance Man-hours $(X10^3)$	Number of Maintenance Actions	MMH/MA	Ratio to APQ-120
APQ-120[a]	225	28,400	9.0	1.0
APG-66[b]	9.0	1,491	6.0	0.67

[a]SOURCE: Research Study of Radar Reliability and Its Impact on Life-Cycle Costs for the APQ-113-114,-120, and -144 Radars, p. 213. (Reporting Period: June to November 1971).

[b]SOURCE: RCS LOG-MMO(AR) 7170. (Reporting Period: August 1980 to January 1981).

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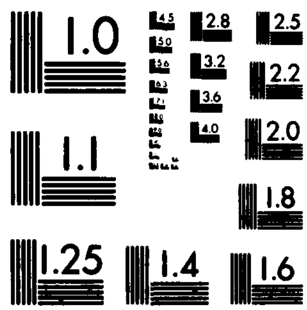

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Considering the many facets that impact maintenance: equipment utilization, maintenance approach, manpower familiarity and training, among others, the APG-66, despite its early point in system maturity, fares well when compared against the APQ-120.

CHAPTER VI

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This thesis effort examined, as a case study, the field reliability and maintainability of the APG-66 fire control radar in comparison with its contractual requirements, its pre-production development and test results and with the development and performance of an earlier generation radar (APQ-120).

In order to properly evaluate the effectiveness of the APG-66 subcontractor's reliability and maintainability programs, it is necessary to form qualitative as well as quantitative estimations of program performance.

In addition, the conclusions that follow have several obvious limitations. Foremost is the fact that the APG-66, in its earliest phase of operational maturity, has not yet exhibited the period of constant failure that is typical of an equipment's useful life. This factor pessimistically affects the quantitative assessment of the APG-66 field reliability performance. The nature of the comparison of the APG-66 with the APQ-120 radar is the second limitation. This comparison provides only an evolutionary examination of reliability programs and does not attempt to compare the relative technical capabilities of the systems.

Findings and Conclusions

Reliability

The reliability predictions presented during the F-16 fire control radar critical design review were very optimistic in comparison with the operational performance experienced to date. Some of this optimism is no doubt founded in the subcontractor's propensity to overstate the radar's capabilities. Other factors may contribute to this situation, however, such as substandard parts performance and an equipment environment different than that forecast.

The reliability qualification test was an important phase in the development of the APG-66. The fact that the radar achieved 95 percent of its target MTBF can be atrributed to both the high level of management emphasis on reliability and the strict enforcement of contractual test requirements. The test results proved to be an accurate prediction of initial field reliability performance (both MTBF and reliability growth) which indicates the testing environment was representative of the actual field environment. As observed in the comparison with the APQ-120, the test function in weapon systems acquisition is a primary determinant of equipment field performance.

The decreasing APG-66 failure rate, determined according to reported field data, is asymptotically approaching a constant figure representative of the radar's useful life. It is at this juncture where intense and concentrated management emphasis on the system's enhancement will contribute significantly to final reliability performance. This is evident in the positive reliability growth experienced to date.

Maintainability

The APG-66 maintainability analysis resulted in two general findings. The first is that the APG-66 critical design review and the intermediate level maintainability demonstration predictions were extremely optimistic of forecast field maintainability. Although the maintainability concept of the radar received a significant degree of management and design emphasis, the reported field experience indicates that actual repair times exceed demonstration predictions by 400 percent. When compared with the APQ-120, however, maintainability figures indicate that a good deal of progress has been made in this area with the APG-66 fire control radar.

The second finding is that the reported field maintainability data suggests that a maintenance learning curve may not exist. Conversely, the figures indicate the ratio of maintenance-man-hours per failure occurrence to be increasing as cumulative flight time increases.

These two findings may be due to any of several factors. One factor may be a deficiency in training the personnel who maintain the system. A second possible explanation is that the field deployment of diagnostic equipment may be lagging the radar inventory. These conditions are somewhat to be expected, and only future analysis will reveal true APG-66 maintainability.

Recommendations

The two major recommendations as a result of this thesis effort are that systems program office personnel continue to enforce strict compliance of contractual efforts; these efforts must be demonstrated to program officials' satisfaction through intense and thorough system testing.

In view of the research findings and conclusions, an expansion and continuation of this case study is recommended. In the future, APG-66 reliability and maintainability field experience should be more representative of the performance typical of a mature system.

APPENDICES

APPENDIX A

REPORTED FIELD DATA

TABLE 15

APG-66 REPORTED FIELD DATA

Year	Month	Flight Time	Failures
79	June	430	41
	July	474	27
	August	479	36
	September	779	56
	October	1095	48
	November	1069	67
	December	955	103
80	January	1161	61
	February	1424	77
	March	1589	75
	April	1783	85
	May	2370	68
	June	2048	56
	July	2366	69
	August	2493	82
	September	2276	65
	October	3269	61
	November	2931	92
	December	2805	87
81	January	3002	93

SOURCE: RCS LOG-MMO(AR) 7170. Reporting Period: June 1979 to January 1981.

TABLE 16

APG-66 FAILURE RATE DISTRIBUTION

$\lambda \left(\frac{1}{\text{Monthly MTBF}}\right)$	Cumulative Flight Time
.095	430
.057	904
.075	1383
.072	2162
.044	3257
.063	4326
.108	5281
.053	6442
.054	7866
.047	9455
.048	11238
.029	13608
.027	15656
.029	18022
.033	20515
.029	22791
.019	26060
.031	28991
.031	31796
.031	34798

SOURCE: RCS LOG-MMO(AR) 7170. Reporting Period: June 1979 to January 1981.

TABLE 17

APG-66 MMH, INVENTORY AND FAILURE OCCURRENCES

Month/Yr	Inv	MMH	Total Occurrences	Total MMH÷Occurrences
Jun 1979	21	319	118	2.70
Jul	27	311	74	4.20
Aug	33	370	149	2.48
Sep	39	399	185	2.17
Oct	47	487	173	2.82
Nov	58	627	207	3.03
Dec	63	985	370	2.66
Jan 1980	72	777	202	3.85
Feb	79	751	253	2.97
Mar	89	1070	385	2.78
Apr	96	1194	334	3.57
May	110	1363	308	4.43
Jun	117	1064	198	5.37
Jul	121	1504	310	4.85
Aug	125	1685	301	5.60
Sep	135	1230	203	6.06
Oct	145	1253	212	5.91
Nov	157	1623	263	6.17
Dec	173	1730	268	6.46
Jan 1981	158	1507	244	6.18

SOURCE: RCS LOG-MMO(AR) 7170 (includes scheduled and unscheduled "on-equipment" maintenance). Reporting Period: June 1979 to January 1981.

APPENDIX B

ABBREVIATIONS

ACF	Air Combat Fighter
AFLC	Air Force Logistics Command
AFSC	Air Force Specialty Code
AFSC	Air Force Systems Command
AIS	Avionics Intermediate Shop
AOJ	Acquisition-On-Jam
BIT	Built-In-Test
BITE	Built-In-Test Equipment
CDR	Critical Design Review
CFE	Contractor Furnished Equipment
DBS	Doppler Beam Sharpened
Demo	Demonstration
DOD	Department of Defense
DSARC	Defense Systems Acquisition Review Council
DSP	Digital Signal Processor
DT&E	Development Test and Evaluation
ECM	Electronic Counter Measures
EO	Electro-Optical
FCR	Fire Control Radar
FSD	Full-Scale Development
GAO	General Accounting Office
ILMD	Intermediate Level Maintainability Demonstration
INV	Inventory

λ	Failure Rate
LCC	Life-Cycle Cost
LCOSS	Lead Computing Optical Sight System
LPRF	Low-Power-Radio-Frequency
LRU	Line Replaceable Unit
MA	Maintenance Actions
M_{ct}	Corrective Maintenance Time to Repair an LRU
MFL	Maintenance Fault List
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MMH	Maintenance Man-Hours
$\underline{M}$ Rate	Mean Flight Hours Between Maintenance Actions
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
O&S	Operations and Support
OCC	Failure Occurrence
RADC	Rome Air Development Center
RAF	Royal Air Force
RCP	Radar Control Panel
RCS LOG-MMO(AR) 7170	Maintenance Actions, Man-hours, and Aborts by Work Unit Code
RCS LOG-MMO(AR) 7179	Summarized Maintenance Actions for Selected Work Unit Codes
ROC	Required Operational Capability
RQT	Reliability Qualification Testing

<u>R</u> Rate	Reported Flight Hours Divided by Failure Occurrences
SPO	Systems Program Office
SRU	Shop Replaceable Unit
TAC	Tactical Air Command
UE	Unit Equipment
XMTR	Transmitter

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