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A Strategy for Reforming Avionics Acquisition and Support

Executive Summary

J. R. Gebman, H. L. Shulman

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PREFACE

This summary and the report that it summarizes[1] explain why and how the Air Force would benefit from major changes in how it acquires and supports aviation electronics (avionics) equipment. This report describes an integrated strategy for implementing such reform, and it examines the rationale upon which the strategy is founded. The reasons for reform have been building for 20 years, as witnessed by a continuing stream of RAND research[2] sponsored by the Air Force and often with direct special assistance from operational units.[3]

A strategy for reforming the avionics acquisition process by rearranging avionics development responsibilities was proposed in

D. W. McIver, A. I. Robinson, and H. L. Shulman, with W. H. Ware, *Proposed Strategy for the Acquisition of Avionics Equipment*, The RAND Corporation, R-1499-PR, December 1974.

Although this strategy was partially implemented, the controversy over its main elements led the Air Force to adopt such other measures as the 1978 creation of a Deputy for Avionics Control (DAC). The DAC, who has responsibility for controlling avionics acquisition, lacks direct authority over both budgeting and program management.[4]

As the DAC was being established, RAND was researching alternatives for addressing the deficiencies in the support process for the F-15's avionics equipment. Air Force actions resulting from this work included the procurement and deployment of $150 million of additional test equipment for the avionics intermediate shops and the procurement of additional spares for the avionics.

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[1]J. R. Gebman and H. L. Shulman, with C. L. Batten, *A Strategy for Reforming Avionics Acquisition and Support*, The RAND Corporation, R-2908/2-AF, July 1988.

[2]Selected reports on the early research include A. I. Robinson and H. L. Shulman, *Comparison of Repair Operations: Newark Air Force Station and Industry*, The RAND Corporation, RM-5397-PR, September 1967. A. I. Robinson and H. L. Shulman, *Experience with Air Force Inertial Navigation Systems: Some Effects of Research, Development, Procurement, and Support Policies on Life Cycle Costs*, The RAND Corporation, R-892-PR, February 1972. J. R. Nelson, P. Konoske Dey, M. R. Fiorello, J. R. Gebman, G. K. Smith, and A. Sweetland, *A Weapon-System Life-Cycle Overview: The A-7D Experience*, The RAND Corporation, R-1452-PR, October 1974.

[3]Assisting Air Force units have been stationed at Bitburg, Cannon, Camp New Amsterdam, Hahn, Hill, Holloman, Langley, Myrtle Beach, Pease, and Plattsburg and have operated and supported the F-4C, A-7D, F-111A, F-111D, FB-111, F-15A, F-15C, and F-16A.

[4]The DAC does, however, report to both the Air Force Systems Command through the Air Force Aeronautical Systems Division and the Air Force Logistics Command; such reporting appears to be a main method for influencing avionics acquisition decisions.

When the need for these procurements was briefed to General Alton Slay, then Commander of the Air Force Systems Command, during September 1979, he decided to sponsor a new RAND project on *Avionics Acquisition and Support.* Under that project, RAND's charter was to assess the Air Force's progress with such measures as the DAC and to suggest further steps the Air Force might take to improve the avionics acquisition and support processes. RAND's effort initially consisted of two phases:

Phase I. Assess progress to date as manifested by the performance of fielded equipment and identify areas of needed improvement.

Phase II. Define and examine alternative ways of achieving needed improvements.

Phase I work raised serious concerns about the ability of maintenance personnel to identify and fix faults that maintenance records suggested may be persisting for weeks and even months. Phase II work led to the recommendation that the Air Force institute a special and separate phase of development (termed maturational development). During the Stage 1 (Assessment) of such a phase, the government would contract directly with the weapon system prime contractor, as well as selected subsystem contractors,[5] for four engineering services:

1. Fielding a joint team to collect detailed reliability and maintainability (R&M) information from one or more operational units.
2. Performing engineering analyses to define the most serious deficiencies in R&M.
3. Defining and analyzing alternatives for dealing with the most serious deficiencies.
4. Working with the government to define an appropriate and comprehensive package of improvements.

During Stage 2 (Implementation) the Air Force would use the results of such services to initiate integrated improvement programs aimed at the most cost beneficial improvements.

RAND's 1980 briefing of Phase I and Phase II final results raised two controversial issues:

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[5]Selected subsystems would be the complex types that are known to be difficult to mature (radar, weapon delivery, electronic warfare, etc.).

- *What was the real condition of the sophisticated avionics equipment being used in the field?*[6]
- *Would ongoing Air Force activities make it unnecessary to invest scarce time and funds in a maturational development phase for such avionics?*

The first issue was fueled by well-known problems with the accuracy of the Air Force's standard data collection systems, the second by the concerns of some that instituting a maturational development phase would be costly, could lengthen the development process, might retard the incorporation of new technologies, and could resurrect old arguments about an even larger rearrangement of responsibilities for avionics development.

During the fall of 1980, the Air Force Systems Command Directorate for Plans decided that RAND and the Air Force would undertake two measures to help resolve these issues:

- RAND would extend its research to include a Phase III that would provide an opportunity to more thoroughly research the real condition of the fielded radars with the help of information to be collected by the radar contractors.
- The F-15 and F-16 radar contractors, along with the corresponding weapon system prime contractors, would be given government funded opportunities to apply data collection and engineering analysis methods similar to those needed for maturational development. Within the Air Force this effort became known as the F-15/F-16 Radar R&M Improvement Program.

These two measures would provide RAND with an opportunity to further assess the need for a formalized maturational development phase before publishing the project's final report.

During June of 1981, the Deputy Chief of Staff for Research, Development, and Acquisition approved the concept for the F-15/F-16 Radar R&M Improvement Program. However, the contractor teams did not start collecting data until June 1984.[7]

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[6]Fire control radars on the F-15A and F-16A appeared to be experiencing serious difficulties with reliability or maintainability. All the squadrons studied had many aircraft with radars that required much more maintenance than other aircraft. These data (summarized in R-2908/2-AF, App. A) raised the disturbing and controversial implication that maintenance personnel could not promptly fix certain radar problems. Unfortunately, subsequent in-depth data collection and analysis by the radar contractors confirmed this implication. Section IV of R-2908/2-AF summarizes the contractors' findings.

[7]The chief activities that consumed the three years included: (1) coordination among Air Force organizations and review of the need for a special data collection effort (12 months), (2) preparation of a Program Management Directive (six months), and (3) the

One year later the contractors presented findings and recommendations to the Aeronautical Systems Division (ASD) Strike Systems Program Office (SPO), which had been designated as the program manager for the contractor efforts.[8] The Strike SPO and the cognizant Air Logistics Centers (Ogden for the F-16 radar and Warner Robins for the F-15 radar) then briefed results and recommendations to Air Force organizations during late 1985 and early 1986.

Drawing from contractor results and the Air Force briefings, RAND completed its Phase III research during which it:

- Further assessed the condition of the subject radars as they are used in the field.
- Examined the need for a formalized maturational development phase during avionics acquisition.
- Considerably revised its proposed strategy for improving avionics acquisition and support.

The results of this Phase III research have been combined with results from the first two phases to produce this final report for the *Avionics Acquisition and Support* project, summarizing research spanning seven years.

Although these results stem from research directed toward the more complex avionics subsystems for fighter airplanes, armed services can also consider applying the strategy to the acquisition and support of complex electronics in other mobile military systems such as bombers, helicopters, and tanks.

All three phases of RAND's work were accomplished within the Project AIR FORCE Resource Management Program, first under the *Avionics Acquisition and Support* project, then as a special assistance effort under the Resource Management Program's *Concept Development and Project Formulation* project, and finally under a project on *Methods and Strategies for Improving Weapon System Reliability and Maintainability*, sponsored by the Air Force Special Assistant for Reliability and Maintainability.

At the time of publication, several radar R&M improvements identified here have been implemented, others are under development and test, and some are planned to enter development later. Moreover, several ASD SPOs plan to use adaptations of the maturational

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contracting process, including preparation of Requests for Proposals and negotiation of Memoranda of Understanding among the participating Air Force organizations: three System Program Offices, two Air Logistics Centers, and four air bases (18 months).

[8]RAND assisted the Strike SPO in defining the contractor efforts, monitoring progress, and reviewing results. The Strike SPO also hired Support Systems Associates, Inc., to further help oversee the equipment contractor efforts.

development concept. Also, the Air Force Deputy Chief of Staff for Logistics and Engineering is reviewing a potential use of maturational development to form the backbone of component improvement programs for avionics subsystems.

ACKNOWLEDGMENTS

Over the past seven years, many people and organizations have contributed to the research described in this report. Throughout our efforts, we have received continued assistance from Headquarters United States Air Force, Headquarters Tactical Air Command, Headquarters United States Air Forces Europe, Warner Robins Air Logistics Center, Ogden Air Logistics Center, the F-15 System Program Office, the F-16 System Program Office, and the Strike Systems Program Office.

During the 1984–1985 data collection and analysis efforts, we especially benefited from the assistance of Major Rodney Fisher and Robert Benitez, the program managers for the F-15/F-16 Radar Reliability and Maintainability Improvement Program data collection and analysis phase. This phase was administered by the Aeronautical Systems Division Strike Systems Program Office, which received engineering support from Lieutenant Dale Evers and Robert Reed of the Air Force Acquisition Logistics Center and program technical direction support from Gary Munoz and Gene Swenson of Support Systems Associates, Inc. Charles Spruck led the Hughes Aircraft Radar Systems Group data collection and analysis for the F-15 radar, and Roy Pyle led the Westinghouse Defense and Electronics Center data collection and analysis for the F-16 radar. William McAllister led the group providing assistance from McDonnell Douglas, the prime contractor for the F-15; James Ross led the group providing assistance from General Dynamics, the prime contractor for the F-16. Participating F-15 units were the 1st Tactical Fighter Wing (TFW) at Langley Air Force Base (AFB), Virginia, and the 36th TFW at Bitburg Air Base, Federal Republic of Germany (FRG); participating F-16 units were the 50th TFW at Hahn Air Base, FRG, and the 388th TFW at Hill AFB, Utah.

Recent work on the PORTER (Performance Oriented Tracking of Equipment Repair) prototype has benefited enormously from the enthusiastic assistance of the people of the 36th TFW and the contributions of RAND colleagues Douglas McIver, Earl Gardner, and Captain Jeffrey Snyder.

Support, guidance, and encouragement came from RAND's Project AIR FORCE Resource Management Program, directed by Michael Rich during much of this study and more recently by Charles Kelley.

Finally, Alvin Ludwig assisted in writing the final draft, William Stanley and Bernard Rostker provided thoughtful and thorough reviews, and Helen Turin edited the manuscript.

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INTRODUCTION

For combat avionics,[1] the Air Force continues to have problems maintaining the full measure of designed capabilities essential to sustaining combat superiority into the next century. The problems result from weaknesses in the processes that the Air Force uses to acquire and support avionics. These processes have been weakened by a rapid growth in the complexity of avionics that has been accompanied by a failure to adapt them to the growing challenges of acquiring and supporting such equipment. This report aims to stimulate consideration of a major reforming of these processes.

The report reviews current problems of supporting modern avionics, identifies the underlying weaknesses responsible for these problems, and then describes a set of related proposals that form a coherent strategy for reforming these processes.[2] Although these proposals are derived almost exclusively from our research on avionics equipment for fighter airplanes such as the F-15 and F-16, they should prove beneficial to other aircraft and mobile military systems such as helicopters and tanks that rely heavily on sophisticated avionics or electronics to perform their wartime missions.[3]

PROBLEMS OF SUPPORTING MODERN AVIONICS

Supporting the full designed capability of mission-essential avionics equipment has become increasingly challenging in recent years. Nowadays, avionics equipment rarely experiences total failure. Rather, faults erode its performance superiority over potential enemy weapons. When equipment fails to deliver its full measure of designed performance, the performance degradation is often subtle and difficult to observe.

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[1]The term avionics is used here to refer to all aviation electronics, including airborne electronic warfare equipment.

[2]The major proposals constituting the strategy are developed in R-2908/2-AF, Secs. III through VI.

[3]Many factors that drive the avionics R&M challenges confronting the Air Force's fighter airplanes apply to other mobile military systems, including (1) performance specifications that lead to complex applications of advanced technologies in highly integrated collections of subsystems; (2) designs that must satisfy tight space, weight, power, and cooling constraints; (3) an operating environment of extremes in thermal and dynamic loads; (4) peacetime training use that only partially replicates wartime needs; and (5) a multiple level support process with different test equipment and tests at each level.

Many faults manifest symptoms only in specific operational modes. Moreover, a subsystem with multiple modes, such as a fire control radar, can have a fault that affects performance in only certain applications of particular modes. Other faults manifest symptoms only in specific environments, such as in an aircraft that may be vibrating or executing a violent maneuver. Thus, it is important to distinguish between two different types of faults, which we term *Type A* and *Type B* faults:

- Type A faults have what we call *stationary observability*. They manifest observable symptoms no matter when or where the equipment is operated or tested. A broken picture tube in a video display is a Type A fault.
- Type B faults have what we call *nonstationary observability*. They manifest symptoms only some of the time. A faulty connection can be a Type B fault.

The current avionics acquisition and support processes implicitly concentrate on Type A faults. Such faults dominated during the early days of aviation electronics, but now Type B faults dominate because greatly improved reliability has combined with larger and more highly integrated avionics systems. Type B faults seriously frustrate the identification and correction of faulty avionics equipment. Equipment with Type B faults all too often circulates between shops and airplanes, degrading the full measure of design capabilities of fighter airplanes, until it either acquires a more easily observable fault or maintenance technicians set it aside for special attention. Certain weaknesses in the acquisition and support processes allow Type B faults to persistently degrade the capabilities of some avionics equipment.

WEAKNESSES IN THE ACQUISITION AND SUPPORT PROCESSES

The Acquisition Process

The current acquisition process can actually hinder the avionics developer when he attempts to solve the extraordinarily difficult and formidable engineering challenges associated with Type B faults. The main weaknesses in the acquisition process include:[4]

- Lack of engineering data on developing technologies and equipment.

[4]See R-2908/2-AF, Sec. II for details.

- No corporate memory for tracking why and under which conditions technologies fail.
- Inadequate time to develop and mature equipment.
- Lack of information on support problems with new equipment.
- Problematic timing of transfer of management responsibility for equipment.

The Support Process

The current support process similarly can hinder avionics technicians when they attempt to solve the extraordinarily difficult maintenance challenges associated with Type B faults. The main weaknesses in the current support process include:[5]

- Inadequate information about performance degradations during routine training flights.
- No system for tracking avionics equipment performance by serial number to identify equipment with problems eluding repair efforts.
- No feedback to compensate for the use of different tests and pass/fail criteria at each maintenance level (flightline, shop, and depot).
- Inability of avionics technicians to repeat certain tests and initiate others before thermal equilibrium is achieved.
- Lack of an adequate procedure for technicians to report avionics supportability problems and recommend possible solutions.

A PROPOSED STRATEGY FOR REFORM

The strategy proposed for reforming avionics acquisition and support concentrates on the major weaknesses and their most promising solutions that have come to our attention during 20 years of research in this field. The recent research has focused on avionics for such fighter airplanes as the F-15 and the F-16. The main source of data for this research was the special data collection effort conducted during the assessment stage of the F-15/F-16 Radar R&M Improvement Program.

Two goals guided formulation of the proposed strategy:

- To strengthen the reliability and maintainability (R&M) of mission-essential avionics equipment already in the field so that

[5]Ibid.

it may more regularly deliver the full measure of its designed capabilities.

- To strengthen the development process so that future generations of mission-essential avionics equipment can more regularly deliver their full designed capabilities.

To help the Air Force achieve these goals, the proposed strategy consists of six major proposals (Fig. 1). To address weaknesses in the acquisition process the first proposal suggests that the Air Force:

1. Accelerate advancement of R&M-related avionics technologies.

The next three proposals address weaknesses in both the acquisition and support processes:

2. Improve the ability to test avionics equipment.
3. Provide more complete feedback on equipment performance.
4. Adopt a maintainability indicator.

The fifth proposal addresses a weakness in the acquisition process whose persistence is occasioned by insufficient feedback from the support process.

5. Institute maturational development.[6]

The sixth proposal addresses a weakness that limits the Air Force's ability to implement the foregoing proposals. The weakness stems from inefficiencies with the current organization of the Air Force's avionics engineering resources.

6. Reorganize avionics engineering resources.

Proposal 1: Accelerate R&M-Related Avionics Technologies

The first line of defense for R&M is for engineers to provide a correct design from the outset. However, engineers' ability to do this is influenced greatly by the accumulated knowledge regarding the capabilities and limitations of the technologies used in a design. Unfortunately, to deliver a subsystem design with the specified levels of functional performance, engineers often must apply the latest advances in technology. For such emerging technologies that are critical to achieving mission-essential performance, it is essential to accumulate a body of engineering knowledge as rapidly and efficiently as possible to form

[6]See R-2908/2-AF, Sec. III, for a fuller discussion of the concept.

Weaknesses (Sec. II)	Proposals[a]					
	1. Accelerate R&M-related technologies (Sec. V)	2. Improve the ability to test avionics equipment (Sec. IV)	3. Provide more complete feedback on equipment performance (Sec. VI)	4. Adopt a maintain-ability indicator (Sec. III and IV)	5. Institute maturational development (Sec. III and IV)	6. Reorganize avionics engineering resources (Sec. VI)
Acquisition Process						
Lack of engineering data on new technologies	Strong	None	None	None	None	Strong
Insufficient corporate memory	Strong	Some	Moderate	Some	Moderate	Strong
Inadequate time to develop and mature equipment	Strong	None	None	None	Strong	Strong
Lack of information on support problems	None	Strong	Strong	Strong	Moderate	Some
Problematic timing of transfer of program responsibility	None	None	None	None	None	Strong
Support Process						
Inadequate information provided to maintenance	None	None	Strong	Strong	Moderate	Some
Ineffective indentification of unrestored equipment	None	None	Strong	None	None	Some
Insufficient flow of information between maintenance levels	None	Strong	None	Strong	None	Strong
Low maintenance capability for Type B faults	None	Strong	None	None	None	Strong
Inadequate procedures for reporting support deficiencies	None	None	Strong	Strong	None	Strong

[a]Section VII presents a detailed description for each of the recommended proposals. Further discussion of the basis for each proposal is presented in Secs. III through V, especially the sections noted within parentheses.

Fig. 1—Applicability of proposals to weaknesses in processes for avionics acquisition and support

a solid basis from which design may proceed. The Air Force can help strengthen the engineering knowledge available to designers by accelerating the development of important avionics technologies. Certain technologies, moreover, promise especially great benefit to R&M. These need to be searched out and emphasized. To help do this, we propose three areas of acceleration:

- Development of selected functional performance technologies.
- Research on failure pathologies.
- Research and development of Built-in Test (BIT) technologies.

Although the Air Force already has efforts in each of these areas, there are considerable opportunities to beneficially increase their level.

Accelerate Development of Selected Functional Performance Technologies. Several avionics development efforts that are important to combat aircraft, such as fighters, will be entering full-scale engineering development during the next few years. To more fully prepare for these important design efforts, the Air Force should review the current state of critical electronics technologies in search of opportunities to accelerate the pace of research and advanced development where appropriate.[7] Following such a review, the Air Force could reassess the adequacy of its investment in these areas and then tailor both the level and composition of its investments. Candidate technologies for accelerated research and development include:

- **Active Phased Array Technology.** Some new technologies promise to greatly improve R&M and thereby reduce the time and expense of a maturational development phase. One such technology for radars is an active phased array that can provide an electronically scanned antenna.
- **Gallium Arsenide Technology.** This technology promises to expand the analog processing capacity on board combat airplanes the way Very High Speed Integrated Circuits (VHSIC) are expected to revolutionize digital processing. Because this technology is a recent development, engineering knowledge of this technology is still evolving.[8]

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[7]The Air Force could assess ways to accelerate development of avionics technologies to allow more time for learning about the conditions under which technology-peculiar faults will arise—both Type A and Type B faults. Such efforts would complement the maturational development process (discussed in Proposal 5) for the selected avionics equipment that undergoes the process and would also help improve the R&M characteristics of equipment not subjected to the maturational development process.

[8]At this point designers need a better engineering database to support the selection of operating temperatures that achieve appropriate balance between reliability benefits and design penalties in terms of the size, weight, and power required by the environmental control system.

Accelerate Research on Failure Pathologies. During the next decade, the Air Force will use such technologies as VHSIC to expand the functional capabilities of new and existing combat airplanes. The magnitude of this investment and the extent of this reliance make it very worthwhile for the Air Force to aggressively sponsor research into the failure modes for these technologies.[15]

Accelerate Research and Development of Built-in Test Technologies. Here the Air Force has two especially important opportunities: improvement of methods and techniques and exploitation of VHSIC.

- **Methods and Techniques.** An initial step could be the immediate launching of a special, high-priority project to assess and accelerate the advancement of BIT technology. Such a project could
  - — Review current BIT mechanizations and catalog approaches, strengths, and weaknesses
  - — Assess the major weaknesses in BIT technology and in its contemporary applications
  - — Develop a research plan to further the technology and to institute guidelines for testing BIT and for applying BIT technology during hardware and software design.
- **Exploitation of VHSIC.** VHSIC technology has considerable untapped potential for improving subsystem level BIT. Increased research in this area could pay large dividends.[16]

By selectively accelerating the advancement of important R&M-related technologies, the Air Force can best strengthen the engineer's ability to correctly design the equipment from the outset. This is the first line of defense for R&M. However, even the best of designs will exhibit unpredicted faults during operational service or develop faults over time. This is where we need a second line of defense: comprehensive and accurate testing for faults.

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[15]New technologies often raise great expectations about improved reliability and even raise expectations about invulnerability to potentially serious failures. Time and again, development programs have fallen victim to what might be termed the "Titanic Syndrome." Expected to be invincible, equipment using new, sophisticated technologies has fallen prey to unforeseen faults. The Air Force can avoid catastrophic R&M "icebergs" only by improving knowledge *in advance* about failure pathologies for critical new technologies.

[16]One promising idea that warrants increased attention is to use VHSIC to capture better information about the operating state and environment of avionics equipment when faults are detected.

Proposal 2: Improve the Ability to Test Avionics Equipment

In the airplane, on the flightline, in the shop, and at the depot, the Air Force needs improved abilities to test avionics. Even with the best of efforts to accelerate the advancement and application of important R&M technologies, faults are inevitably going to develop in avionics equipment. As a consequence, the ability to test and find faults is essential to maintaining designed capabilities.

To improve the testability of avionics equipment, the Air Force should place greater emphasis on fault-isolation in ongoing programs, and it should require specific types of improvements in test capabilities.

Improve Ongoing Programs. The programs that could benefit from greater emphasis on fault-isolation include: Ultra-Reliable Equipment, Modular Avionics, and Avionics Integrity.

- **Ultra-Reliable Equipment Program.** Developing subsystems with ultra-high levels of reliability (2,000 to 10,000 hours between failure) is desirable as long as the subsystems are practical.[11] However, projects exploring ways to build such equipment need to ensure that their labors do not ignore maintainability, especially because current fault-isolation systems fail to consistently identify the more difficult and elusive Type B faults that plague current weapon systems.
- **Modular Avionics Program.** The packaging of avionics equipment needs to be examined in light of the high costs of flightline replaceable units (LRUs), some of which approach $1 million. One alternative currently drawing much interest would have flightline technicians remove modules—less expensive and about the same size as a current circuit card—directly from the airplane. Although this is a seemingly attractive idea, the need for flightline replacement of avionics modules may increase the likelihood of disrupting delicate connections.[12] Moreover,

[11]They must not become unaffordable, too large and heavy for a combat airplane, too demanding in their cooling requirements, or too hard to fix when they fail. Some proponents believe that ultra-high levels of reliability (with fighter radars enjoying a 2000-hour mean time between confirmed failure) are both affordable and achievable given the current state of the art. Further, some believe that such reliability levels justify decreased emphasis on BIT. Others strongly disagree. Given the complexity of the equipment and the disagreement about realizable levels of reliability, the Air Force should strive for ultra-high reliability only to the extent that it does not short change the maintainability that will be needed for realizable levels of reliability.

[12]There is a further concern that the trend toward micro-miniaturization may appreciably increase the density and number of pins on a typical circuit card. Such an outcome would further increase the risk of faulty connections that can be a source of Type B faults.

because current BITs cannot consistently isolate faults to specific LRUs (especially for Type B faults) research on modular avionics must place great emphasis on improving the BITs' fault-isolation capabilities.[13]

- **Avionics Integrity Program.** The Air Force has been considering a plan for an Avionics Integrity Program (AVIP) patterned after its Structural and Engine Integrity Programs, which aim at helping designers choose materials that avoid undue risks of catastrophic failures or unaffordable maintenance burdens. The AVIP can potentially help designers most by measuring thermal and dynamic stresses placed on electronic assemblies during routine operations, but it must not ignore improving fault-isolation capabilities in general and BIT capabilities in particular.[14]

Improve Capabilities of Tests. For ground-based test equipment, the Air Force can improve test capabilities by developing test translation dictionaries, direct entry into test sequences for specific sections of lengthy ground avionics tests, loop testing for specific tests, and special environmental and system bench capabilities for depots.[15]

- **Test translation dictionaries** would enable avionics technicians at one maintenance level to translate test results from another maintenance level into terms they will find useful for isolating and correcting faults.
- **Direct entry into test sequences for specific sections of lengthy ground avionics tests** would enable technicians to avoid having to run tests in an invariable, predetermined sequence. Technicians would then have greater ability to find Type B faults that are sensitive to time-varying thermal conditions.

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[13]There is disagreement about whether adequate BITs and sufficiently robust connections can be designed for the flightline environment. A shortfall in either area would adversely effect a fighter airplane that depends on quick isolation and correction of faults.

[14]At one time, people had hoped that an AVIP would share the successes of previous integrity programs for engines and structures. However, few believe that AVIP by itself will be a panacea for avionics R&M.

[15]Typically, depot maintenance technicians must arrange to use the same system bench that depot engineers use to check out new software. Generally, depot maintenance technicians need their own system bench to work on difficult fault isolation problems. The following elements of this proposal are not new. In the past, Weapon System SPOs have rejected them because they did not appear cost effective. These SPOs, however, lacked information from the field that now supports these proposals. (See R-2908/2-AF, Sec. IV.)

- **Loop testing for specific tests** would enable technicians to run the same test repeatedly, thereby improving the prospects for catching certain Type B faults.
- **Special environmental and system bench capabilities for depots** would enable test equipment to better replicate operational modes and environmental settings that especially influence Type B faults.

Proposal 3: Provide More Complete Feedback on Equipment

Even with the best of test capabilities, some faults will inevitably escape detection by ground support equipment. R&M therefore requires a third line of defense: Maintenance personnel need timely and reasonably complete feedback to deal quickly and effectively with faulty assets that escape repair.[16]

To better provide such information, the Air Force can improve the quality of information received from the pilot's postflight debriefing to maintenance technicians and the technicians' capability to track and identify hard-to-fix faults.

Improve Quality of Information Received by the Pilot Debriefing. The Air Force should explore improving the quality of pilot debriefings by using an automated system that would provide a menu of questions concerning airplane malfunctions. Such an automated system could use

- Data transfer units to capture information from the BIT.
- Personal computers to record information interactively from pilots.

These measures would help solve the very difficult problem of obtaining sufficient information about symptoms and operating conditions for Type B faults.

Improve the Tracking and Correction of R&M Deficiencies. To improve the tracking and correction of R&M deficiencies, the Air Force could institute a capability to do Performance Oriented Tracking

[16]Improved training cannot compensate for lack of improved information. On a few occasions we have had the opportunity to compare the performances of contractor maintenance personnel with those of less well trained and less experienced Air Force maintenance personnel; we have seen no difference in the effectiveness of their maintenance actions as measured in terms of mean flight time between LRU removals on the flightline, mean flight time between LRU failures confirmed by the shop, and percent of LRUs that bench test serviceable in the shop. (See R-2908/2-AF, Sec. IV.) In spite of the great differences in their training and experience, these two groups have had the same record in isolating and correcting faulty avionics equipment largely because they must rely on the same kinds of limited information.

of Equipment Repair (PORTER), an experimental prototype system using personal computers to track, identify, and help correct faulty equipment. PORTER aims at reducing avionics maintenance burdens, especially for sophisticated equipment, through judicious collection and timely transmission of performance and maintenance information to critical points in the support process. This information should enable maintenance personnel to identify and more quickly fix equipment that otherwise would circulate repeatedly through the support process, using up time and scarce resources.[17]

Proposal 4: Adopt a Maintainability Indicator

Even with the best of feedback to maintenance technicians about problems with equipment performance, R&M needs a fourth line of defense to attract needed management attention to resolve the more serious maintainability problems. Such attention is essential to identify and fix the underlying root causes of problems. It is also essential for effective communication of maintainability problems to the research and development community, which will avoid repetition of maintainability problems in the development of new equipment.

A single measure to indicate the overall maintainability of a subsystem and its associated ground support system would be desirable. Such a maintainability indicator could:

- Complement the existing reliability indicator (MTBF)[18] and together with it provide a meaningful composite picture of equipment R&M.
- Be sensitive to the full range of problems that arise in identifying faults and isolating their causes.
- Account for all flights with indications of faulty subsystem operation.

The following proposed maintainability indicator is consistent with these principles:

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[17]To apply PORTER to different weapon systems, the software will need to be tailored to accommodate differences in subsystems (and pods), failure indicators (including BIT), and maintenance parameters peculiar to specific subsystems. The proposed architecture calls for the use of PCs to provide PORTER services, while they also provide data entry or extraction services for the Air Force's Core Automated Maintenance System (CAMS). An alternative architecture calls for building the PORTER services into the CAMS software. The current CAMS architecture could incorporate as much of the PORTER services as possible. An Air Force exploration of each alternative could help assure a timely fielding of a PORTER capability (see R-2908/2-AF, Sec. VI for details).

[18]Mean Time Between Failure. A more specific definition is taken up shortly.

$$\text{Fault Removal Efficiency} = \frac{\text{MTBI}}{\text{MTBF}} \times 100\%$$

where MTBI = Mean flying Time Between flights with one or more Indications of faulty operation of the avionics subsystem.

MTBF = Mean flying Time Between flights with a shop confirmed Failure of the avionics subsystem.

A fault removal efficiency of 100 percent means that for every flight during which a subsystem manifested a symptom of degraded performance, technicians removed a fault from that subsystem before the next flight. A 25 percent efficiency means that an average of four flights with symptoms occurred before technicians removed a fault.

Application of this indicator (Table 1) to the data from the F-15 C/D Radar R&M Improvement Program and the similar program for the F-16 A/B illustrates the value of this measure as a management tool. Table 1 is a comprehensive summary of the overall R&M situation for the two subsystems. The results for MTBF look very good compared with historical experience for this type of subsystem on older aircraft. The MTBI and the fault removal efficiencies tell us, however, that the Air Force is encountering major difficulties in removing faults that degrade the dependable operation of these subsystems.

Table 1

R&M MANAGEMENT INDICATORS FOR THE RADARS ON THE F-15 C/D AND THE F-16 A/B

Management Indicators	F-15 C/D Radar (APG 63)	F-16 A/B Radar (APG-66)
MTBF (hrs)	19	82
MTBI (hrs)	4	6
Fault removal efficiency (percent)	21	7

SOURCE: Special data collection efforts at four air bases during six months in 1984. See R-2908/2-AF, Sec. IV for details.

Engineering analysis[19] showed that the majority of these faults were of Type B—did not manifest consistent symptoms. Pilots would see symptoms that flightline maintenance technicians failed to duplicate, flightline technicians would see symptoms that shop technicians failed to duplicate, and shop technicians would see symptoms that depot technicians failed to duplicate. The net result was that some equipment was returning to flight service even though its designed capability was not fully restored. To help resolve these problems, R&M improvements were identified for each radar.[20]

Proposal 5: Institute Maturational Development

Concept. Even with the best of implementations for the preceding proposals, some important R&M problems will inevitably evade early, satisfactory resolution. This is especially likely for Type B faults in large, complex, and tightly integrated subsystems that incorporate many new technologies. Fire control radars for fighter airplanes fall in this category. Such subsystems and their associated ground support systems need a development phase to mature their R&M to the levels that will allow them to regularly deliver the full measure of performance for which they were designed. Such a maturational development phase needs two stages:[21]

- **Stage 1 (Assessment):** Collection and analysis of engineering data while the subsystem is in normal use by the operator, followed by analysis of candidate improvements and formulation of a comprehensive package of improvements.[22]
- **Stage 2 (Implementation):** Bringing about the most cost-effective improvements that aim at regular delivery of full design performance.

Such a process offers a further line of defense that is needed to assure the delivery of necessary R&M characteristics for the most complex avionics subsystems. It would be an important supplement to the measures suggested by the foregoing proposals.

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[19]See R-2908/2-AF, Sec. IV.

[20]See R-2908/2-AF, Sec. IV.

[21]As discussed in R-2908/2-AF, Sec. III, this two-stage process is modeled after development programs that have launched special efforts to mature R&M. It is also derived from our experience in helping the Air Force address R&M and support issues over the past 20 years with the F-4, the F-111D, the FB-111, the F-15, and the F-16.

[22]Areas of needed improvement may include airborne equipment, ground support equipment, hardware, software, and maintenance procedures.

Implementation. To carry out the maturational development concept, the Air Force should complete the implementation stage for efforts to mature the F-15 and F-16 radars, start data collection and analysis stages for selected other equipment, and institute a formally planned maturational development phase for avionics equipment on new airplanes:

- **Complete the Implementation Stage for Ongoing Efforts to Mature the F-15 and F-16 Radars.** The Air Force is demonstrating maturational development on the F-15 C/D APG 63 and the F-16A/B APG 66 radars, as a result of the F-15/F-16 Radar R&M Improvement Program. Integrated sets of improvements have been defined, evaluated, and briefed by the cognizant Air Force organizations, including the Aeronautical Systems Division (ASD) Strike SPO that managed the radar contractors' efforts. Unfortunately, management responsibility for implementing these improvements has since been diffused through many different organizations. The Air Force's current challenges are to continue its support for efforts to improve the R&M of the F-15 and F-16 radars and to demonstrate its commitment to maturational development as a concept and to R&M as a major goal.
- **Start Assessment Stage for Selected Other Equipment.** In addition to the F-15 C/D and F-16 A/B radars, other avionics equipment can derive comparable benefits from maturational development. This equipment includes radars (the APG 68 for the F-16 C/D, the APG 70 for the F-15E), electronic counter measures equipment, weapon delivery systems, and pods such as those forming the Low Altitude Night Targeting Infrared Navigation (LANTIRN) and targeting subsystem.[23]
- **Institute a Formally Planned Maturational Development Phase.** Because it costs extra money and runs the risk of creating undesirable publicity about R&M problems, some weapon system development programs may be reluctant to add a maturational development phase to their development efforts. To minimize such reluctance, a maturational development phase should be institutionalized as a formal and preplanned part of each program's management plan.

[23]These subsystems have been selected because they are nearly as complex as the two radars already subjected to the data collection and analysis process. Moreover, like the two radars, these subsystems depend on leading edge technologies that may still be experiencing growing pains.

Maximizing the Benefit. Generally, maturational development will offer the greatest rewards for new equipment that enters development early enough to allow one or more follow-on development efforts (see Fig. 2) for maturation before high-rate production. Such early application is what we call Approach A to maturational development. It is the preferred approach in terms of maximizing the opportunity to avoid the high costs of retrofitting hardware. Approach B pertains to situations where avionics subsystems do not benefit from an early start to their full-scale engineering development. Opportunities for beneficial application of Approach B include

- Situations where because of R&M difficulties already fielded equipment and its associated support equipment are struggling to deliver designed levels of mission-essential performance.[1]
- Situations where already fielded equipment and its support equipment are going to receive considerable performance-oriented improvements.

Although Approach B may prove to be the predominant approach, experiences from the exploratory applications of maturational development have shown that there is considerable value to be gained by speeding up the acquisition and development process to start avionics development earlier. The typical late start leads to a hurried development effort that yields little time to explore the implications of using new technologies and materials.[25]

Late start and early termination of engineering are compounded by transition of engineering management responsibilities from the SPO to the Air Force Logistics Command (AFLC) long before the equipment has matured. This transfer generally occurs during the equipment's early operational life, when engineers assigned to the SPO are only beginning to identify the equipment's strengths and weaknesses. Once the AFLC System Program Manager assumes responsibility, a new and much smaller group of Air Force engineers becomes responsible for the

[24]See R-2908/2-AF, Sec. III, for a further discussion of the concept and Sec. IV for recent applications of Approach B.

[25]This late start has been compounded by prematurely terminating the involvement of engineers. Even without the late start, merely the complexities of the equipment and its multi-layered support process guarantee that complex R&M problems will accompany the equipment when it enters operational service. At this juncture, an engineering database and analysis of the situation are critical to resolving dominant problems. Engineering involvement at this point has been far too shallow to build the kind of R&M database and associated analysis that the F-15/F-16 Radar R&M Improvement Program found essential.

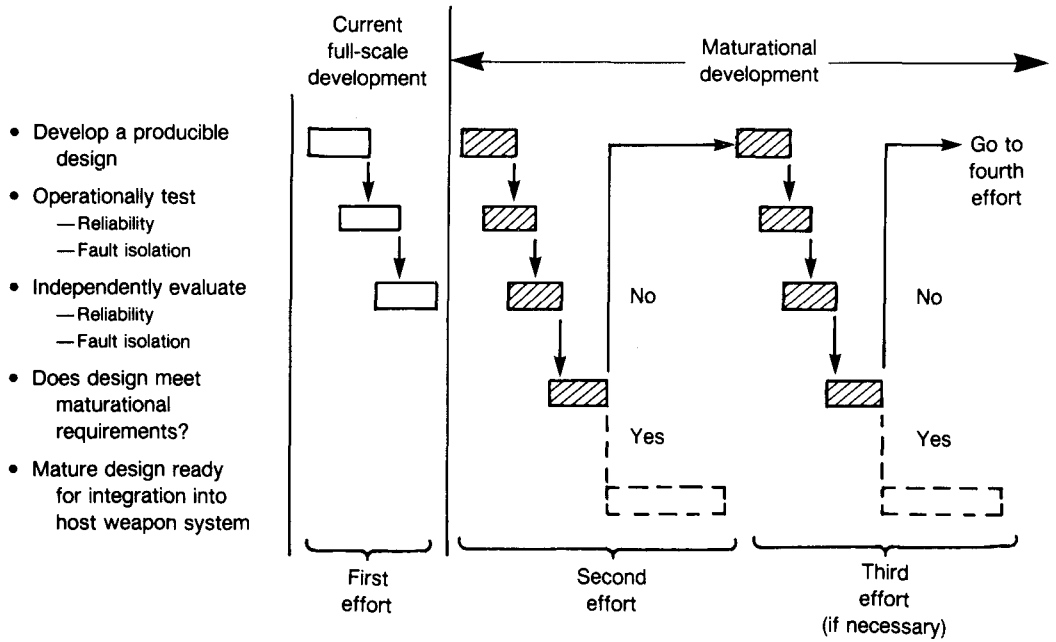

Fig. 2—Maturational development: A multiple phase process

equipment's further maturation.[26] With an impending transfer of R&M engineering responsibilities, it is hard to keep a development organization enthusiastically engaged in improving R&M. Such considerations support the idea of starting full-scale engineering development of avionics soon enough to allow most maturation to occur before PMRT.

Even with an early start, the maturation process is costly and time consuming.[27] A cost effective strategy for improving R&M must therefore include additional lines of defense minimizing the number of problems that need to be cleaned up during a maturational development phase. The strategy's first four proposals aimed to reduce the residual set of problems that would need to be addressed by maturational development (Proposal 5). The sixth and final proposal addresses an opportunity to amplify the benefits the Air Force can reap from the first five proposals.

Proposal 6: Reorganize Avionics Engineering Resources

For complex advanced technology subsystems, multiple lines of defense must be called upon to achieve needed levels of excellence in R&M. By reorganizing its avionics engineering resources, the Air Force can better posture itself to coordinate defenses in a synergistically beneficial manner. R&M-related technologies (especially BIT technology) have to support development programs that need improved test capabilities, and advances in performance-oriented tracking of equipment repair have to be coordinated to exploit improvements to the type of information that new test technologies and development programs can provide.

In contrast to such finely tuned coordination, past avionics research and development efforts have suffered from lack of R&M guidance to

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[26]In addition, these engineers must initiate entirely new contracting documents to begin any redesign work. This contracting procedure is far more burdensome than the one the SPO follows to accomplish the same sort of design changes before Program Management Responsibility Transfer (PMRT). Thus, any improvements in equipment maturation slow considerably after PMRT.

[27]Since the concept of a formal maturational development phase was proposed in 1980, some have expressed concern about how it could adversely influence development cost and schedules. These and other concerns are discussed in R-2908/2-AF, Sec. III, which also examines the possibility of alternatives to maturational development. The possibilities include better use of existing maintenance data, application of warranties, and improvements to requirements and testing. The effectiveness of each of these is critically linked to the development of R&M measures that provide appropriately comprehensive coverage of reliability and maintainability and lend themselves to simple and explicit delineation of responsibilities. Unfortunately, such a set of measures has yet to be developed. (All of the measures in Table 1 fail to satisfy the requirement for clear delineation of responsibilities.)

laboratory projects, no potent sponsor for the advanced development of critical elements, no agency dedicated to supervising maturational development, and none with a robust engineering organization overseeing post-PMRT maturation of both airborne and ground support equipment.

One way that the Air Force could address such deficiencies is to reorganize its avionics engineering resources in the form of what we call an Avionics Engineering Center. Such a center would *help*[28] oversee research, development, and maturation of sophisticated avionics subsystems (fire control radars, electronic warfare systems, and the like) by

1. Sponsoring Advanced Development of Critical Elements. An Avionics Engineering Center could sponsor advanced development of complex and important equipment (such as major electronic assemblies, new architectures, and digital communication protocols).
2. Starting FSED Early for Critical Subsystems. Even with the benefit of advanced development of high-risk critical elements, some subsystems are sufficiently complex that they would also benefit from starting full-scale engineering development (FSED) in advance of the airframe.
3. Supervising Maturational Development for Critical Subsystems. An Avionics Engineering Center could have responsibility not only for selected new avionics equipment but also for selected avionics equipment already in the field.[29]

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[28]Primary responsibility for managing subsystem development may reside with a weapon system's prime contractor, *or* its System Program Office (SPO), *or* an Avionics Engineering Center. In the first two situations the role of the Center would be to assist the cognizant SPO. For further details see R-2908/2-AF, Sec. VI.

[29]To ensure objective management of such an effort, the group that manages the data assessment effort could be independent of the group responsible for the subsystem's development. While independent, both groups could reside within an Avionics Engineering Center or within a weapon system SPO. In the case of the Radar R&M Program, such independence proved very beneficial. Although certain tensions were created, they stimulated creativity and concentrated attention on important problems and critical uncertainties. Such a center could also help in preplanning, which is another key to formalizing the maturation process. Certain types of equipment have a high enough likelihood of benefiting from the process that the program management plan for development could usefully specify time and funds for the Stage 1 assessment effort. An up-front commitment could save time and funds. Up to two-thirds of the cost of implementing the R&M improvements for the F-15 C/D radar and the F-16 A/B radar probably could have been avoided (see R-2908/2-AF, Sec. IV) by promptly executing such an R&M maturation process immediately upon the equipment's entry into operational service.

4. Overseeing Post-PMRT Maturation and Engineering Support. An Avionics Engineering Center could be responsible for avionics subsystems both before and after PMRT. In addition, avionics contractors could provide both technical assistance to the Avionics Engineering Center and a stable base for retaining corporate memory.

In the past there has been resistance to such concepts as an Avionics Engineering Center and subsystem-focused maturational development. Commonly cited reasons include concerns about the adequacy of the Air Force's resources that could be allocated to managing subsystem development and maturation, especially in areas with complex interfaces. Other concerns are based upon fears that the application of technological advances may be retarded and the prime contractors' ability to optimize an overall weapon system may be seriously constrained. Against such concerns the Air Force needs to weigh two considerations. First is the relationship between past practices and current difficulties with avionics R&M. Second is the new challenges that will flow from the rapidly changing character of avionics technology.

CONCLUSIONS

For its combat airplanes to meet and defeat future threats, the Air Force's avionics subsystems will continue to grow in terms of functions, sophistication, and complexity, while relying heavily on the latest advances in technology. To meet the challenge of acquiring and supporting the full designed capabilities of such equipment, the Air Force needs to aspire to even higher standards in avionics R&M. The Air Force would benefit from the kind of improved coordination that an Avionics Engineering Center could provide to managing the multiple lines of defense necessary for excellence in R&M. Such a center would cap a major reform built upon four concepts:

- Explicit recognition of Type B faults.
- Implementation of PORTER to more rapidly identify Type B problems.
- Use of fault removal efficiency as a management indicator for maintainability.
- Institutionalization of maturational development as a last line of defense for R&M.

Although any of these concepts would prove beneficial, the complete strategy would constitute a major reform to how the Air Force acquires and supports avionics. With such reform, the Air Force could more fully exploit electronics technologies to help ensure the continued superiority of its combat airplanes.

RAND/R-2908/1-AF