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This document records the activities and presents the findings of the F-16 APG-66 Fire Control Radar Case Study Working Group part of the IDA/OSD Reliability and Maintainability Study, conducted during the period from July 1982 through August 1983.

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IDA RECORD DOCUMENT D-21

F-16 APG-66 FIRE CONTROL RADAR CASE STUDY REPORT

(IDA/OSD R&M STUDY)

Paul F. Goree
IDA R&M Case Study Director

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August 1983

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Office of the Assistant Secretary of Defense
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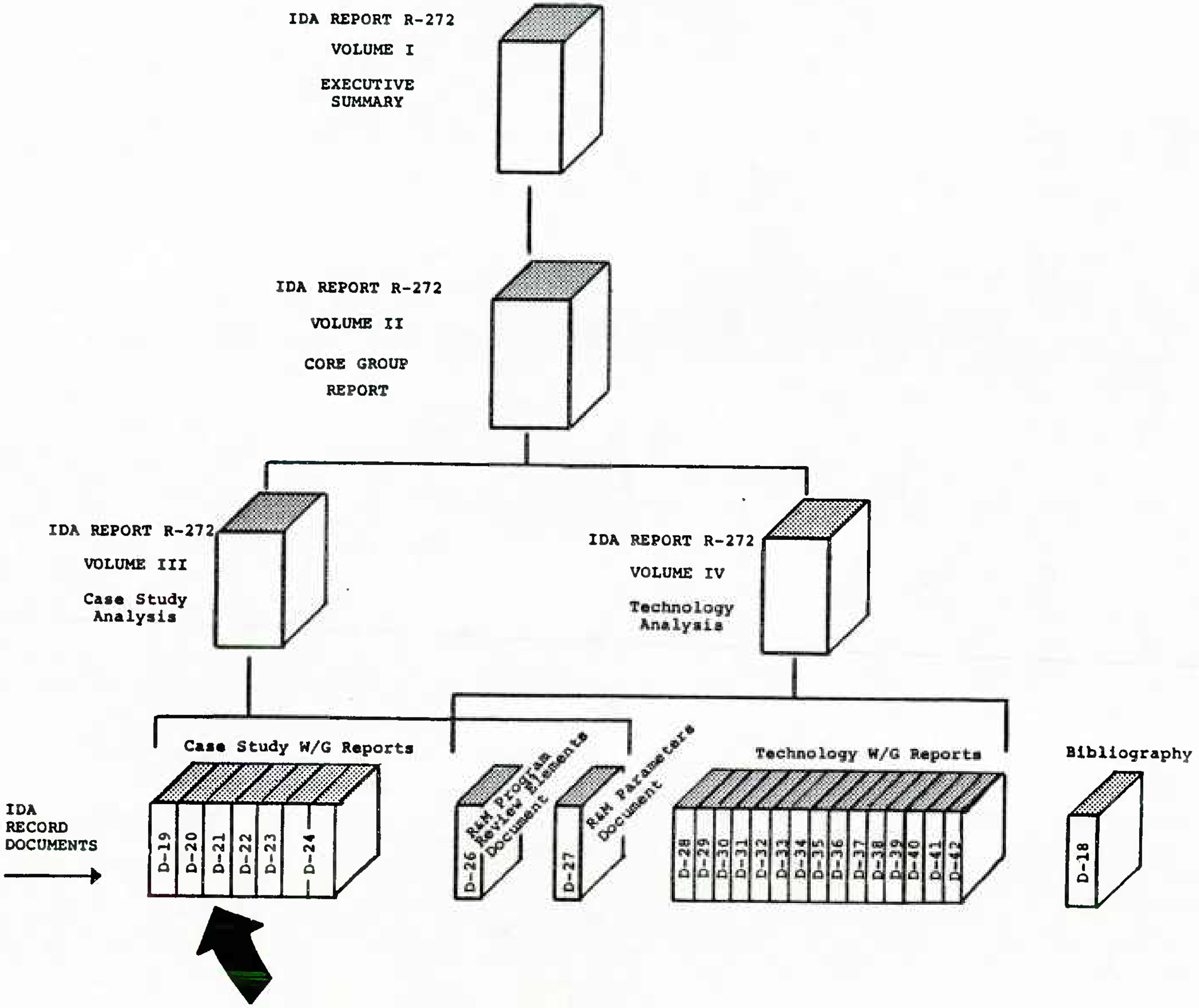
1801 N. Beauregard Street, Alexandria, Virginia 22311
Contract MDA 903 79 C 0018
Task T-2-126

RELIABILITY AND MAINTAINABILITY STUDY

— REPORT STRUCTURE —



THIS DOCUMENT (IDA Record Document D-21)

PREFACE

As a result of the 1981 Defense Science Board Summer Study on Operational Readiness, Task Order T-2-126 was generated to look at potential steps toward improving the Material Readiness Posture of DoD (Short Title: R&M Study). This task order was structured to address the improvement of R&M and readiness through innovative program structuring and applications of new and advancing technology. Volume I summarizes the total study activity. Volume II integrates analysis relative to Volume III, program structuring aspects, and Volume IV, new and advancing technology aspects.

The objective of this study as defined by the task order is:

> "Identify and provide support for high payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvement in R&M and readiness through innovative uses of advancing technology and program structure."

The scope of this study as defined by the task order is:

> To (1) identify high-payoff areas where the DoD could improve current system design, development program structure and system support policies, with the objective of enhancing peacetime availability of major weapons systems and the potential to make a rapid transition to high wartime activity rates, to sustain such rates and to do so with the most economical use of scarce resources possible, (2) assess the impact of advancing technology on the recommended approaches and guidelines, and (3) evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative uses of advancing technology.

The approach taken for the study was focused on producing meaningful implementable recommendations substantiated by quantitative data with implementation plans and vehicles to be provided where practical. To accomplish this, emphasis was placed upon the elucidation and integration of the expert knowledge and experience of engineers, developers, managers, testers and users involved with the complete acquisition cycle of weapons systems programs as well as upon supporting analysis. A search was conducted through major industrial companies, a director was selected and the following general plan was adopted.

General Study Plan

Vol. III ● Select, analyze and review existing successful program

Vol. IV ● Analyze and review related new and advanced technology

Vol. II (● Analyze and integrate review results
(● Develop, coordinate and refine new concepts

Vol. I ● Present new concepts to DoD with implementation plan and recommendations for application.

The approach to implementing the plan was based on an executive council core group for organization, analysis, integration and continuity; making extensive use of working groups, heavy military and industry involvement and participation, and coordination and refinement through joint industry/service analysis and review. Overall study organization is shown in Fig. P-1.

The basic case study approach was to build a foundation for analysis and to analyze the front-end process of program structuring for ways to attain R&M, mature it, and improve it. Concurrency and resource implications were considered. Tools to be used to accomplish this were existing case study reports, new case studies

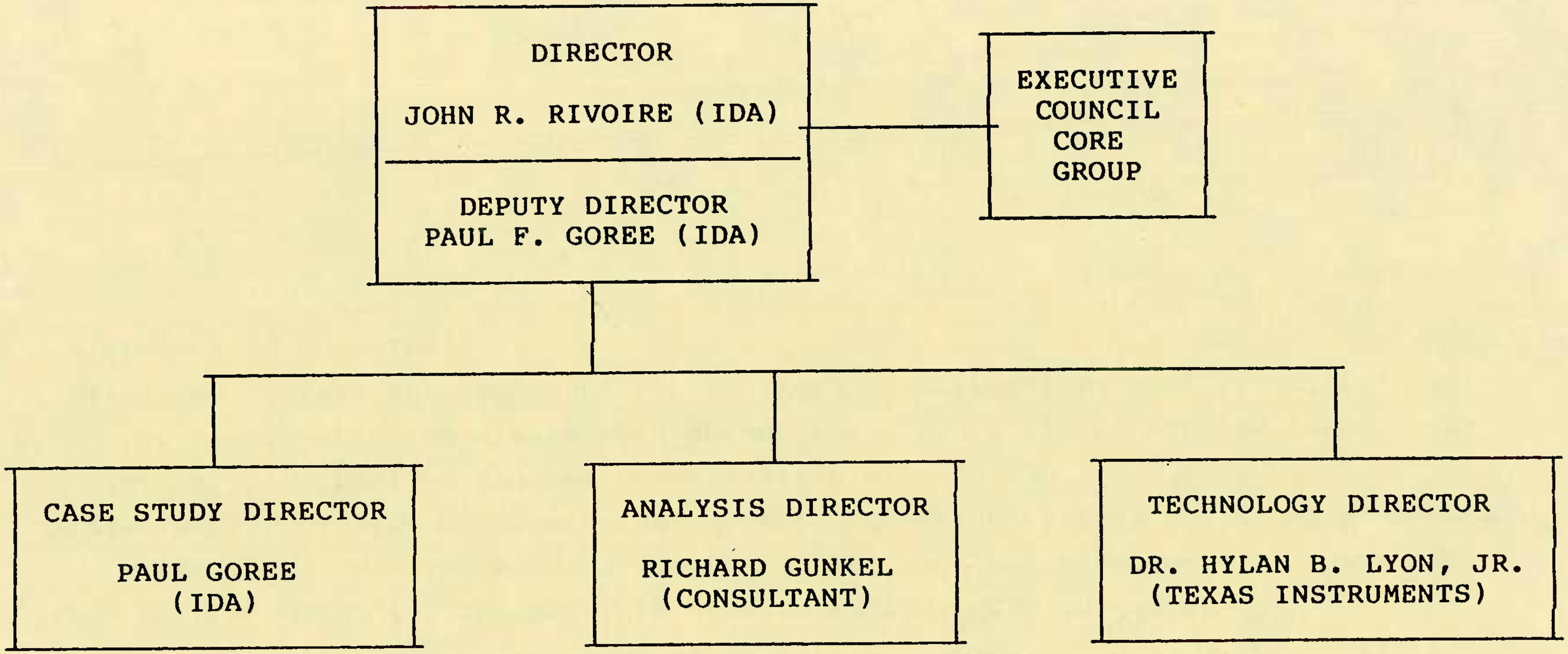


FIGURE P-1. Study Organization

conducted specifically to document quantitative data for cross-program analysis, and documents, presentations, and other available literature. In addition, focused studies for specific technology implications were conducted by individual technology working groups and documented in their respective reports. To accomplish the new case studies, the organization shown in Fig. P-2 was established.

In some areas where program documentation and records did not exist, the actual experience and judgement of those involved in the programs were captured in the case studies. Likewise, in the analysis process, the broad base of experience and judgement of the military/industry executive council members and other participants was vital to understanding and analyzing areas where specific detailed data were lacking.

This document records the program activities, details and findings of the Case Study Working Group for the specific program as indicated in Fig. P-2.

Without the detailed efforts, energies, patience and candidness of those intimately involved in the programs studied, this case study effort would not have been possible within the time and resources available.

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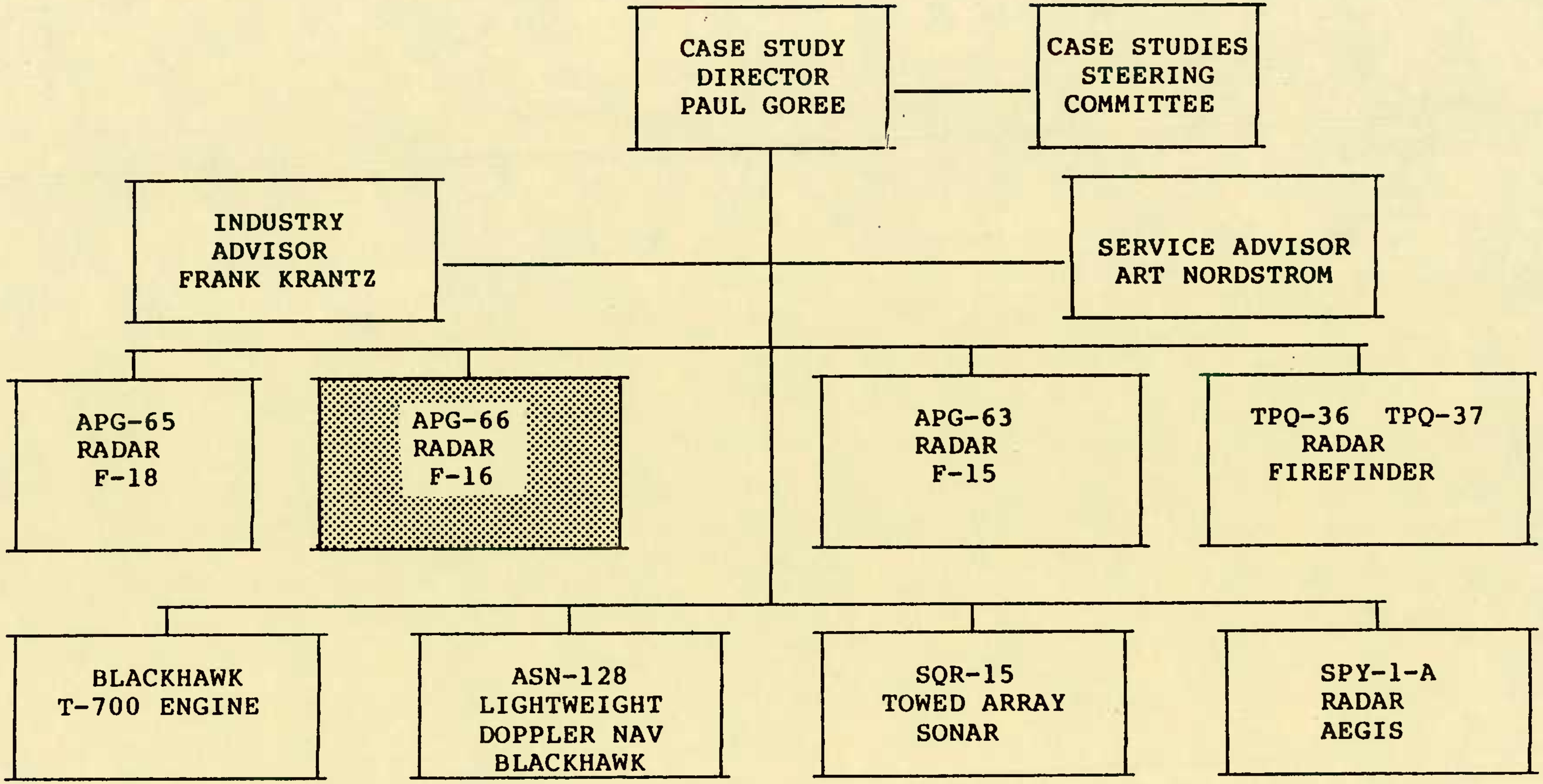

FIGURE P-2. Case Study Organization

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

40A/12

FOREWORD

This case study represents an assessment of the predominant factors that most strongly influenced the outcome of the F-16 Fire Control Radar Reliability and Maintainability Program.

Radar systems used within the military and identified as successful programs were selected for study to determine the factors that most strongly influenced the outcome of the programs. The case study was directed toward identifying program elements that were significant influencing factors on reliability and maintainability, documenting the lessons learned and establishing recommendations for future programs. This study, although directed specifically toward reliability and maintainability, encompassed a broad view of program elements and considered the complex interrelationship between contractual arrangements, management, design, manufacturing, and test and evaluation.

Reports documenting other case studies are published under separate cover. This report documents the case study for the AN/APG-66 fire control radar used on the USAF F-16 airplane.

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CASE STUDY CONTENTS

ABBREVIATIONS

AFPRO	Air Force Program Resident Office
AIS	Avionics Intermediate Shop
ATP	Acceptance Test Procedure
BIT	Built-in-Test
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CFE	Contractor Furnished Equipment
CMSEP	Contractor Management System Evaluation Program
CND	Cannot Duplicate
COD	Correction of Deficiencies
DESC	Defense Electronics Supply Center
DLA	Defense Logistics Agency
DSP	Digital Signal Processor
ECP	Engineering Change Proposal
ECS	Environmental Control System
EPG	European Participating Governments
EQT	Environmental Qualification Test
ESD	Electrostatic-Sensitive Devices
ESS	Environmental Stress Screening
FAR	Failure Analysis Report
FCC	Fire Control Computer
FET	Field Effect Transistor
FFP	Firm Fixed Price
FMC	Fully Mission Capable
FSD	Full Scale Development
FTM	Flight Test Model
GD	General Dynamics
GFE	Government Furnished Equipment
HAFB	Hill Air Force Base
HUD	Head-Up Display
ILS	Integrated Logistic Support (System)
INU	Inertial Navigation Unit
IR&D	Independent Research and Development
LCC	Life-Cycle Cost
LRU	Line Replaceable Unit
LSI	Large Scale Integration
MCL	Master Caution Light
MFL	Maintenance Fault List
MFTBF	Mean Flight Time Between Failure
MHP	Multiple Chip Hybrid Package
MMH/FH	Maintenance Man Hours per Flight Hour
MOT&E	Multi-National Operational Test and Evaluation
MRB	Material Review Board
MRN	Material Rejection Notice
MTBF	Mean Time Between Failure
MTBMA	Mean Time Between Maintenance Actions
OFP	Operational Flight Program
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PFL	Pilots Fault List
PSP	Programable Signal Processor
RADC	Rome Air Development Center
R&M	Reliability and Maintainability
RAT	Reliability Acceptance Test

RGT	Reliability Growth Test
RIW	Reliability Improvement Warranty
RQT	Reliability Qualification Test
RTOK	Retest O.K.
SOW	Statement of Work
SRU	Shop Replaceable Unit
STALO	Stable Local Oscillator
ST	Self Test
STFF	Self Test Fault Flag
TAC	Tactical Air Command
TAT	Turnaround Time
TLSC	Target Logistic Support Cost
TWT	Traveling Wave Tube
WEC	Westinghouse Electric Corporation
WUC	Work Unit Code

INTRODUCTION

The Westinghouse APG-66 radar is the heart of the fire control system on the USAF F-16 airplane. This radar system comprises about 50 percent of the F-16 avionics.

This report describes briefly the APG-66 radar and then presents a historical roadmap to show how the program developed. Quantitative measures are defined which were the design criteria for a successful reliability/maintainability program. This is followed by a description of the many factors that contributed to the R&M program. The lessons learned during the course of the APG-66 program are summarized to provide insights and guidance for later programs.

INTRODUCTION

- MISSION NEEDS
- SYSTEM DESCRIPTION
- PROGRAM SUMMARY
- MEASURES OF SUCCESS

MISSION NEEDS

MISSION NEEDS

The fire control radar (FCR) for the F-16 is a coherent, multimode, digital fire control sensor designed to provide all-weather air-to-air and air-to-surface modes with advanced dogfight and weapon delivery capabilities. The air-to-air modes provide the capability to detect and track targets at all aspect angles and at all altitudes both in the clear and in the presence of ground clutter. Target information in the air-to-air modes is presented as synthetic video on a "clean scope" display, both on a head-up display (HUD) and a head-down display, the Radar/Electro-Optical Display. Air-to-surface modes provide extensive mapping, target detection and location, and navigational capabilities.

DESCRIPTION OF
THE APG-66
FIRE CONTROL RADAR

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APG-66 SYSTEM COMPONENTS

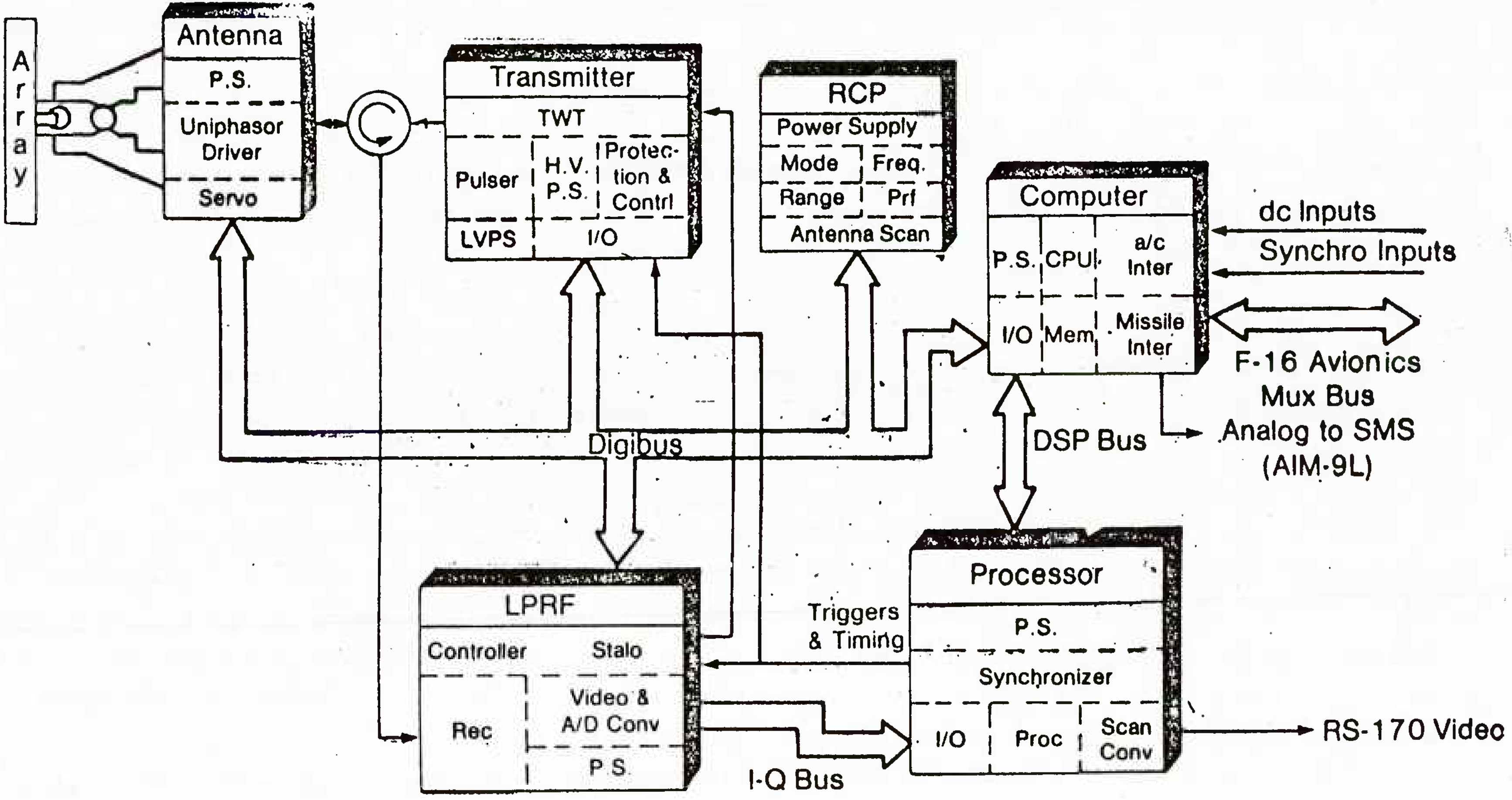
The F-16 Radar consists of six functional line replaceable units (LRUs) which are organized for autonomy, logical function, minimum interconnection, ease of maintenance, and co-production potential.

The six replaceable units are antenna, transmitter, low-power radio frequency (RF) unit, digital signal processor, the radar computer, and a radar control panel. A digital multiplex bus system provides a "party line" interface between the radar computer and the other line-replaceable units, with the exception of the digital signal processor. A separate high-speed data bus connects the radar computer with the digital signal processor.

All radar LRUs are mounted in the nose of the F-16 aircraft and are accessible from ground level, except for the radar control panel installed in the cockpit.

The primary means of communication with the other F-16 avionic systems is by use of MIL-STD-1553B Multiplex System. Video is provided to the cockpit displays in an RS-170 format.

F-16 APG-66 SYSTEM COMPONENTS



APG-66 RADAR LINE REPLACEABLE UNITS

1. ANTENNA

The planar array antenna, gimballed in two axes, provides high gain and low sidelobes over all scan angles. It includes a lightweight balanced electric drive system.

2. TRANSMITTER

The transmitter contains an air-cooled traveling wave-tube (TWT), a solid-state grid pulser, high voltage power supplies and regulators, and protection and control circuitry. The entire transmitter is solid state, except for the final TWT output tube. The pilot may select among four of the 16 available APG-66 operating frequencies in any given F-16 aircraft.

3. CONTROL PANEL

The radar control panel in the cockpit is used by the pilot to command the desired radar channel mode, range scale, scan width, and elevation bar scan. The avionics system can, under many conditions, assume control of the radar functions .

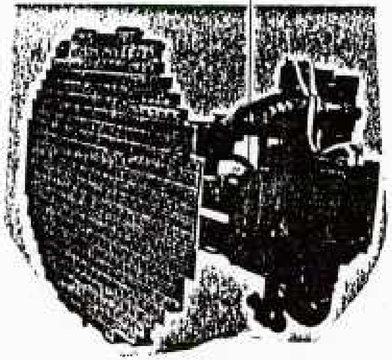
4. LOW POWER RF

The low-power radio frequency unit contains a receiver protector, low-noise Field Effect Transistor (FET) amplifier, receiver, analog/digital converters, stable local oscillator (STALO), and the system clock generator. All needed analog processing of the radar return signal is performed in this LRU. The LPRF also provides frequency agility for certain air-to-surface modes.

APG-66 RADAR LINE REPLACEABLE UNITS

1

Antenna



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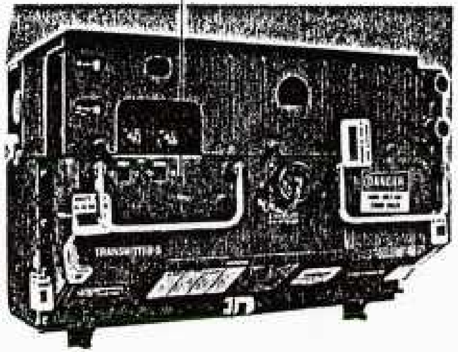
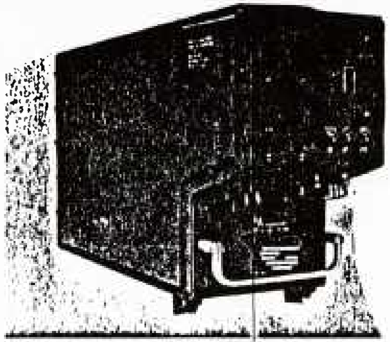
Transmitter



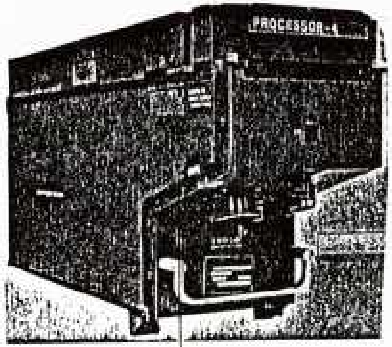
3

Control Panel



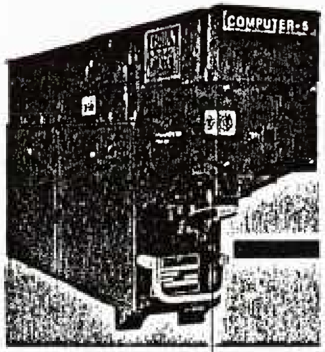
Low Power RF

5



Digital Signal Processor

6



Computer

5. DIGITAL SIGNAL PROCESSOR

Clutter rejection and other radar signal processing is performed by the digital signal processor. Digital radar techniques have been used extensively to replace contemporary analog hardware. The digital signal processor uses standard integrated circuits mounted in dual-in-line packages. Large scale integration (LSI) devices are used where industry standards and multiple sources exist. Thus, a high circuit density is achieved which decreases size and weight at a low cost. Custom LSI devices were avoided for cost and availability reasons in favor of standard devices, which have exhibited reliability maturity.

6. COMPUTER

The radar computer configures the radar system for the various operating modes, directs the digital signal processor to embed symbols in the video output, makes calculations, routes data to the fire control computer, interfaces with other F-16 avionic systems as well as other radar LRUs and controls all of the self-test and built-in-test functions of the radar. Growth provisions have also been made in the F-16 Radar for addition of the missile illuminator required for the Sparrow (AIM-7) missile. The computer is equipped with 48,000 16-bit words of programmable, semiconductor read-only memory. Temporary scratch pad memory requirements are met using volatile, semi-conductor random access memory. Memory reserve exists for introduction of new features and modes.

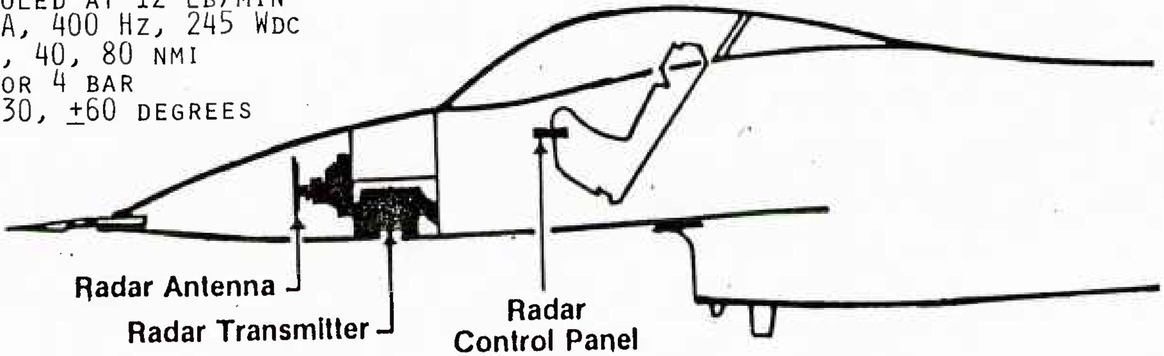
F-16 APG-66 RADAR INSTALLATION

The installation of the APG-66 is shown in the accompanying figure. The Radar Control Panel is installed in the cockpit. The other LRUs are installed in the forward portion of the aircraft. The forward-installed LRUs other than the antenna are mounted in a rack which provides interface with the airplane. Key APG-66 parameters are shown in the table in the upper left corner of the figure.

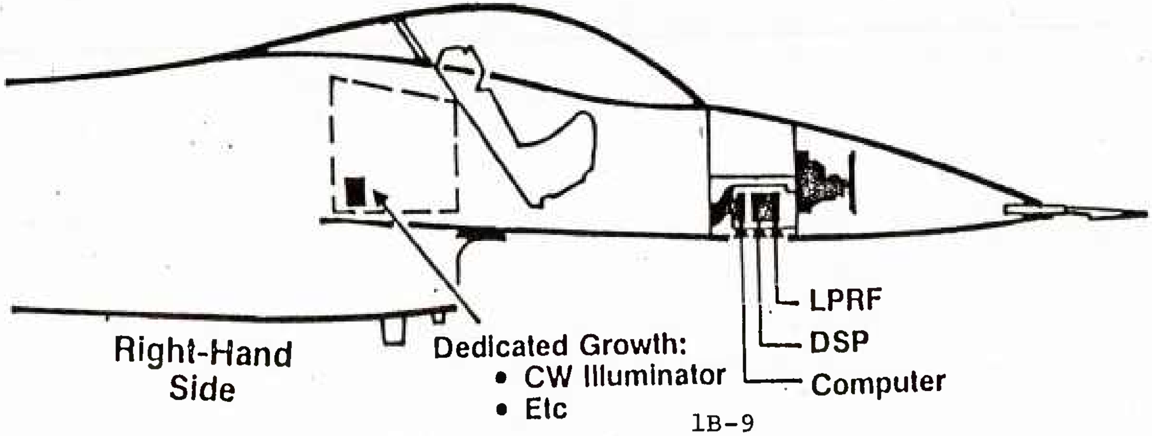
F-16 APG-66 RADAR INSTALLATION

APG-66 RADAR PARAMETERS

VOLUME	3.6 FT^3 (.102 M^3)
WEIGHT	296 LB (134.3 KG)
FREQUENCY	X BAND PULSE DOPPLER
RELIABILITY	97 HOUR LAB DEMONSTRATED MTBF
MAINTENANCE	<.05 HR MCTT M_{CT} (MEAN) AND <1.0 HR MCTT M_{CT} (MAX)
ELECTRONIC PARTS	9500
COOLING	AIR COOLED AT 12 LB/MIN
INPUT POWER	3580 VA, 400 HZ, 245 WDC
RANGE SCALES	10, 20, 40, 80 NMI
ELEVATION COVERAGE	1, 2, OR 4 BAR
ANTENNA AZIMUTH SCAN	±10, ±30, ±60 DEGREES
POWER OUTPUT AVERAGE	~200W



Left-Hand
Side



Right-Hand
Side

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F-16 APG-66 SYSTEM PARAMETERS

This table presents a number of the physical characteristics of the APG-66 radar by LRU early in its development program. These bogies are allocations made by WEC to achieve system objectives. Subsequent development efforts led to changes in these parameters that are not reflected here. These parameters are as of May 29, 1976 only.

F-16 APG-66 SYSTEM PARAMETERS
(AS OF MAY 29, 1976)

	ACTUAL/BOGIE	WEIGHT (LB)	VOLUME (FT^3)	NUMBER OF INTEGRATED CIRCUITS	NUMBER OF ELECTRONIC COMPONENTS (TOTAL)	NUMBER OF INTERNAL COAX CONNECTORS	NUMBER OF EXTERNAL COAX CONNECTORS OR TRIAX	NUMBER OF LRU CONNECTIONS ACTIVE PINS/TOTAL PINS	INPUT POWER (VA) 115V, 3φ 400 HZ WORST CASE	INPUT POWER (W) 28 VDC WORST CASE	COOLING AIR FLOW LB. PER MIN. @ 3 IN. W.P. @ 27°C	INHERENT MTBF (HOURS)	MTTR (Repair Hours) Current Prediction	COST ($K) 112 LOT TCS	Total heat dissipation (Watts)	Heat dissipation cooled by forced air (Watts)	Mechanical Parts	
ANTENNA	ACT	61.9	NA	116	753	4	0	Sig 10/13 Pwr 5/10	650	0	0.75	1764	0.34	18.4	317	192	900	
	BOG	57.2	NA	265	748	0	0	Sig 18/37 Pwr 10/18	657	0	0	2877	0.33	18.8	335*	210	2000	
TRANSMITTER	ACT	69.4	1.2	49	750	11 SMA 1 TNC	2	Sig 15/22 Pwr 7/10	1424	29	3.6	1366	1.123	19.9	1227	1227	1400	
	BOG	63.1	1.2	48	746	10	2	Sig 16/20 Pwr 11/18	1269	48	2.8	2061	1.75	20.0	1227	1227	2500	
LPRF	ACT	47.5	.93	322	1620	62	4	Sig 60/79 Pwr 7/10	603	106	2.6	755	0.7106	29.3	582	582	1200	
	BOG	37.7	.9	249	1781	40	3	Sig 74/81 Pwr 10/13	660	86	1.9	1199	0.72	25.0	579	579	2500	
COMPUTER (INCL PWR. SUP)	ACT	28.4	.55	760	1800	1	1	Sig 68/79 Pwr 8/10	209	0	1.4	1353	0.5035	13.1	289	289	900	
	BOG	27.4	.51	1015	1755	0	0	Sig 88/97 Pwr 39/43	361	34	1.5	1071	0.50	15.1	284	284	1800	
DSP (INCL INVERTER)	ACT	58.4	.95	2758	3300	0	3	Sig 68/100 Pwr 5/10	965	0	4.3	491	0.5106	21.0	900	900	1250	
	BOG	52.7	.9	3083	3503	0	3	Sig 90/100 Pwr 6/18	857	0	3.8	338	0.52	21.5	900	900	2500	
RADAR CONTL. PNL.	ACT	3.5	.08	34	95	0	0	Sig 12/22 Pwr 8/13	5	12	-	12048	0.47	2.0	12	0	150	
	BOG	3.5	.08	65	112	0	0	Sig 6/22 Pwr 13/22	0	17	0	13250	0.45	1.7	20	0	700	
RACK & CABLE & WAVEGUIDE ASSY.	ACT	17.3	.35	0	13	0	2	Sig 41/55 Pwr 28/32	0	0	-	4808	-	3.4	0	0	650	
	BOG	16.7	NA	0	0	0	0	Sig 70/128 Pwr 33/43	0	19	0	-	-	2.6	0	0	1000	
SYSTEM TOTAL	ACT	286.4	4.06	4039	8328	79	12	Sig 274/370 Pwr 68/95	3995	147	12.8	176	0.7008	107.4	3327	3190	6450	
	BOG	258.2	3.59	4725	8647	50	8	Sig 362/485 Pwr 122/175	3375	204	10.0	178	0.75	10[illegible].4**	3345	3200	13000	

N/A Not Applicable

* watts RF dissipation included.

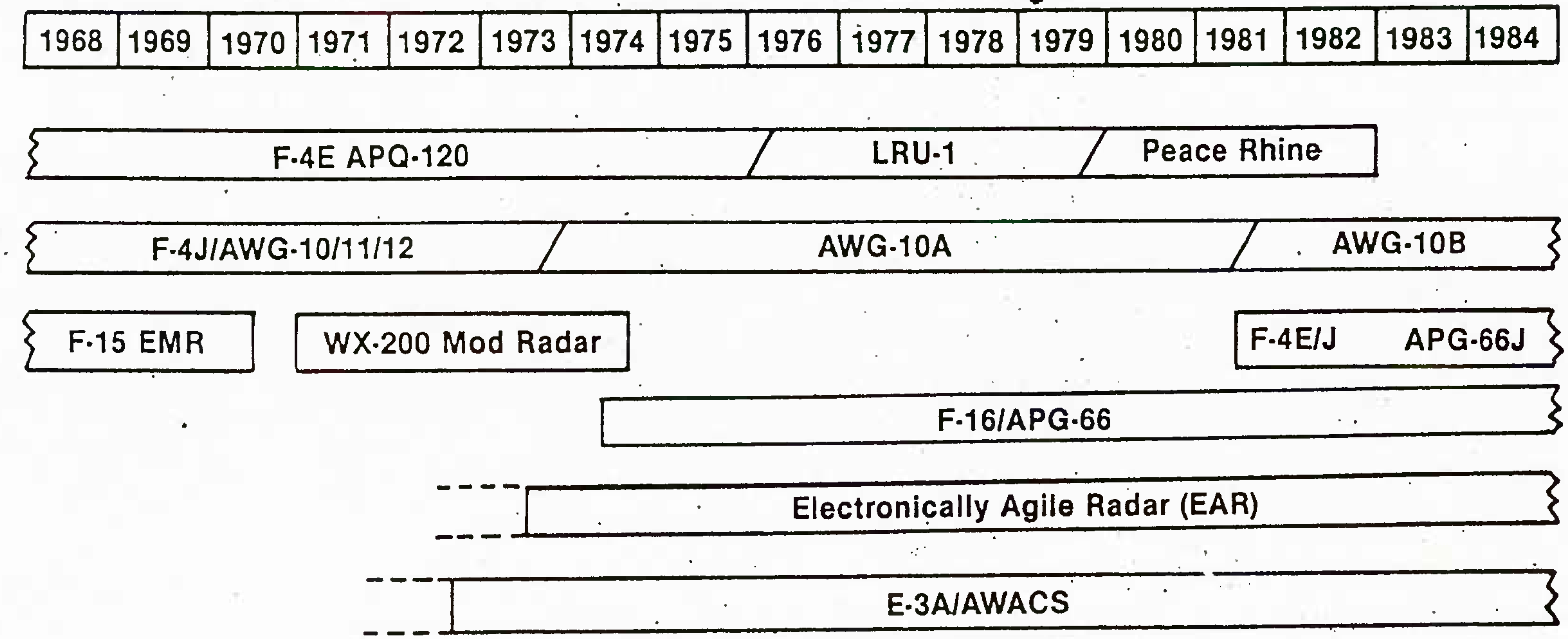
** Including 1.2 for assembly and test.

APG-66 RADAR SYSTEM EVOLUTION

The chart depicts the evolution that led to the development of the modular APG-66 radar. Westinghouse began design and development activity in 1971 for a new series of modular radar, designed to a cost. The WX series of radars, and in particular the WX200, used the pulse doppler principle and advanced digital techniques. Demonstration of these balanced design techniques led directly to the subsequent balanced design and development of the APG-66 in July 1974.

AN/APG-66

Westinghouse Advanced Radar Systems Evolution



1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984

F-4E APQ-120 / LRU-1 / Peace Rhine

F-4J/AWG-10/11/12 / AWG-10A / AWG-10B

F-15 EMR

WX-200 Mod Radar

F-4E/J APG-66J

F-16/APG-66

Electronically Agile Radar (EAR)

E-3A/AWACS

PROGRAM SUMMARY

F-16 APG-66 PROGRAM SUMMARY

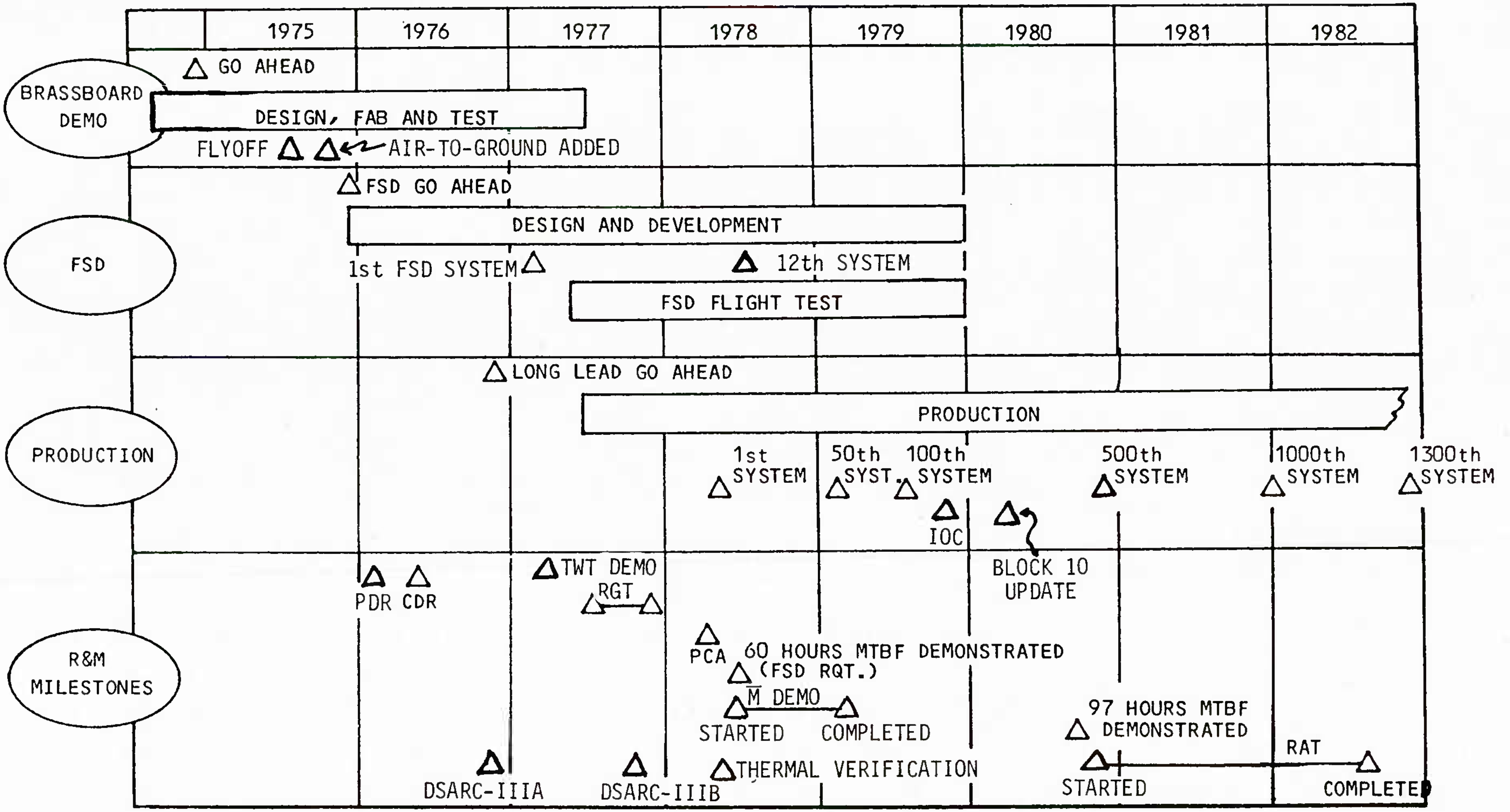
The APG-66 radar system development was highly concurrent; the design of the radar was actually initiated long before the RFP was issued.

The F-16 APG-66 radar development effort started with the award of two contracts by the Air Force in December 1974, to Hughes Aircraft and Westinghouse Electric Co. to develop and build two flight test model (FTM) radar systems which were, at the time, essentially air-to-air radars. The culmination of the development was a "fly off" flight test program that was conducted by General Dynamics and the USAF. Each radar contractor flew its respective FTM radar in an F-4 aircraft under identical flight conditions. During October 1975, approximately 80 flights were flown, data reduced and reports written.

As a result of the fly off and evaluation of FSD proposals, Westinghouse was awarded the FSD contract in November 1975 to develop the F-16 FCR. Flight testing continued in the Westinghouse F-4 vehicle at Baltimore. The first FSD radar was delivered to Fort Worth 16 March 1977 and began flight test in an F-16 airplane on 24 May 1977. On two different occasions, F-16 flight test airplanes were based in Baltimore for the purpose of a concentrated effort to work radar problems. Flight test continued at Edwards AFB through 1979.

In December 1976, before FSD was completed, the go-ahead was received to procure long-lead items for production. Production started in the middle of 1977, only weeks after FSD flight test was initiated. Coincident with the initiation of production, reliability growth testing was started. The FSD requirement of 60 hours MTBF was demonstrated in the middle of 1978 shortly <u>after</u> the first production system emerged from the production line. Moreover, the 100th production system was delivered before FSD and flight testing of the full scale development items were completed. Note that after FSD was completed, the various R&M activities continued with the production and fielding of the production systems. Major delivery and R&M milestones are shown on the facing page.

F-16 APG-66 PROGRAM SUMMARY



F-16 APG-16 RADAR FSD RELIABILITY SCHEDULE

Planned versus actual FSD reliability test schedules and their relationship to major program milestones are shown on the facing chart. Differences in planned and actual test start dates were due primarily to unavailability of hardware.

The number of systems used for reliability growth and development reliability qualification tests was also impacted by asset availability.

F-16 APG-66 RADAR FSD RELIABILITY SCHEDULE

---- PLANNED
==== ACTUAL

			1976	1977	1978
TWT RELIABILITY TEST	3 UNITS		11 |-	---| 4	
	3 UNITS			1 |====| 6	
RGT	4 UNITS			5 |------| 10	
	1 UNIT			7 |=====	=| 12
THERMAL ANALYSIS AND VERIFICATION				2 |-| 3	3 |=|
RQT	3 UNITS			7 |--| 10	
	2 UNITS				3 |=| 4 |==| 6 #1 #2
GO AHEAD	11/24/75	Δ			
PDR	4/76		Δ		
CDR	6/8-11/76		ΔΔ		
FIRST F-16 RADAR FLIGHT	5/27/77			Δ	
RADAR PCA	4/24/78				Δ

MEASURES OF SUCCESS

MEASURES OF SUCCESS

Program success can be measured in terms of reliability and maintainability characteristics and their effect on field operations and supportability. Reliability and maintainability emphasis throughout the AN/APG-66 program, from design inception through field use, have resulted in high mean-flight-time-between-failures (MFTBF) and low maintenance manhours per flight hour (MMH/FH) accompanied by reduced support costs and increased operational readiness in field use.

MEASURES OF SUCCESS

- FIELD RELIABILITY - MFTBF = 65 HOURS
- OPERATIONS AND SUPPORT COST - LOWER THAN PREVIOUS RADAR
- FIELD MAINTAINABILITY - MATURE PREDICTION ACHIEVED
- PERCENT OF FLIGHTS WITH NO RADAR FAULTS - GROWTH FROM 35 TO 89%
- DEPOT REPAIR TURNAROUND TIMES LESS THAN 20 DAYS
- OPERATIONAL READINESS EXCEEDING 98% FULLY MISSION CAPABLE (FMC)

RADAR SET FIELD MFTBF EXCEEDS PREDICTION BY 45%

This figure shows the Mean Flight Time Between Failure (MFTBF) for the APG-66 radar, installed in production F-16 aircraft, operated by Air Force personnel in service environments.

The measured field MFTBF is a 3-month moving average plotted monthly and compared to the predicted MFTBF growth for the F-16 APG-66 radar. This MFTBF is based on Air Force AFR 66-1 data for the F-16 Tactical Air Command (TAC) fleet and is defined as

$$\text{MFTBF} = \text{MTBMA}_{\text{TYPE 1}} = \frac{\text{FLIGHT HOURS}}{\text{GROUND TYPE 1 FAILURES + FLIGHT TYPE 1 FAILURES}}$$

where Type 1 (inherent) failures are as defined in AFR 800-18.

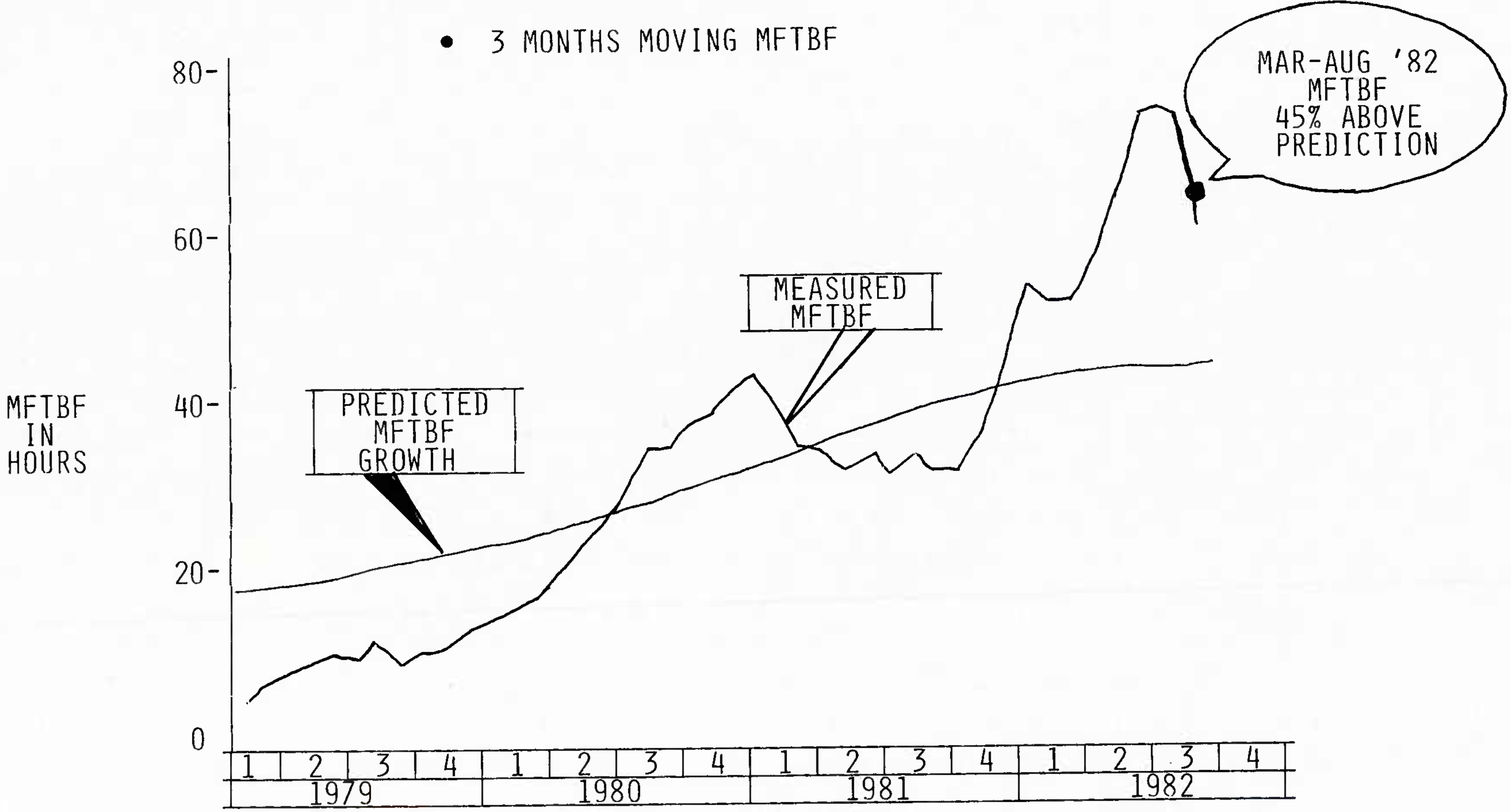
The predicted growth curve was developed (during FSD) as an indicator to determine if the radar would achieve its mature predicted MFTBF.

The growth in measured field MFTBF is the result of an aggressive failure analysis and corrective action emphasis implemented for reliability testing, manufacturing tests and field operations during the first 150,000 hours of flight.

The measured MFTBF for the six months ending in August 1982 is 65 hours and is 45% above the mature predicted MFTBF of 45 hours for the radar.

RADAR SET FIELD MFTBF* EXCEEDS PREDICTION BY 45%

- AIR FORCE AFR 66-1 DATA
- TAC EXPERIENCE
- 150,000 FLIGHT HOURS
- 3 MONTHS MOVING MFTBF



$$*\mathrm{MFTBF} = \mathrm{MTBMA}_{\mathrm{TYPE\ 1}} = \frac{\text{FLIGHT HOURS}}{\text{GROUND TYPE 1 FAILURES + FLIGHT TYPE 1 FAILURES}}$$

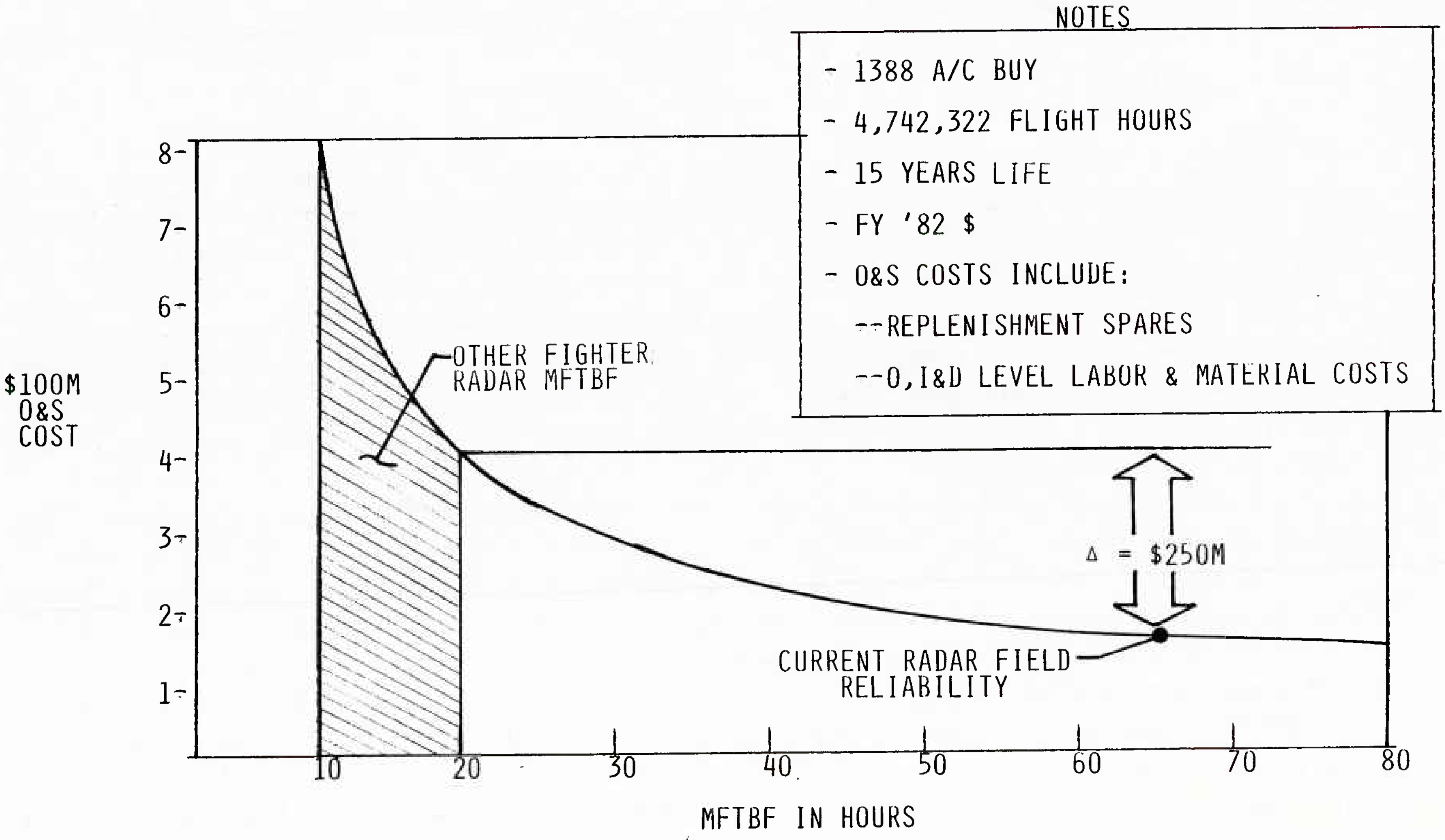
WHERE TYPE 1 (INHERENT) FAILURES ARE AS DEFINED IN AFR 800-18

IMPROVED RELIABILITY RESULTS IN LOWER O&S COSTS

The sensitivity of operations and support cost due to improved radar reliability is presented on this chart. The operations and support cost includes replenishment spares; organization-, intermediate- and depot-level maintenance labor and material costs for the F-16 APG-66 radar. Program characteristics, upon which the O&S cost estimate is based, reflect an F-16 program of procuring 1388 aircraft flying a total of 4,742,322 flight hours over 15 years. The cost estimates were calculated using a General Dynamics operations and support cost model for a range of radar system reliabilities from an MFTBF value of 10 to 80 hours.

The curve shows that an operations and support cost savings of $250M could be realized throughout the life of the F-16 program over the costs that would have been incurred if the F-16 radar had been a 20-hour MFTBF radar (typical of today's fighter radar). This cost avoidance will more than offset the up-front cost of added reliability design, testing and reliability improvement warranty programs that lead to the current high field MFTBF of the APG-66 radar.

IMPROVED RELIABILITY RESULTS IN LOWER O&S COST



NOTES

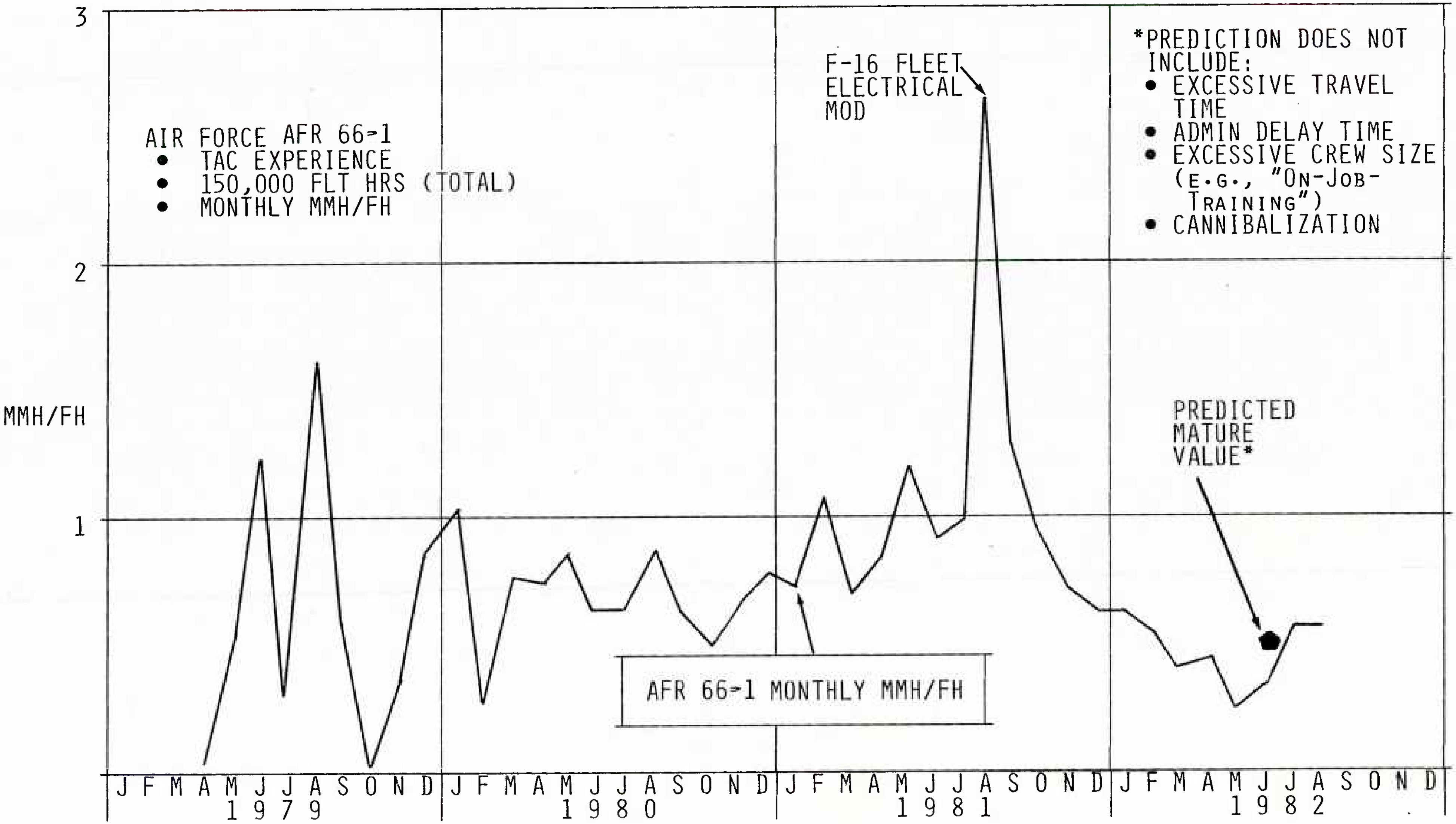
- 1388 A/C BUY
- 4,742,322 FLIGHT HOURS
- 15 YEARS LIFE
- FY '82 $
- O&S COSTS INCLUDE:
  - --REPLENISHMENT SPARES
  - --O,I&D LEVEL LABOR & MATERIAL COSTS

APG-66 RADAR MMH/FH PREDICTION ACHIEVED

Excellent maintainability characteristics have been achieved by the APG-66 radar. As shown in the figure, the APG-66 MMH/FH typically runs under one hour. This is derived from the Air Force maintenance data collection system AFR 66-1, and applies to TAC experience with more than 150,000 flight hours. Other than the peaks at the beginning, there is only one other large peak occurring in summer-fall of 1981. This peak does not reflect radar maintainability problems but occurred because the F-16 airplane flying activity was curtailed during this period to modify the airplane's electrical system. Since very few flying hours occurred during this period and maintenance actions continued, the MMH/FH increased drastically. However, after full flying schedules were resumed near the end of 1982 the MMH/FH rapidly improved and approached the predicted mature value of 0.5.

The predicted mature value (circa 1977) of MMH/FH for the APG-66 Fire Control Radar was 0.56 hours. Attainment of this value was predicated on the achievement of anticipated system reliability, availability of necessary support equipment and personnel, and compliance with the recommended maintenance concepts and procedures. This prediction did not include travel times for maintenance personnel and administrative delay times. Reported field data includes these additional time parameters. The fact that Air Force AFR 66-1 field data indicates that this prediction is being met is a conservative estimate of the MMH/FH measure. These results are based on monthly reports from Hill, MacDill and Nellis Air Force Bases.

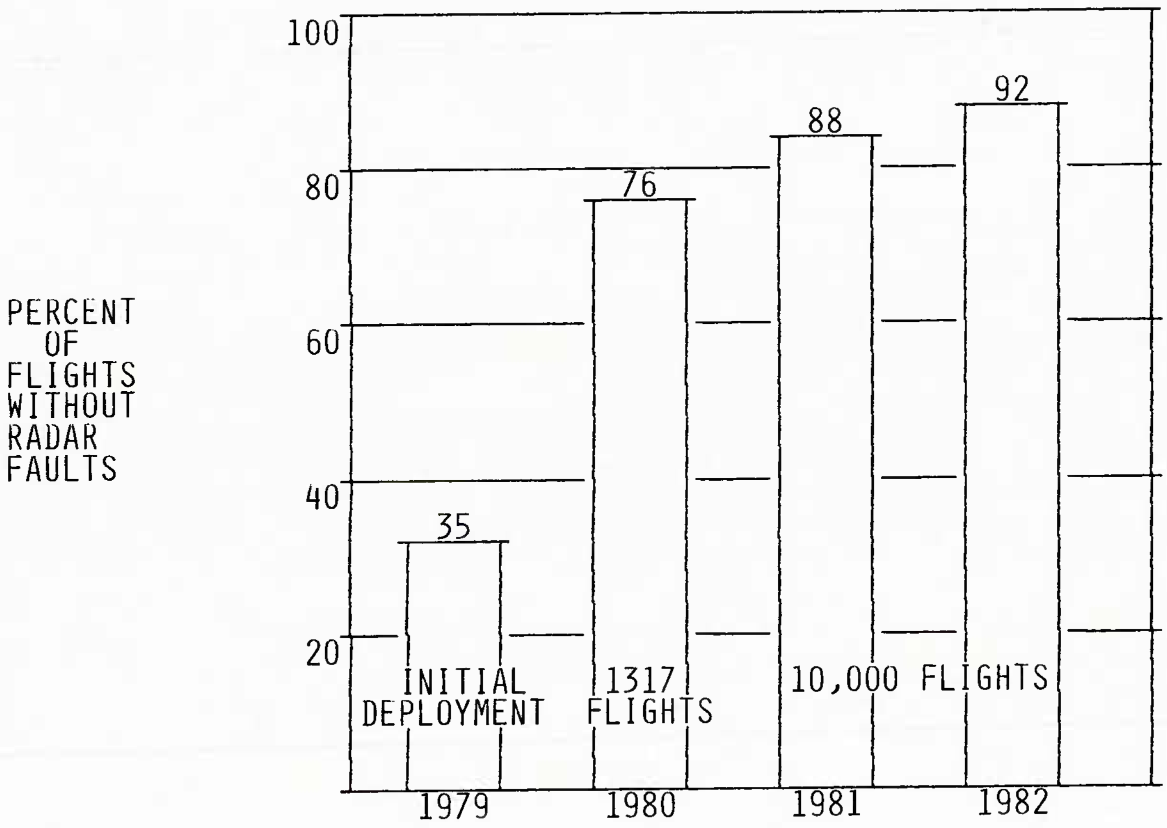
F-16 APG-66 RADAR MMH/FH PREDICTION ACHIEVED



PERCENT OF FLIGHTS WITH NO RADAR FAULTS

Another measure of program success is the steady increase in the percentage of F-16 flights which had no radar malfunction reported. This parameter grew from approximately 35% in 1979 to 92% in 1982. Flights without fault would be even higher if flights which contained repeat faults (faults which were known but not corrected) were discounted. The improvement in flights without faults during the 1979-1980 time period is a result of a number of modifications incorporated during that period. One of the most significant improvements was General Dynamics ECP 331, which is discussed in more detail in the test and evaluation portion of this report.

PERCENT OF F-16 FLIGHTS HAVING NO RADAR FAULTS 1/



MAJOR CLASS I CHANGES ---> Δ Δ ΔΔΔ Δ

1977 -----------------> ≈5700 PROGRESSIVE CLASS II CHANGES -----> |

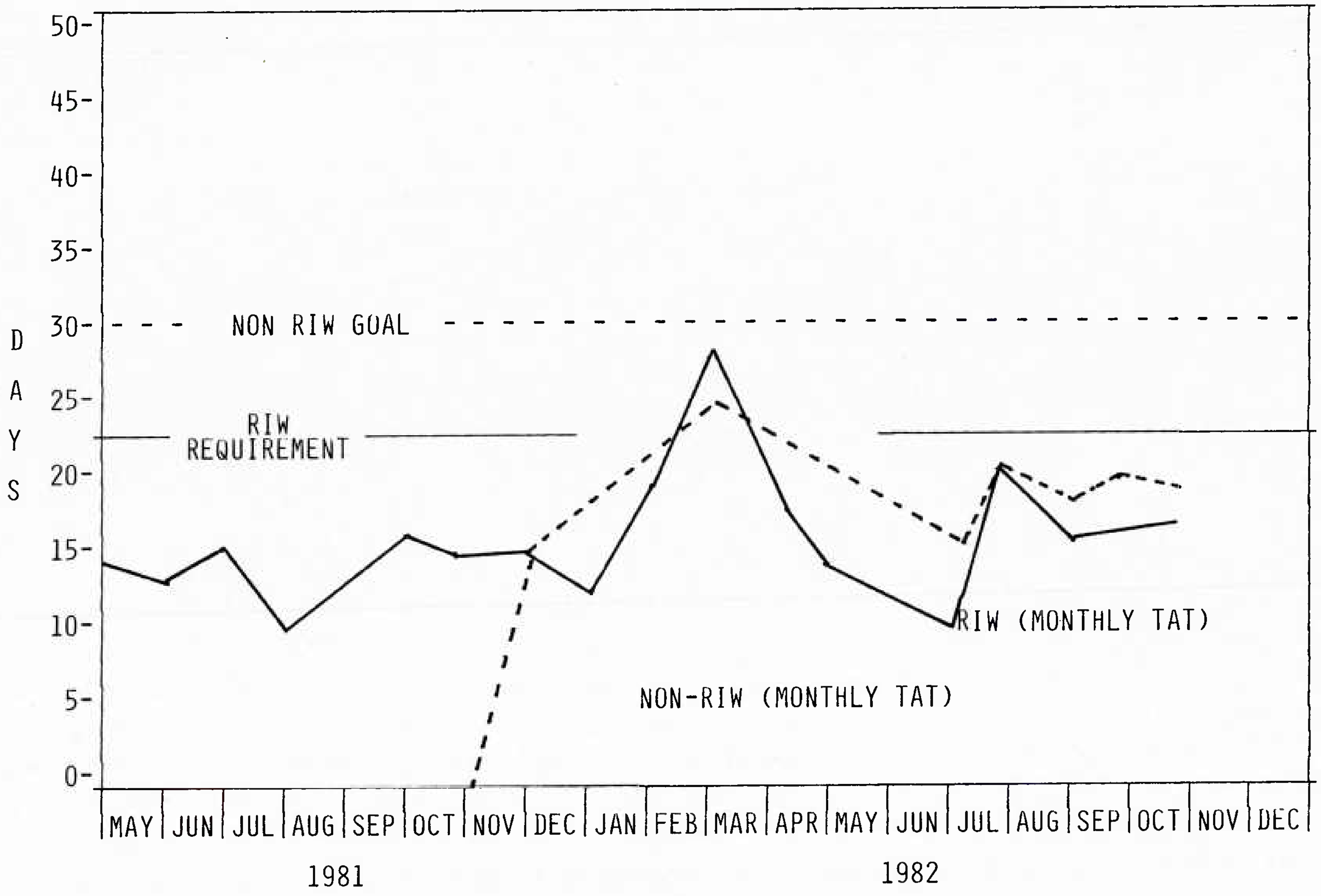
1/ HILL AFB 1979-1980

2/ NATO BASE 1981-1982

REPAIR TURNAROUND TIMES (TAT)

The RIW contract specified that units returned to the manufacturer were to be repaired and made ready for return to the Air Force within 22 days. Those units manufactured that were not under the RIW contract were given 30 days for TAT. It will be noted that except for one short period of time a 20-day turnaround time (TAT) was achieved for the entire period for both RIW and non-RIW units. This record is better than the records associated with previous avionic systems and is better than the goals and requirements that were originally set for this system. Non-RIW units benefited from the repair system set up for the RIW units.

F-16 APG-66 RADAR TURNAROUND TIMES (TAT)
BETTER THAN GOALS AND REQUIREMENTS



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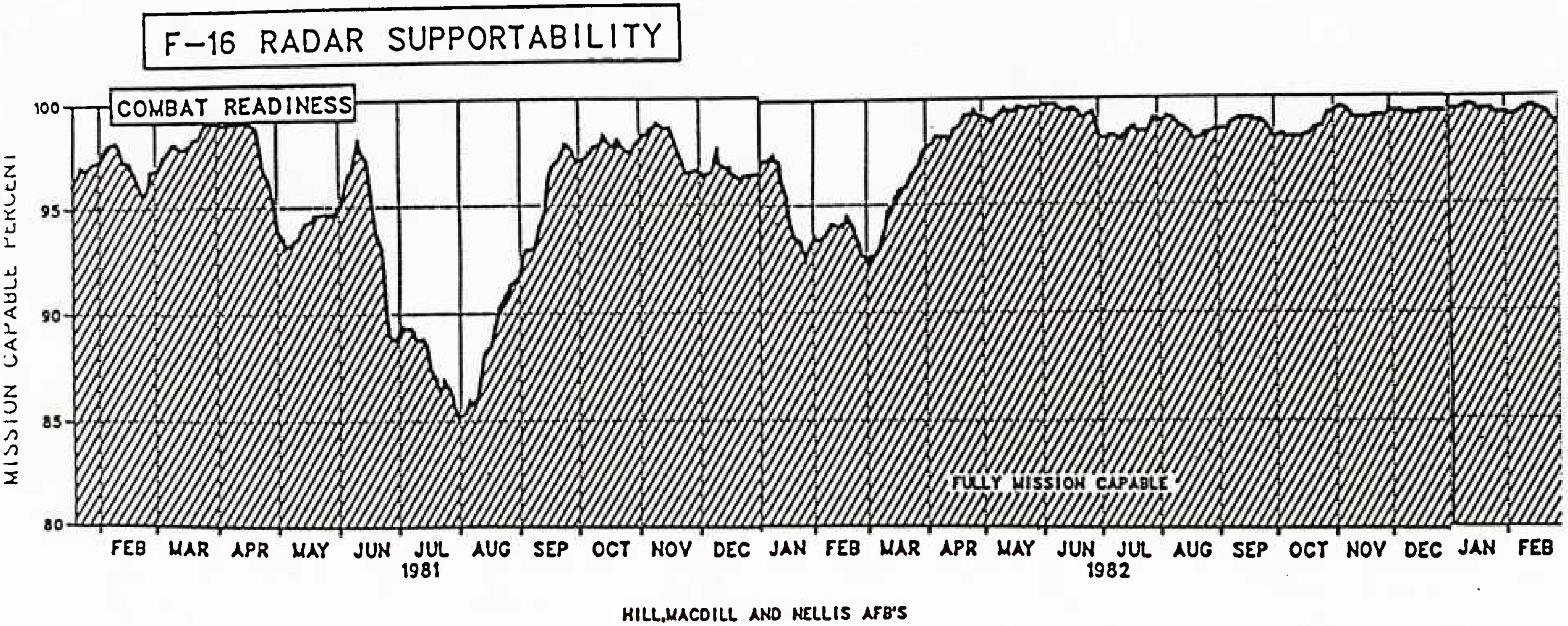
OPERATIONAL READINESS

The data on this figure represent operations at three Air Force bases. Nellis AFB is represented in the top panel, while Hill and MacDill AFBs are jointly represented in the bottom panel. The charts show the proportion of aircraft in each set that had fully mission capable radars on each of the calendar days shown in the abscissa. It should be noted that for all bases represented, the radar FMC rate was in the range of 98-99 percent for the most recent six months shown. This trend is expected to continue.

F-16 RADAR SUPPORTABILITY



PROGRAM ELEMENTS

PROGRAM ELEMENTS

Many factors contributed to the results of the APG-66 radar program. The key development factors have been divided into five groups. We must caution, however, that although this grouping may assist in this exposition, these elements are not independent of each other and in fact have large overlaps. The more significant of these overlaps are identified and described in the pages that follow.

PROGRAM ELEMENTS

- CONTRACT
- MANAGEMENT
- DESIGN
- MANUFACTURING
- TEST AND EVALUATION

CONTRACT

- STRUCTURE
- $\overline{R}$ & $\overline{M}$ REQUIREMENTS
- INCENTIVES
- SOURCE SELECTION
- LCC

STRUCTURE--CONTRACTUAL RELATIONSHIPS

The contractual relationship that results from the radar procurement being contractor furnished equipment (CFE) enjoys some flexibility over a government furnished equipment (GFE) procurement during the development period. Not only does the flexibility exist in the technical area but also in the program management efforts. Two examples illustrate these points.

In the technical area, the prime/sub interface is such that problem solving can be accomplished on either side of the interface and still be timely and in scope; that is, no additional cost to the government. For instance, a software filter to correct a problem could be either in the CFE procured radar computer (GD responsibility) or in the fire control computer (GD responsibility). The decision can be influenced not only by the technical consideration but also the cost and program schedule impact. If the interface were between GFE radar and CFE avionics, then the flexibility is severely limited and any problem on the GFE side of the interface results in an out of scope change on the CFE side of the interface.

An example of a programmatic problem might be late delivery of radar equipment from the supplier such that the installation into the airplane would be out of the planned work station. With a CFE contract GD could consider the cost impact as in-scope, whereas with GFE late delivery could be out-of-scope and subject of a cost claim to the government.

STRUCTURE -- CONTRACTUAL RELATIONSHIPS

- CONTRACT INTERFACE SIMPLICITY
- FREEDOM TO EFFECT CHANGES WITHIN SCOPE
- FLEXIBILITY FOR MANAGEMENT DECISIONS

EXAMPLE:

1. GD HAD TOTAL WEAPON SYSTEM VIEW. DIRECTED OTHER SUPPLIERS TO MAKE CHANGE TO HELP SOLVE PROBLEMS WITH RADAR INTEGRATION.

2. RADAR SPARES--DIVERTED FROM GD BANK EARLY IN PROGRAM.

REALISTIC REQUIREMENTS

Radar requirements were derived from the overall weapon system requirements. By defining requirements from the "top down," the radar specification represented a firm, practical performance level. The statement of work (SOW) to WEC contained a requirement for verification through demonstrations. The design approach was formally documented and contractually approved by GD.

The contract to Westinghouse Electric Corporation (WEC) from GD included a specification (16ZE-009) that laid down the requirements for the F-16 radar. These were firm requirements, not goals, and were derived through a balanced design based on experience from previously-designed radars. The requirement was considered stringent yet possible to achieve at that time.

Other requirements included operating in an environment with 100% relative humidity over a range of temperatures from -40°F to +70°C, to include sand and dust. At the O-level only external cleaning and wiping was allowed. Removals at the O-level were to be rapidly accomplished by one man using standard tools. The antenna was the one allowable exception because of its weight. No adjustments, alignments or calibrations were allowed at the O level. Mechanical boresighting requirements were such to permit replacement of the antenna without further realignment.

The aircraft ready condition was specified as meeting performance requirements after seven days without maintenance, checkout or flight. For ease of maintenance at the I-level, functionally related parts were to be grouped within common SRUs with no adjustment required when replacing an SRU. Also, it was to be made impossible to install equipment incorrectly, either mechanically or electrically, by using methods other than tubing shape, color coding or labeling.

REALISTIC REQUIREMENTS ESTABLISHED

- DEFINED IN SPECIFICATION 16 ZE 009
    - REQUIREMENTS FIRM, NOT GOALS
    - DERIVED THROUGH A BALANCED DESIGN
    - DETAILED COMPARABILITY ANALYSIS
    - STRINGENT BUT NOT IMPOSSIBLE
- SPECIFIC LINE ITEMS IN SOW AND CDRL
    - VERIFICATION THROUGH DEMONSTRATIONS
    - APPROACHES FORMALLY DOCUMENTED AND CONTRACTUALLY APPROVED

CONTRACTOR INCENTIVES

Contractor motivation was provided by various incentives in the contract. Keeping the costs to a minimum was encouraged by the cost sharing arrangement. Various award fees were provided for achieving certain performance goals. With the CFE contractual arrangement many of these incentives were passed on directly to the radar supplier.

A dynamic, continuing incentive was the reliability improvement warranty (RIW) program where the supplier was constantly looking for ways to improve the reliability/maintainability performance of the equipment. The supplier was given the freedom (from a configuration management standpoint) to process and incorporate RIW-type changes. With the supplier functioning as the depot for the production equipment, high visibility was afforded to Westinghouse in areas which could benefit from RIW-related changes.

While there was an award fee for completing FSD RQT and production RQT early, Westinghouse received neither fee since the tests ended in a reject decision in the time allotted for the award. However, the incentive was present and Westinghouse did attempt to meet the award criteria for the tests. As a result of the RQT failure corrective actions were incorporated early that matured the radar faster than would have otherwise happened.

A significant motivation was the correction of deficiencies (COD) clause of the contract which basically required the contractor to fix problems at his own expense that did not meet the requirements of the specification.

The developing of high quality equipment is always helpful in maintaining a good company image and the opportunity for future sales. In the case of the F-16, this was especially true, since the airplane was being marketed throughout the world. High reliability from the radar would serve to increase its competitiveness with other contenders. This type of contractor incentive may be the most powerful force at work in motivating companies to produce reliable products. In addition, the modular APG-66 radar was a good building block for other radar programs like DIVAD and the B-1B.

INCENTIVES WERE IMPORTANT TO PROGRAM SUCCESS

- <u>FORMAL</u>
  - COST SHARING ABOVE/BELOW TARGET
  - AWARD FEES--DESIGN TO COST/RQT
  - CORRECTION OF DEFICIENCIES
  - RELIABILITY IMPROVEMENT WARRANTY

- <u>OTHER</u>
  - ADDED SALES
  - PRIDE/IMAGE

COST SHARING

The AF contract with GD was a firm fixed price contract (FFP) with cost sharing. If full-scale development costs went above or below the target, the Air Force and the contractor shared in the ratio of 85/15 percent, respectively. If production costs went above or below the target, the sharing ratio was 60/40 percent. There was a cost floor and a cost ceiling also. Above the ceiling all costs were assumed by the contractor, and below the floor all costs were paid by the Air Force.

This is the classic FFP structural format; as the contractor risks are reduced, he is expected to assume more liabilities of cost sharing.

In a CFE program the contracts are compatible between the USAF and GD as well as between GD and WEC. Therefore, the incentives and cost sharing exist at both contractual levels.

FIRM FIXED PRICE CONTRACT WITH COST SHARING -- A MAJOR INFLUENCING FACTOR

PROGRAM COST

	FSD	PRODUCTION
• ABOVE CEILING	ALL COSTS ASSUMED BY CONTRACTOR	
CEILING (127.5%)		
• ABOVE TARGET	COSTS SHARED 85%/15% (USAF/CONTRACTOR)	COSTS SHARED 60%/40% (USAF/CONTRACTOR)
TARGET (100%)		
• BELOW TARGET	UNDERRUN SHARED 85%/15% (USAF/CONTRACTOR)	UNDERRUN SHARED 60%/40% (USAF/CONTRACTOR)
• FLOOR (%)		
	ALL COSTS ASSUMED BY USAF	

- COST SHARING PASSED FROM
  - ✓ USAF TO GD
  - ✓ GD TO WEC

RELIABILITY IMPROVEMENT WARRANTY (RIW)

In an attempt to further motivate the contractor after he won the contract award, the Air Force included in the contract an option to exercise RIW provisions.

Twelve F-16 LRUs were selected as "control LRUs." These were selected because they were expected to contribute at least 50 percent of the F-16 logistics support cost. The proposed contract provisions would permit the government to select any or all of the 12 LRUs for the RIW option. The government could also select an RIW with an MTBF guarantee. A firm fixed-price option was obtained from the contractor for these options.

During 1976, the 12 control LRUs were subjected to cost analysis, and the RIW option was extended to the aircraft planned to be procured by the European Participating Governments (EPG). The contract was subsequently signed with GD in 1977 for RIW coverage of nine LRUs for all five EPG nations participating in the Multinational Fighter Program. In addition, two of the LRUs, the radar transmitter and the HUD Processor, were to have MTBF guarantees. The following table presents the list of equipment selected for the RIW program. Note that all five radar LRUs were selected for RIW coverage with one LRU (radar transmitter) requiring an MTBF guarantee.

EQUIPMENT SELECTED FOR THE F-16 RIW PROGRAM

WUC	NOMENCLATURE	MANUFACTURER
14AA0	FLIGHT CONTROL COMPUTER	LEAR-SIEGLER INDUSTRIES
74BC0	HEAD-UP DISPLAY (HUD) PROCESSOR*	MARCONI AVIONICS, LTD.
74BA0	HEAD-UP DISPLAY (HUD) PILOT DISPLAY	MARCONI AVIONICS, LTC.
74DA0	INERTIAL NAVIGATION UNIT (INU)	SINGER-KEARFOTT DIVISION
74AC0	RADAR TRANSMITTER*	WESTINGHOUSE ELECTRIC
74AD0	RADAR SIGNAL PROCESSOR	WESTINGHOUSE ELECTRIC
74AF0	RADAR COMPUTER	WESTINGHOUSE ELECTRIC
74AB0	RADAR RECEIVER	WESTINGHOUSE ELECTRIC
74AA0	RADAR ANTENNA	WESTINGHOUSE ELECTRIC

THE WARRANTY APPLIES TO ALL UNITS INSTALLED IN THE FIRST 250 USAF AND THE FIRST 192 EPG PRODUCTION AIRCRAFT AND TO SPARES PROCURED FOR SUPPORT OF THESE AIRCRAFT.

---

*RIW WITH MTBF GUARANTEE.

RIW FEATURES

The nine LRUs were warranted for a period of four years or a total of 300,000 aircraft flying hours, whichever occurred first. The four-year period began with the delivery of the first production aircraft in January 1979. In case less than 250,000 hours of flying had been accumulated at the end of the four-year period, the price of the contract was to have been adjusted downward in accordance with a formula specified in the contract. The table opposite shows the major features of the RIW contract.

MAJOR FEATURES OF THE F-16 RIW CONTRACT

Characteristic	Description
Units covered	Nine different LRUs (5 radar)
Aircraft	250 USAF and 192 European F-16As and F-16Bs
Coverage period	Four years or 300,000 flying hours (whichever occurs first)
Contract time	Prior to full-scale production
Air Force Logistics Manager	Ogden Air Logistics Command (ALC)
Participating countries	United States, Belgium, Denmark, Norway, and The Netherlands
Contractor	General Dynamics (prime) with four subcontractors
Price	Range from 2% to 6% per year of LRU cost
MTBF guarantee	Radar Transmitter and HUD Processor must demonstrate 318 and 500 hours, respectively, by the end of the warranty
Contract price adjustment for flight hours shortfall	Applicable if flying hours are less than 250,000 in 4 years
Turnaround-time requirement	22-days average (Depot)
Fault isolation at base	Yes

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SOURCE SELECTION

Reliability and maintainability were key factors in the RFP, which specified a supportable radar system with the following supportability characteristics: accessibility, ST/BIT, I-level testability/repairability, etc. Considerations included lower ownership costs of the radar by reducing downtime and by requiring fewer maintenance resources.

In source selection and evaluation over a 3-month period, reliability engineering provided four full-time members: two for reliability problems, one for RIW, one for parts control and standardization. In addition, life-cycle cost and thermal design engineering provided at least one member. Maintainability engineering provided two members. Contractor inquiries and modification requests were sent to applicable functional engineering groups for additional information for evaluation. These members were also part of the team at negotiations with each competing vendor and required a meeting from each competitor relative to the design and testing of TWTs, as well as the requirement for random vibration. Here again, requirements were reaffirmed and failures defined. Reliability was a key factor in all computations of life-cycle costs.

SOURCE SELECTION

- R&M KEY FACTORS IN RFP
- COMPETITION FORCED ACCEPTANCE OF STRINGENT REQUIREMENTS
- CONTRACTOR PERCEIVED R&M A KEY FACTOR
- REQUIRED RIW/MTBF GUARANTEE COMMITMENT
- R&M EVALUATED ON AN EQUIVALENT BASIS WITH OTHER TECHNICAL FACTORS
- R&M PRIMARY MEMBERS OF SELECTION COMMITTEE

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LIFE-CYCLE COST

Reliability and maintainability are driving forces in life-cycle cost. A major concern in the APG-66 radar development program, relative to LCC, was the TWT. Problems identified on earlier radar programs led to this concern. As a result, separate tests for the TWT were required in addition to the design requirements for simplicity, ease of maintenance and reliability. Data submitted by WEC in response to the RFP were analyzed by General Dynamics and the Air Force using cost models specifically designed to measure LCC.

LIFE-CYCLE COST -- AN IMPORTANT CONSIDERATION

- DRIVING FORCE
  - RIW/TLSC COD OPTION
  - CONTRACTUAL RADAR R&M REQUIREMENTS
- SPECIFIC REQUIREMENTS FOR ANALYSIS
- SERVED AS BASIS FOR COST INCENTIVES/DESIGN TO COST
- INFLUENCED DESIGN TO OPTIMIZE R&M

MANAGEMENT

MANAGEMENT

Management is the second of the five areas identified as important to producing high quality military equipment. The three major facets of management shown are discussed in the pages following.

MANAGEMENT

- ORGANIZATION
- CONTROL & EMPHASIS
- SUBCONTRACTORS/SUPPLIERS

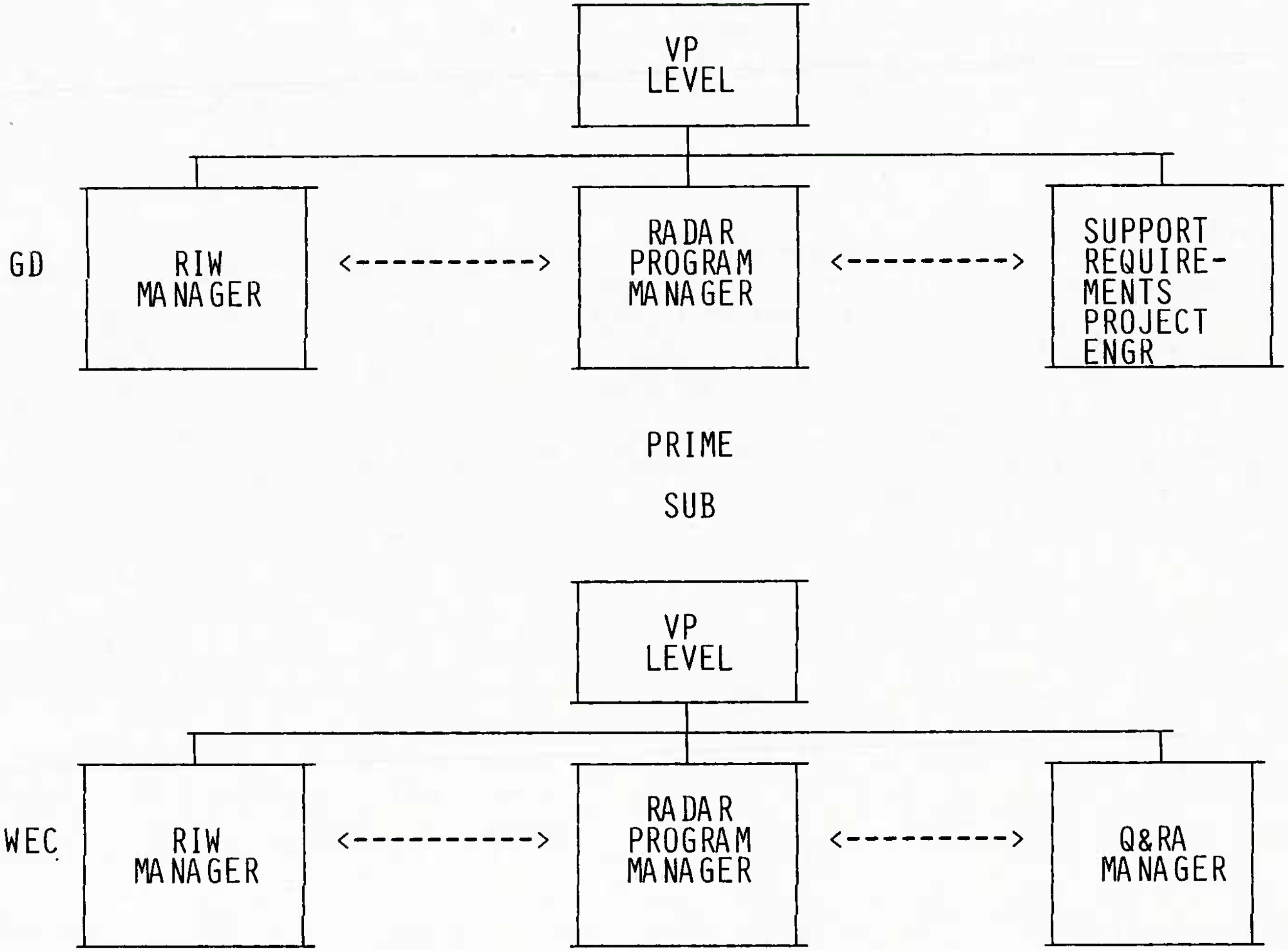
41/18

MANAGEMENT

Management commitment to and involvement in reliability and maintainability objectives set the stage for success early in the program. A management level organization was structured with Support Requirements/Q&RA Managers and RIW Managers reporting to Vice Presidents at General Dynamics and Westinghouse while working directly with their respective Radar Program managers.

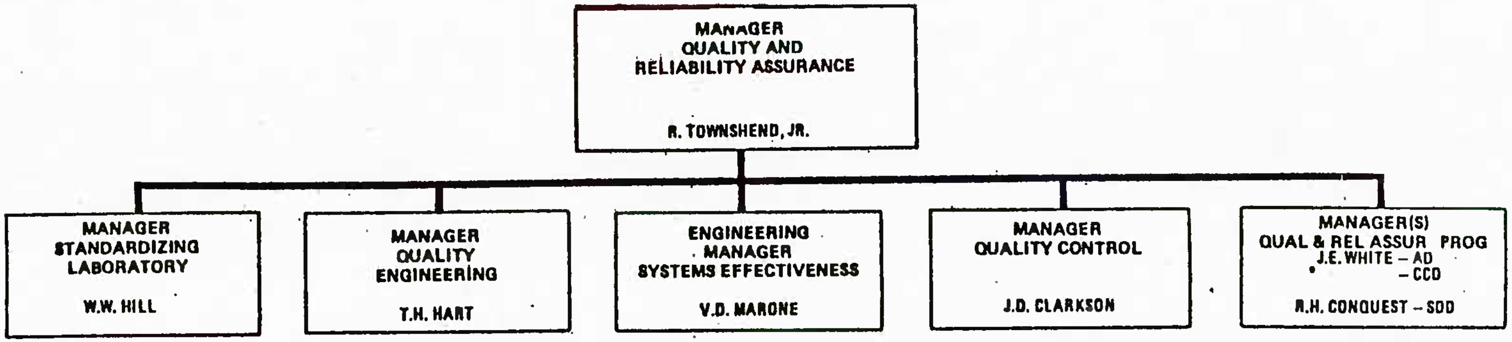
The reliability and maintainability management functions provided visibility and timely information for management control. Aggressive and informed management emphasis assured effective integration of reliability and maintainability considerations into the total program.

EFFECTIVE MANAGEMENT LEVEL ORGANIZATION



Q&RA ORGANIZATION

This chart shows the quality and reliability assurance organization at WEC. The depth of the organization and how it is tied into the system program manager at the appropriate level is reflected.



MANAGER
QUALITY AND
RELIABILITY ASSURANCE

R. TOWNSHEND, JR.

MANAGER
STANDARDIZING
LABORATORY

W.W. HILL

Calibration System Policy & Direction
Precision Measurements Standards
Calibration Traceability
Calibration Services
Customer Interface
Measurement Development
Measurement Consultation
NBS Liaison

MANAGER
QUALITY
ENGINEERING

T.H. HART

Q&RA Program Manual
Quality Policy
Quality Program Plans
Quality Procedures & Directives
Quality Specification Interpretation
  & Implementation
Quality Training
Quality Records
Govt. Rep. Liaison
Workmanship Standards
Quality Performance Data & Visibility
SEAP Engineering
Technology Development
Industry Associations
Special Activities
Failure Analysis
Quality Assurance Engineering
Quality & Process Control R&D
Systems & Procedures Audit
Quality Audits
Electrical Performance
  Evaluation Engineering
MRB Disposition & Corrective Action
Technology Area Engineering
Program Quality Engineering

ENGINEERING
MANAGER
SYSTEMS EFFECTIVENESS

V.D. MARONE

Reliability & Maintainability
- Engineering
- Requirements
- Program Plans
- Prediction

Reliability Test Procedures
Parts Selection
Maintainability Demonstration
  Plans/Procedures
Safety Standards
Safety Requirements
Hazard Identification
Mission Maintenance Requirements
Stress Analysis
Design Review
Design Monitoring
Specification Review
Subcontractor Review
Built-In Test
- Requirements
- Fault Detection Predictions
- Fault Isolation Predictions
- System Interrogation
- Software Configuration

Product Qualification
POL Facilities Planning &
  Maintainability
Environmental Evaluation Testing
Environmental Test Procedures
Environmental Tooling
Environmental Sample Testing
Test Analysis & Reports
Design & Failure Reviews
Failure Analysis & Reporting
Quality Data Center
ATL Quality Assurance
- Incoming Inspection & Test
- Feeder Inspection
- Assembly Inspection
- Quality Control Evaluation & Audit
- Quality Control Procedures
- Manpower Analysis
- Facilities and Technology
- Quality Standards
- Training
- Gage Control

MANAGER
QUALITY CONTROL

J.D. CLARKSON

Procurement Quality Engineering
Supplier Evaluation & Qualif.
Source Inspection
Incoming Inspection & Test
Feeder Inspection
Gage Lab
Engineering MDL Inspection
MRB Coordination & Records
Inspection Methods
Assembly Inspection
Configuration Verification
Customer Sell-Off
Shipping Inspection
SEAP Inspection & Test
Quality Data Reporting

MANAGER(S)
QUAL & REL ASSUR PROG
J.E. WHITE – AD
– CCD

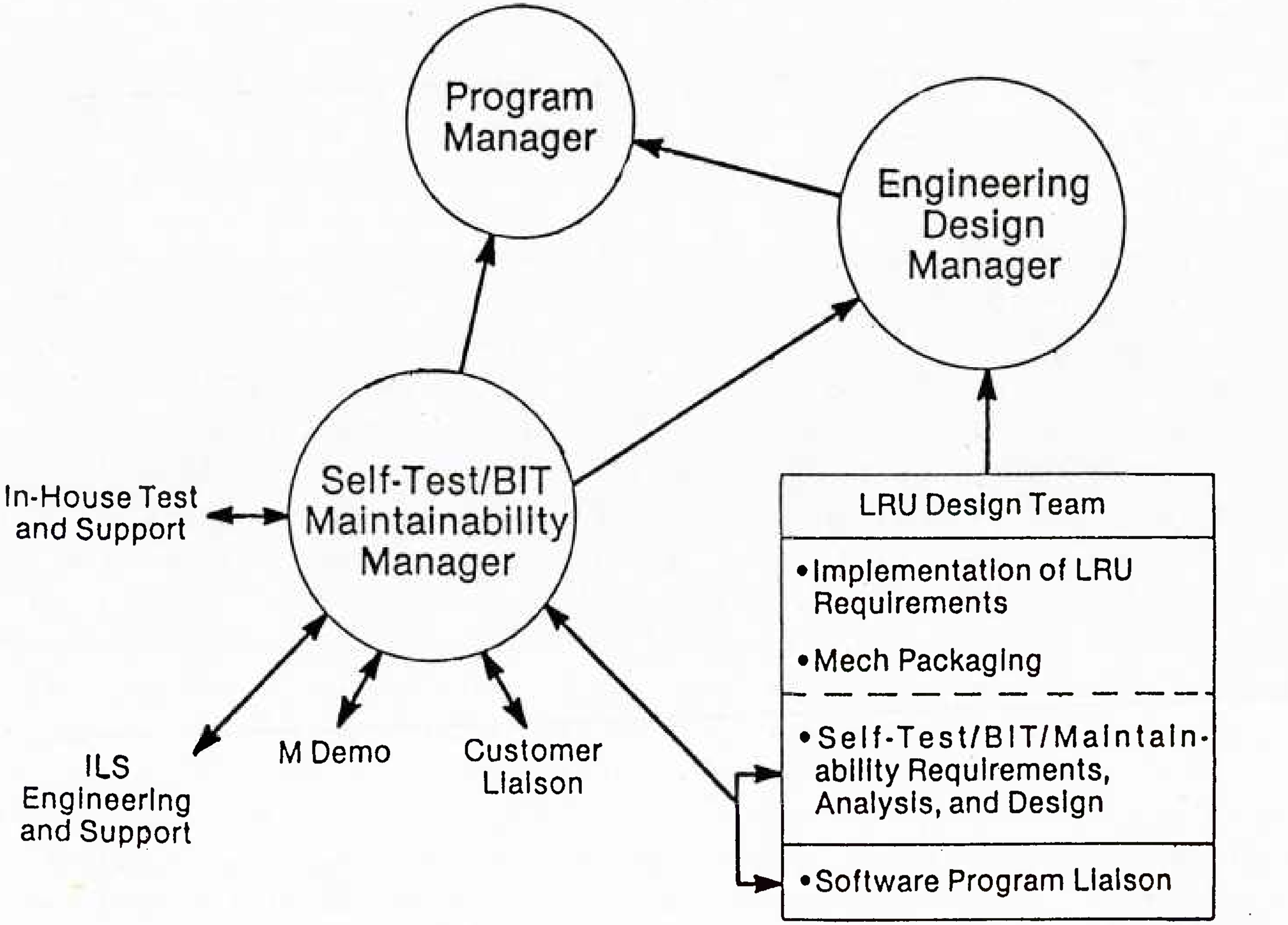
R.H. CONQUEST – SOD

Develop & Define Q&RA Program
  Requirements
Q&RA Program Technical and
  Management Proposal Inputs
Q&RA Program Cost Estimate Review
Q&RA Pre-Contract Negotiations with
  Customer
Q&RA Program Cost and Schedule
  Control and Visibility
Q&RA Program Assignment of Q&RA
  Functional Selections Task
Direct and Manage Q&RA Resources
  to Fulfill Contract Requirements
*Quality Control West Bldg
    Feeder Inspection
    Gage Lab
    Engineering MDL Inspection
    MRB Coordination & Records
    Inspection Methods
    Assembly Inspection
    Configuration Verification
    Customer Sell-Off
    Shipping Inspection
    Quality Data Reporting

ST/BIT ORGANIZATION

The ST/BIT/Maintainability organization for the APG-66 radar was an integral part of the design team as depicted in the chart. A BIT/Maintainability engineer was assigned to each LRU project engineer to assure that the maintainability requirements were met. The ST/BIT/Maintainability manager was responsible not only to the engineering design manager but also to the program manager for support functions not directly related to design, per se.

ST/BIT/M Organizational Interface



Program Manager

Engineering Design Manager

Self-Test/BIT Maintainability Manager

In-House Test and Support

ILS Engineering and Support

M Demo

Customer Liaison

LRU Design Team

- Implementation of LRU Requirements
- Mech Packaging

- Self-Test/BIT/Maintainability Requirements, Analysis, and Design
- Software Program Liaison

RBP 12/31/80

The Q&RA organization has direct access to the Operations Manager in the Systems Technology Division at Westinghouse. The Operations Manager reports directly to the General Manager of the Systems Technology Division. Q&RA activities are the direct responsibility of the APG-66 Program Q&RA Manager who reports directly to the APG-66 Program Manager. Key personnel serving as coordinators/directors are assigned to the program by the APG-66 Q&RA Manager to whom they report for the duration of the program. The Q&RA Manager maintains quality and reliability control over all functions pertaining to the APG-66 fire control radar from initial quality planning to shipment to the customer. All work affecting quality is controlled through work instructions published in the functional manuals. Purchasing, handling, machining, assembling, fabricating, processing, testing, modification, installation and any other treatment of product or facilities, from the ordering of materials to the dispatch of shipments, is under continuous quality control.

Quality assurance records are maintained to show that inspections and tests were performed, to provide information, and to provide management with tools needed to determine that the program is under control. Some of the more important records include:

1. <u>Assembly/Inspection Control Tags</u>. Used for all serialized units. Verifies that assembly and test operations have been completed. Discrepancies are documented and must be cleared before hardware is approved. Also indicates and verifies that approved mods have been incorporated. Provides configuration control for the end product.
2. <u>PROMPT Receiver Cards</u>. PROMPT I is a mechanized data collection and information reporting system for material control and manufacturing information. It assists in following purchased material status from initiation of purchase order to material disposition.

PLANNING CONTROL AND EMPHASIS (Continued)

3. Test Data. Test data and inspection measurements are entered on appropriate data sheets developed exclusively for a particular operation or test level.
4. Material Rejection Notices (MRN). Rejects procured material when it is unacceptable toi ncoming inspection or when it is rejected at higher level for reasons of vendor fault not originally detected at incoming inspection. This record is submitted to an MRN panel for disposition. Full records are maintained.
5. Material Review Board (MRB) Forms. Documents details of rejection, corrective action and disposition of non-conforming material that cannot be adequately reworked. MRB decides how to process such material.
6. Rejection/Failure Documentation. Non-conforming and Defective Material Reports are used to document defects found after acceptance by incoming inspection. Defect causes are determined and documented. System is used as a basis for reordering parts, initiating repairs and recognizing trends that would trigger corrective action.
7. Failure Analysis Reports (FAR). Delineates details of failure mechanisms and establishes fault where possible. Trend analysis and records are maintained by the laboratory.
8. Audit and Corrective Action Reports. Contractor Management System Evaluation Program (CMSEP) audits are used to determine adequacy and compliance of each requirement. Audits are randomly scheduled by Quality Systems Evaluation Engineering and are conducted unannounced. Unsatisfactory conditions thus found are discussed with the responsible supervisor and a commitment is obtained for corrective action. Each unsatisfactory condition is reaudited within 10 workdays to ensure that corrective action has been implemented and is appropriate for long-range correction.

If reaudit shows unsatisfactory condition, next higher level of management is notified to obtain the needed action.

9. Letters of Complaint. Details nature of a discrepancy and provides supporting data. May require a formal reply as to the vendor's corrective action.
10. Submittal Records. Material submittal records, final system test logs, and Assembly/Inspection Control Tags will be maintained at the LRU and system levels.
11. Other Records. Physical Configuration Audit, calibration, training, certifications of personnel and processes, inspection and test stamp control.

Other procedures are set up to provide for maintaining control of the release of drawings and changes and to control configurations. All assemblies have serial numbers applied before inspection, and inspection control tags of all subassemblies are kept together with the higher assembly's control tags. Control tags are kept for a period of at least three years past the end of the contract.

Test equipment configuration is maintained by the Integrated Logistics Support (ILS) group. Changes by Engineering are incorporated in the test tools. Initial certification and compliance/compatibility checkouts of Engineering changes will be performed by a cognizant Product Evaluation Test Engineer.

Other features of the Westinghouse plans for quality control include controls over drawings, serialization controls, test equipment configuration controls, controls over measuring and test equipment, control over purchases, and evaluation of supplier performance, source inspection, incoming inspection, certification of critical processes and personnel, in-process documentation, various stages of inspections, control of registered components, control of inspector's stamps, material review procedures, etc.

PLANNING CONTROL AND EMPHASIS

ACCESS TO OPERATIONS MANAGER

CHAIN OF RESPONSIBILITY

WORK INSTRUCTION MANUALS

QUALITY ASSURANCE RECORDS:

- ASSEMBLY/INSPECTION CONTROL TAGS
- PROMPT RECEIVER CARDS
- TEST DATA
- MATERIAL REJECTION NOTICES
- MATERIAL REVIEW BOARD FORMS
- REJECTION/FAILURE DOCUMENTATION
- FAILURE ANALYSIS REPORTS
- AUDIT AND CORRECTIVE ACTION REPORTS
- LETTERS OF COMPLAINT
- SUBMITTAL RECORDS
- OTHER RECORDS

TEST EQUIPMENT CONFIGURATION

VARIOUS CONTROL PROCEDURES

40A/4

MANAGEMENT EMPHASIS ASSURED INTEGRATION OF R&M

To assure integration of reliability/maintainability into the design process, each discipline was required to sign-off all appropriate engineering drawings. Reliability and Maintainability engineers were also members of the configuration control board, failure review board and special corrective action teams to assure that design changes had no adverse impact on reliability and maintainability parameters and that appropriate corrective action was incorporated for identified problem areas.

MANAGEMENT EMPHASIS ASSURED INTEGRATION OF R&M

- R&M DRAWING SIGN-OFF
- R&M REPS ON CHANGE BOARD
- FAILURE REVIEW BOARD
- SPECIAL CORRECTIVE ACTION
- EXECUTIVE MANAGEMENT

PRIME SUB TEAM

During the course of this program confrontational negotiations were avoided. The notion of team effort was strongly supported at all levels and actions were taken to make this highly effective action work. For example, Westinghouse, in developing a set of suppliers, undertook to provide assistance to small business to ensure that their products were up to the quality level that was needed. To do this they provided motivational meetings at which F-16 films were shown to the suppliers' employees, and award dinners were given when goals were met.

On a rare occasion a part supplier was unable or unwilling to make sufficient effort to provide the quality part that was needed. In such cases, after working with the supplier to no avail, they were disqualified.

PRIME, SUB AND SUPPLIER WORKED AS A TEAM

- REQUIREMENTS TAILORED
  - TWT -- HIGHLY RELIABLE, 3 TIMES BETTER THAN PREDICTED BASED ON MIL HANDBOOK 217
- ASSISTANCE -- SMALL BUSINESSES
  - MULTIPLIER -- LOW POWER RF LRU
- MOTIVATED SUPPLIERS
  - SELECTIVELY
- INTERNAL DESIGN ACTIVITY FOCUSED TOWARD SUBCONTRACTOR AND SUPPLIERS
  - TWT
  - MULTIPLIERS
- IF ALL ELSE FAILS, SUPPLIER DISQUALIFIED
  - PHP

SPECIAL EMPHASIS FOR TWT

The TWT development program is an example of special emphasis management placed on system reliability.

During the competition it became evident that the TWT was a high-risk item and a life-cycle cost driver. The Air Force and GD jointly devised a reliability test for the TWT and included this test as a requirement in the RFP.

Westinghouse also imposed a reliability growth test on its subcontractors for TWTs.

As a result of these tests and the subsequent performance of the TWT in field use, the next generation TWTs for the improved APG-66 has a similar reliability program specified.

SPECIAL RELIABILITY EMPHASIS ON TWT

- AIR COOLED 16 KW PEAK POWER TWT INITIALLY CONSIDERED HIGH RISK COMPONENT

- SPECIAL RELIABILITY TESTING IMPOSED BY RADAR CONTRACT TO REDUCE RISK
  - ✓ 3000 HOURS TESTING ON 3 TUBES
  - ✓ ONLY ONE FAILURE ALLOWED
  - ✓ IF TEST FAILED, TUBE WAS TO BE IMPROVED AND TEST RERUN UNTIL TUBES PASSED TEST
  - ✓ 3 SOURCES QUALIFIED

- THE RESULT WAS EXCELLENT
  - ✓ CURRENT FIELD EXPERIENCE ON TWT DURING 45,000 FLIGHT HOURS SHOWS
    - 1600 HOURS MEAN FLIGHT TIME BETWEEN FAILURE (≈2250 HOURS MTBF)
  - ✓ PREDICTED MTBF BASED ON MIL-HDBK-217 IS 500 HOURS

SPECIAL RELIABILITY EMPHASIS RESULTED IN
FIELD PERFORMANCE OVER FOUR TIMES HIGHER
THAN THE PREDICTED TWT MTBF

41/26-1

DESIGN

DESIGN FACTORS

System design is the fundamental element in achieving a supportable system. Key factors in the system design are listed on the facing page and described in subsequent charts.

DESIGN FACTORS

- REQUIREMENTS
- ALTERNATIVE STUDIES
- DESIGN ANALYSES
- PARTS AND MATERIAL SELECTION AND CONTROL
- DERATING CRITERIA
- THERMAL AND PACKAGING CRITERIA
- ST/BIT MECHANIZATION AND GROWTH
- FEATURES TO FACILITATE MAINTENANCE

41/21

DESIGN REQUIREMENTS

The APG-66 design requirement was developed cooperatively by both the Air Force and General Dynamics considering experience on previous programs, the state of technology at that time and the complexity involved. Requirements were determined to be compatible with both mission and support needs and these were documented in the contractual statements which were then given to GD and WEC.

Flexibility was considered a key parameter in the multi-level specification requirements of a CFE development. The top specification which defines the weapon system performance was supported by lower-level subsystem requirements. In the case of the APG-66 FCR, the 16ZE009 GD document contained a detailed level of performance requirements. The avionic system specification necessary to effect weapon delivery accuracy is the next higher level document. The flexibility existed wherein a difficult radar requirement could be analyzed singly and in conjunction with avionics requirements. This flexibility made it possible to modify the radar requirement and still not affect weapon delivery or to modify the avionics mechanization without adversely affecting the radar. The system was designed from the top down, thereby avoiding unrealistic subsystem requirements that have little or no weapon delivery system effects.

Reliability Demonstration requirements were established and enforced using specific accept/reject criteria. For example, the FSD RQT failed once and corrective action was implemented before the test was restarted. As another example, the production reliability qualification test and the reliability acceptance tests both failed twice before they were successfully completed. In each case, a corrective action plan was submitted and approved before a restart was allowed. This was in fact the case because the contract had firm requirements vice goals. It should be noted that even for the successful tests, corrective actions were taken and documented as part of the final report.

REQUIREMENTS BASED ON EXPERIENCE AND NEEDS

- DEVELOPED BY AIR FORCE AND GENERAL DYNAMICS
    - BASED ON EXPERIENCE ON PREVIOUS PROGRAMS CONSIDERING TECHNOLOGY AND COMPLEXITY DIFFERENCES
    - COMPATIBLE WITH MISSION AND SUPPORT REQUIREMENTS
    - DOCUMENTED IN CONTRACT SPECIFICATIONS (009) AND SOW
- SPECIFIED AS FIRM CONTRACTUAL REQUIREMENTS TO GD AND WEC (AIR VEHICLE SPEC & 009)
- SYSTEM CONTRACTUAL REQUIREMENTS TRANSLATED INTO DESIGN REQUIREMENTS BY RELIABILITY & MAINTAINABILITY DIRECTIVES (WEC)
    - SUBSYSTEM REQUIREMENTS
    - GUIDELINES
    - CHECKLISTS

DESIGN ALTERNATIVE STUDIES

The design process for the APG-66 provided for design alternative studies. One set of design alternative studies specifically set objectives for improved R&M. In many cases decisions were made in favor of R&M over performance such as the use of copper heat sinks in some applications on the DSP rather than aluminum. This action resulted in increased weight and cost but increased reliability and subsequently improved life-cycle costs. In addition, the use of wedgelocks on every board rather than alternate boards increased cost and weight but was accepted because it enhanced maintainability. A second set, although undertaken primarily for design-to-cost and weight reduction, provided many fallout benefits to R&M. These benefits were achieved by including R&M in all design tradeoffs.

R&M IMPROVED BY DESIGN ALTERNATIVE STUDIES

- DESIGN ALTERNATIVE STUDIES SPECIFICALLY FOR R&M ENHANCEMENT
  - MANY DESIGN TRADE-OFFS MADE FOR R&M AT EXPENSE OF WEIGHT AND COST

- DESIGN ALTERNATIVE STUDIES WITH R&M BENEFITS
  - R&M AN INTEGRAL PART OF DESIGN TRADE-OFFS IN EARLY DESIGN-TO-COST AND WEIGHT REDUCTION STUDIES

STUDIES TO ENHANCE R&M

The next two charts list seven design alternative studies whose purpose was to improve the R&M of the APG-66 radar. Note that some of these studies involved an improvement to the design of a previous system's component to scale it down for use in the APG-66. Typically, in such an improvement the number of parts involved was reduced, thereby increasing the potential MTBF. Sometimes, however, as in the case of relocating a heat exchanger, the primary purpose was to obtain better cooling and therefore lower temperatures in the component involved.

DESIGN ALTERNATIVE STUDIES AIMED AT ENHANCING R&M

DESCRIPTION	PURPOSES	RELIABILITY IMPACT	MAINTAINABILITY IMPACT
INVERTER DESIGN IMPROVEMENT FROM SCALED-DOWN AWACS DESIGN	• REDUCE PARTS COUNT • REDUCE WEIGHT	PARTS COUNT REDUCED FROM 350 - 230	
A/D CONVERTER DESIGN IMPROVEMENT FROM SCALED-DOWN AWACS DESIGN TO NEW DESIGN	• REDUCE PARTS COUNT • REDUCE WEIGHT	PARTS COUNT REDUCED FROM 482 - 112	
COMPARE LIQUID & AIR-COOLED TWT DESIGNS	• IMPROVE R&M • REDUCE WEIGHT	ELIMINATES LIQUID COOLING SYSTEM COMPONENTS AND THEIR MAINTENANCE PROBLEMS (REDUCE RADAR WEIGHT 8.5 POUNDS)	
UPGRADE QUALITY LEVEL OF 7 MEDs USED EXTENSIVELY IN SYSTEM	• IMPROVE SYSTEM RELIABILITY	APG-66 MTBF IMPROVED BY 4 TO 33%	

DESIGN ALTERNATIVE STUDIES AIMED AT ENHANCING R&M (CONTINUED)

DESCRIPTION	PURPOSES	RELIABILITY IMPACT	MAINTAINABILITY IMPACT
REPLACE HEAT EXCHANGER ON BOTTOM OF POWER SUPPLY WITH VERTICAL EXCHANGER FROM BACK TO FRONT THROUGH CENTER OF UNIT	• BETTER HEAT SINK ARRANGEMENT • SIMPLIFY MANUF. • REDUCE LCC	REDUCE TEMPERATURES	SIGNIFICANT - EASIER "I" LEVEL ACCESSIBILITY TO SRUs
COMPARE DISTRIBUTED POWER SUPPLY WITH CENTRAL POWER SUPPLY FOR ALL RADAR LRUs	• DETERMINE IMPACT ON PARTS COUNT & MAINTAINABILITY	DISTRIBUTED POWER SUPPLY REDUCES PARTS COUNT BY >200	FAULT ISOLATION SIMPLIFIED BECAUSE LOAD VS. POWER SUPPLY DETERMINATION IS NOT REQUIRED SINCE BOTH ARE CONTAINED IN THE SAME SRU
STRUCTURE DSP CORNER TURN MEMORY FOR GROUND MAPPING MODES	• SAVE WEIGHT, COST, COMPLEXITY	MTBF OF DSP INCREASED BY 15 HOURS BY ELIMINATING NEED FOR SEPARATE MEMORY	REDUCED REQUIRED NUMBER OF BIT TESTS TO VERIFY SATISFACTORY PERFORMANCE

ALTERNATIVE STUDIES WITH R&M BENEFITS

The second set of design alternative studies shows five studies that were intended to result in reduced costs or reduced weight and which, in addition, produced better R&M characteristics.

DESIGN ALTERNATIVE STUDIES WITH R&M BENEFITS

DESCRIPTION	PURPOSES	RELIABILITY IMPACT	MAINTAINABILITY IMPACT
SHOULD UNIPHASORS BE FURNISHED IN MATCHED SETS OF 4?	• ELIMINATE COMPLEX MATCHING NETWORKS • REDUCE ACQUISITION COSTS	FAILURE RATE REDUCED 88%	ELIMINATES HARMONIZATION REQUIREMENTS
SHOULD PARAMETRIC AMPs BE REPLACED WITH FETs?	• REDUCE RECURRING SYSTEM COSTS • REDUCE WEIGHT	FAILURE RATE REDUCED 66% 13% INCREASE IN LRU MTBF	SIGNIFICANT IMPROVEMENT
SHOULD THE SEPARATE VCO AND BEACON LO OPERATING IN SAME FREQUENCY RANGE BE COMBINED IN ONE PACKAGE?	• REDUCE COST • REDUCE WEIGHT	FAILURE RATE REDUCED 16%	REDUCE "I" LEVEL FAULT ISOLATION AMBIGUITY
SHOULD A 4K BIT RAM BE SUBSTITUTED FOR EXISTING 1K BIT RAMS IN DSP CT & SC/ MEMORY BOARD	• REDUCE SRUs FROM 4 TO 2 • REDUCE COST • REDUCE WEIGHT	FAILURE RATE REDUCED 18% LRU MTBF INCREASED 5%	IMPROVED
ASSESS BENEFITS OF SINGLE CHANNEL RECEIVE & PROCESSOR	• REDUCE COSTS • REDUCE WEIGHT	INCREASED INHERENT MTBF BY 54 HOURS	

DESIGN ANALYSES

Proven reliability and maintainability design analyses were performed early in the design phase and updated as the design progressed to:

- Assure achievement of reliability and maintainability requirements
- Maintain current estimates of radar reliability and maintainability characteristics
- Evaluate impact of changes on reliability and maintainability
- Provide reliability and maintainability inputs for use in design trades, life-cycle cost, and sparing analyses

A list of analyses performed is provided on the facing page.

DESIGN ANALYSES

RELIABILITY

- RELIABILITY PREDICTIONS
- APPORTIONMENTS
- THERMAL ANALYSIS
- ELECTRICAL/MECHANICAL STRESS ANALYSIS
- FAILURE MODES AND EFFECTS ANALYSIS

MAINTAINABILITY

- QUANTITATIVE MAINTAINABILITY ANALYSIS
- MAINTAINABILITY PREDICTIONS
- OPTIMUM REPAIR LEVEL ANALYSIS
- ST/BIT EFFECTIVENESS ANALYSIS
- TEST TOLERANCE ANALYSIS

PARTS PROGRAM TO IMPROVE RELIABILITY AND MAINTAINABILITY

Aggressive Parts Control and Standardization--Parts requirements imposed on all new designs by specific requirements in the equipment specifications and by statements of work. All subcontractor and in-house parts selections reviewed for military standard part. Full government support provided to develop new military standards for multiple use parts.

Achieved State-of-the-Art Design and Commonality--The F-16 Parts Control Board maintained contact with Rome Air Development Center (RADC) for state-of-the-art device recommendations. Commonality was achieved by selecting, based on RADC recommendations, the preferred state-of-the-art device such as the microprocessor for all equipments to use.

Enhanced Manufacturing Producibility and Field Repairability--Enhanced manufacturing producibility and field repairability by requiring maximum use of military standard parts and standard packaging such as dual-in-line microcircuits.

Required Support Equipment and Trainers to Utilize Sames Parts as Aircraft--All new and peculiar designs are required to select parts from the F-16 Program Parts Selection List the same as the aircraft.

Program Adopted as Model for Future Programs--The F-16 program proved that Parts Control and Standardization is cost effective for aircraft, support equipment and trainers. The F-16 program also developed several innovative approaches such as a formal Part Substitution Board and the use of DESC drawings. Military specifications are being revised to incorporate F-16 techniques.

PARTS PROGRAM TO IMPROVE RELIABILITY AND MAINTAINABILITY

- AGGRESSIVE PARTS CONTROL AND STANDARDIZATION
- ACHIEVED STATE-OF-THE-ART DESIGN AND COMMONALITY
- ENHANCED MANUFACTURING PRODUCIBILITY AND FIELD REPAIRABILITY
- REQUIRED SUPPORT EQUIPMENT AND TRAINERS TO UTILIZE SAME PARTS AS AIRCRAFT
- PROGRAM ADOPTED AS MODEL FOR FUTURE PROGRAMS

AGGRESSIVE PARTS CONTROL AND STANDARDIZATION PROGRAM

Use of high failure rate electromechanical parts was limited for all F-16 avionics. For the radar this resulted in use of only six potentiometers, two relays and four motors.

Commonality was forced by reducing number of standards available to designers and subcontractors. The F-16 Program Parts Selection List was established after a comprehensive review of military specifications. The number of standards was reduced to only those with established reliability requirements.

Several microcircuit technologies were eliminated from the parts selection list. The F-16 Parts Control Board reviewed the microcircuit industry and established that the low power shottky technology would be the leading technology for the 1980s. The 54H and 54L technologies were eliminated from the PPSL. The dual-in-line microcircuit package was selected over the flat pack.

Fastener types were reduced from 226 to 47 and the fastener recess standardized.

The military standards available for designers to select from were reduced to those with established reliability requirements.

All variations from the selection list required detail justification such as the design parameter necessitating the nonstandard. This justification was reviewed by the prime contractor, the military review agency and finally by the F-16 Parts Control Board.

All part requests were reviewed for multiple usage. If two or more subcontractors used the same part, the review agency recommended that a military standard be developed for the part.

AGGRESSIVE PARTS CONTROL AND STANDARDIZATION PROGRAM

- USE OF HIGH FAILURE RATE ELECTROMECHANICAL PARTS LIMITED IN THE F-16 BY A VERY AGGRESSIVE STANDARDIZATION PROGRAM
- FORCED COMMONALITY BY REDUCING NUMBER OF STANDARDS AVAILABLE TO DESIGNERS AND SUBCONTRACTORS
- ELIMINATED SEVERAL MICROCIRCUIT TECHNOLOGIES FROM SELECTION LIST
- REDUCED TYPES OF FASTENERS FROM SELECTION LIST
- LISTED ONLY ESTABLISHED RELIABILITY MILITARY STANDARDS
- JUSTIFICATION REQUIRED FOR ANY VARIATION FROM SELECTION LIST
- REVIEWED VARIATIONS FOR COMMON USAGE TO BECOME MILITARY STANDARDS
- WORKED WITH DEFENSE ELECTRONICS SUPPLY CENTER TO DEVELOP NEW DESC DRAWINGS TO REPLACE MULTIPLE NONSTANDARD PART DRAWINGS

PARTS PROGRAM

A film describing the F-16 parts program was produced by DLA to describe the program they believed to be a model. The film is available through DESC-EP.

MODEL PARTS PROGRAM

- FILM DOCUMENTATION
    - DLA TO DOD
    - AVAILABLE THROUGH
      DESC-EP

DERATING

The General Dynamics reliability specification for subcontractors of F-16 major electronic/electrical equipment, 16PP137, required derating be implemented by Westinghouse. Each piece part had to be derated consistent with its intended use, specified environment and contribution to equipment unreliability. This information was used for a detailed reliability prediction for the equipment at the piece part level using operating stress and temperature environments. This piece part prediction was used to establish the prediction for each higher level assembly and was kept current with design development. Derating was reviewed at the PDR/CDR and reliability design reviews. Thermal derating was evaluated during thermal verification tests.

DERATING VITAL TO RELIABLE DESIGN

- GD CONTRACT REQUIRED WEC TO FORMULATE DERATING POLICY
- RADAR PROGRAM PLAN ESTABLISHED POLICY
- Q&RA DIRECTIVE IMPLEMENTED POLICY
- REVIEWED DURING PDR/CDR
- VERIFIED BY RELIABILITY DESIGN REVIEW AND STRESS ANALYSIS AS DESIGN PROGRESSED

DERATING CRITERIA

A Westinghouse Q&RA directive dated 6 November 1975 establishes the Parts Derating Policy for the APG-66 radar. This policy states that the purpose of derating is to select a part so that the manufacturer's rating of that part is well in excess of the stress values that the part will actually experience in service in order to decrease part failure rate. The following tables present examples of the kinds of derating criteria that were used.

APG-66 RADAR DERATING POLICY

EXAMPLES FROM Q&RA DIRECTIVE: R-3

MICROCIRCUITS	60%	RATED JUNCTION TEMPERATURE
TRANSISTORS	60%	" " "
DIODES	60%	" " "
RESISTORS		
COMPOSITION	50%	RATED POWER (FOR A GIVEN TEMPERATURE)
WIRE WOUND, ACCURATE	50%	" "
WIRE WOUND, POWER	20%	" "
CAPACITORS		
CERAMIC	60%	RATED VOLTAGE
TANTALUM, SOLID	60%	" "

DERATING FOR COILS, CHOKES AND TRANSFORMERS

	MAXIMUM PERMISSIBLE PERCENTAGE OF MANUFACTURER'S STRESS RATIO		
	VOLTAGE		CURRENT
	MAXIMUM	TRANSIENT	OPERATING
COIL, INDUCTOR SATURABLE REACTOR	60%	90%	60%
COIL-RADIO FREQUENCY FIXED	60%	90%	70%
INDUCTOR GENERAL	60%	90%	70%
TRANSFORMER, AUDIO	60%	90%	70%
TRANSFORMER PULSE, LOW POWER	60%	70%	60%
TRANSFORMER, POWER	60%	90%	70%
TRANSFORMER, RADIO FREQUENCY	60%	90%	60%
TRANSFORMER, SATURABLE CORE	60%	90%	60%

$$\text{STRESS} = \frac{\text{I (APPLIED)}}{\text{I (ALLOWED)}}$$

$$\begin{array}{l}\text{PERCENT} \\ \text{DERATED}\end{array} = (1-\text{STRESS}) \times 100$$

THERMAL ANALYSIS AND VERIFICATION

Thermal analysis and verification was an important aspect of the APG-66 design. The process is illustrated on the facing page.

The Air Force and GD established a practical limit of 140°F exit air temperature for the F-16. Forced-air-cooled electronic equipment was provided cooling air from the environmental control system to achieve the desired exit air temperature. This reduced exit air temperature by approximately 20°F relative to earlier GD aircraft. To further enhance reliability, the higher-powered components were placed nearest the edge or coolest part of the SRU where possible and copper heat sinks were used in several locations rather than aluminum since they conduct heat to the cooling plate much better than aluminum. After these design features were incorporated, thermal verification tests were conducted to assure that the analyses were valid.

Two test conditions were established for laboratory thermal verification. These conditions were:

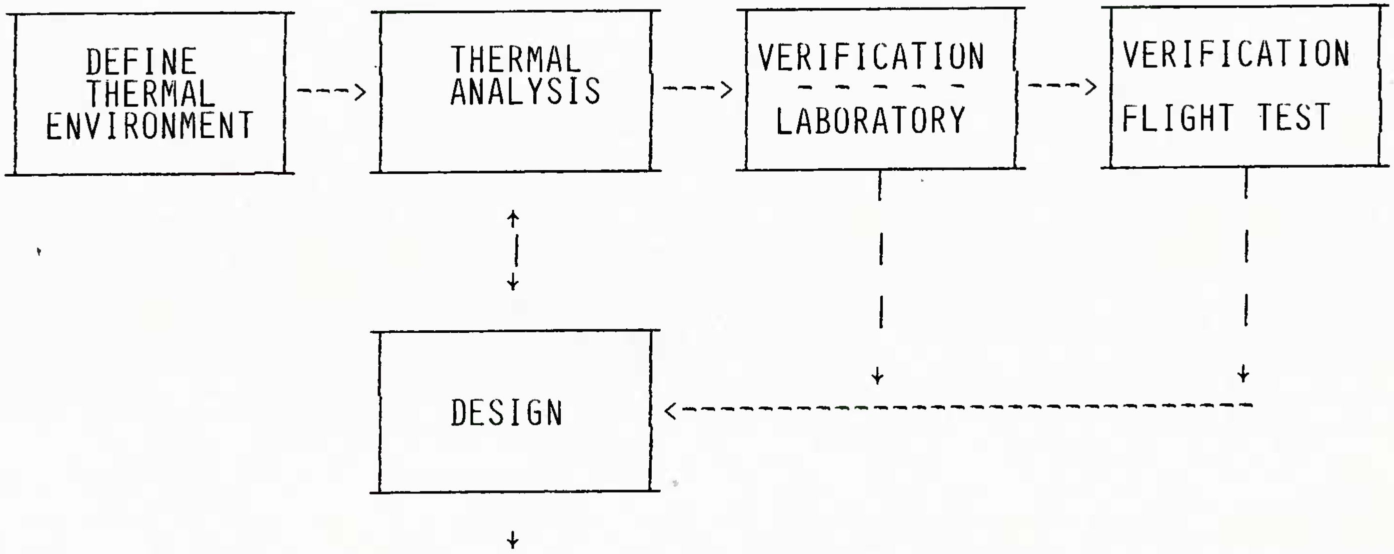
- Radar at maximum heat dissipating mode
- Test conditions

	TEST A	TEST B
Surrounding air	25° ± 2°C	55° ± 2°C
Cooling air		
Temperature	2° ± 2°	40° ± 2°C
Flow rate	7 lb/min	19 lb/min

Corrective action was taken if any measurement varied more than ±5°C from predicted thermal analysis values.

A confirmation of key laboratory thermal values was obtained during flight tests.

THERMAL ANALYSES AND VERIFICATION CRITICAL TO IMPROVED RELIABILITY



DEFINE THERMAL ENVIRONMENT

THERMAL ANALYSIS

VERIFICATION - LABORATORY

VERIFICATION FLIGHT TEST

DESIGN

DESIGN RESULTS

- ✓ RELOCATION OF PARTS
- ✓ RELOCATION OF CIRCUIT BOARDS
- ✓ CHOICE OF HEAT SINK MATERIALS
- ✓ APPORTIONMENT OF COOLING AIR BETWEEN LRUs

SELF TEST/BUILT-IN TEST

The F-16 avionic system incorporates a comprehensive fault detection and isolation capability in support of the standard three level maintenance concept. During the mission, continuous non-interruptive self testing is utilized to alert the pilot to malfunctions. After the flight, maintenance personnel can utilize operator initiated built-in-tests (BIT) for confidence checks and to supplement the self-test fault isolation. These two types of test (self tests and BIT) provide both the capability to inform the pilot of any faults that may require his attention or limit his mission and also provide maintenance personnel with a detailed history and description of avionics failures.

SELF-TEST/BUILT-IN TEST
TERMINOLOGY AND MODES OF OPERATION

- SELF-TEST IS A CONTINUOUS NONINTERRUPTIVE FAULT DETECTION FUNCTION THAT IS MODE ORIENTED
  - CPM: CONTINUOUS PERFORMANCE MONITOR
  - NI: NONINTERRUPTIVE
  - OFFBAR: TESTS CONDUCTED AT ANTENNA TURNAROUND

- SELF-TEST IS USED TO DETERMINE HEALTH STATUS OF THE RADAR
  - SELF-TEST REPORT TO FCC IS A SINGLE BIT REPORT
  - SELF-TEST FAULT KEYED TO 80 DIFFERENT CHECKS

- BUILT-IN TEST IS A HIERARCHICAL GROUP OF INTERRUPTIVE TESTS THAT DETECT AND ISOLATE FAILURES TO A SINGLE LRU
  - $\mathrm{BIT}_{\mathrm{RADAR}}$: AUTOMATICALLY INITIATED AT SYSTEM TURN-ON
  - $\mathrm{BIT}_{\mathrm{FCC}}$: PILOT INITIATED VIA A/C FIRE CONTROL NAV PANEL

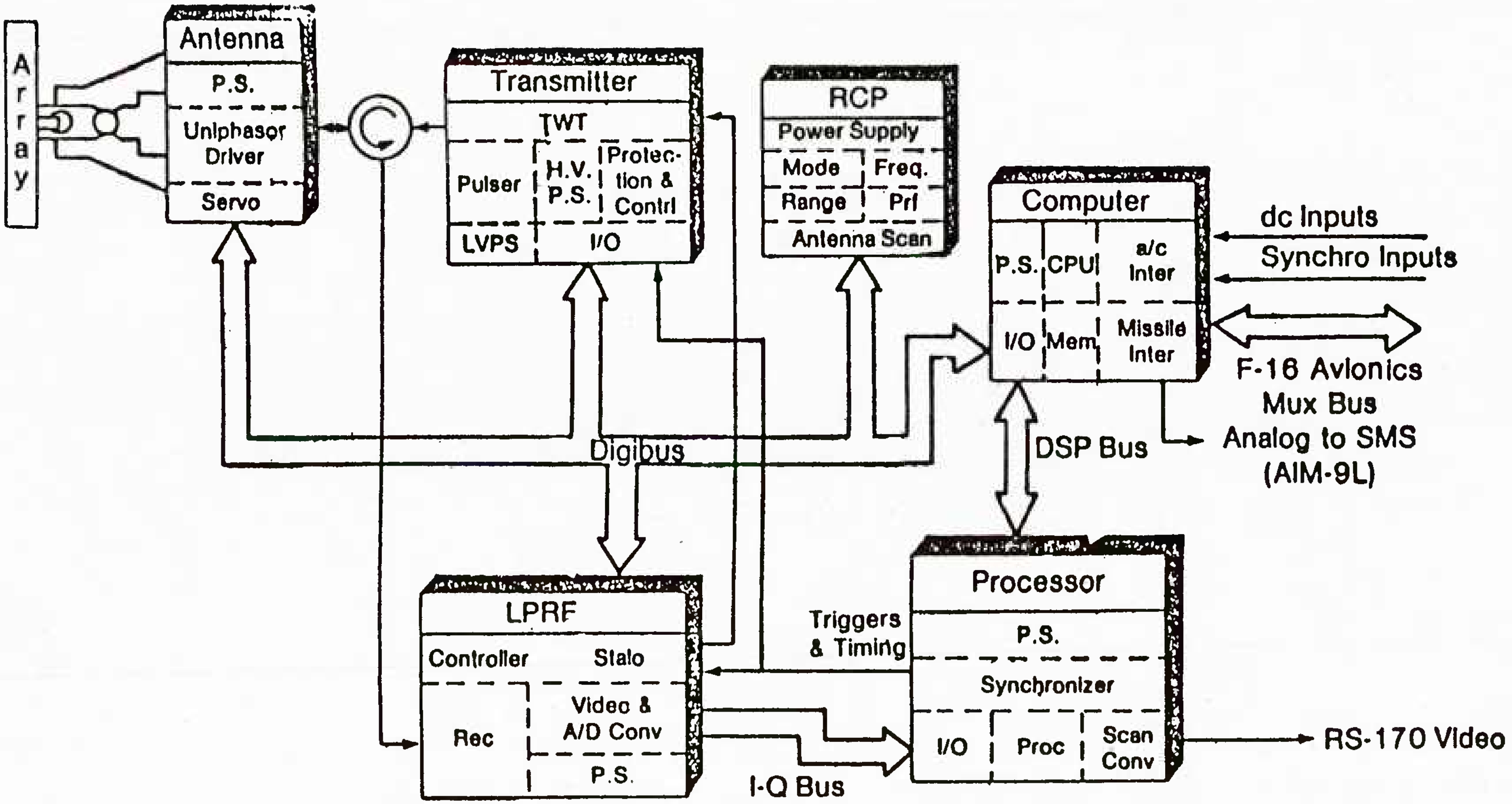
- PASS/FAIL FILTER PARAMETERS CAN BE DIFFERENT FOR SELF-TEST AND BIT

ST/BIT MECHANIZATION

The F-16 APG-66 radar system is packaged into six functional LRUs as indicated in the facing block diagram. The ST/BIT Software program is an integral part of the Software Operational Flight Program (OFP) that resides in the radar computer. All ST/BIT control set-ups and monitoring is done via the system radar digibus/DSP bus--no special command lines or monitor lines are required for ST/BIT. The ST/BIT fault reports and status are transmitted to the A/C FCC for display to the operator via the Fire Control Navigation Panel.

F-16 SIMPLIFIED BLOCK DIAGRAM

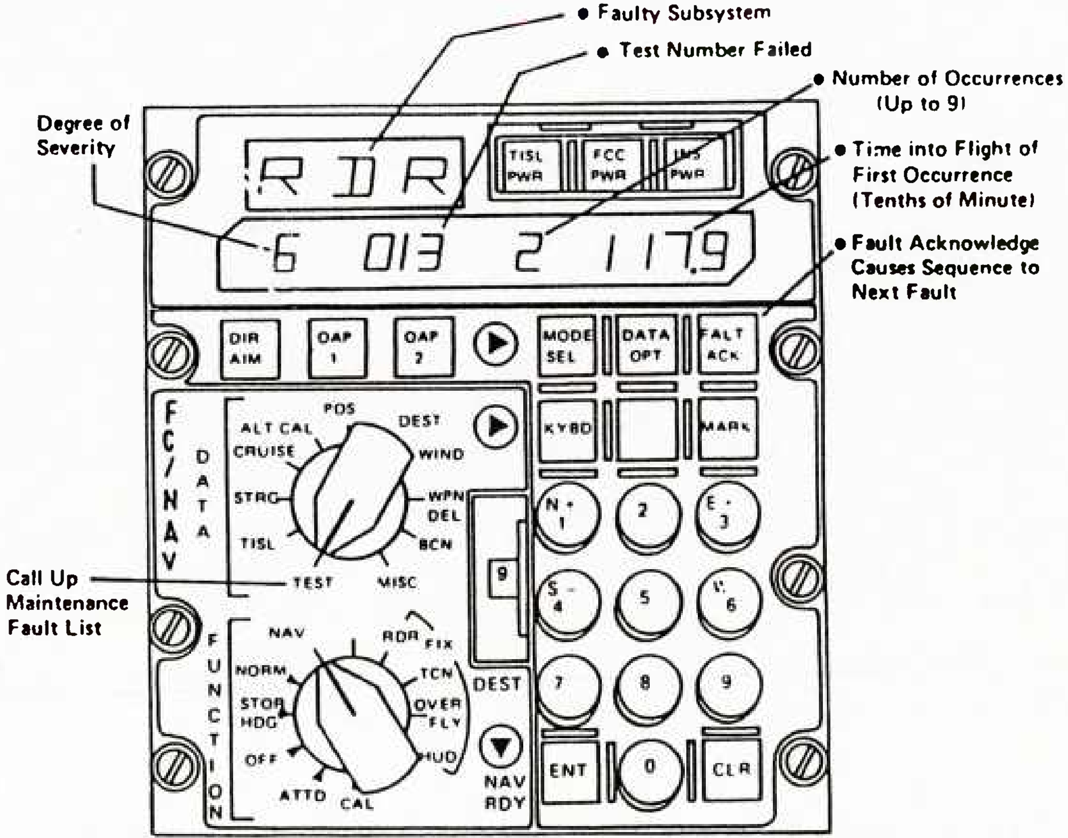
(ST/BIT MECHANIZATION)



F-16 ST/BIT READOUT

The Self-Test function of the F-16 Fire Control System is mechanized to serve a dual purpose. Not only is the maintenance crew provided with all fault information, but the pilot receives certain fault information which he may use to determine any degradation in system performance. To accomplish these functions, two fault reporting schemes are used. The Maintenance Fault List (MFL) contains the detailed information for all reported faults while the pilot's fault list (PFL) contains the same information for only those faults that would be of interest to the pilot. Thus, the PFL is merely a subset of the MFL. A degree of severity is assigned to each fault which is easily interpreted by the pilot under flight conditions.

F-16 ST/BIT READOUT

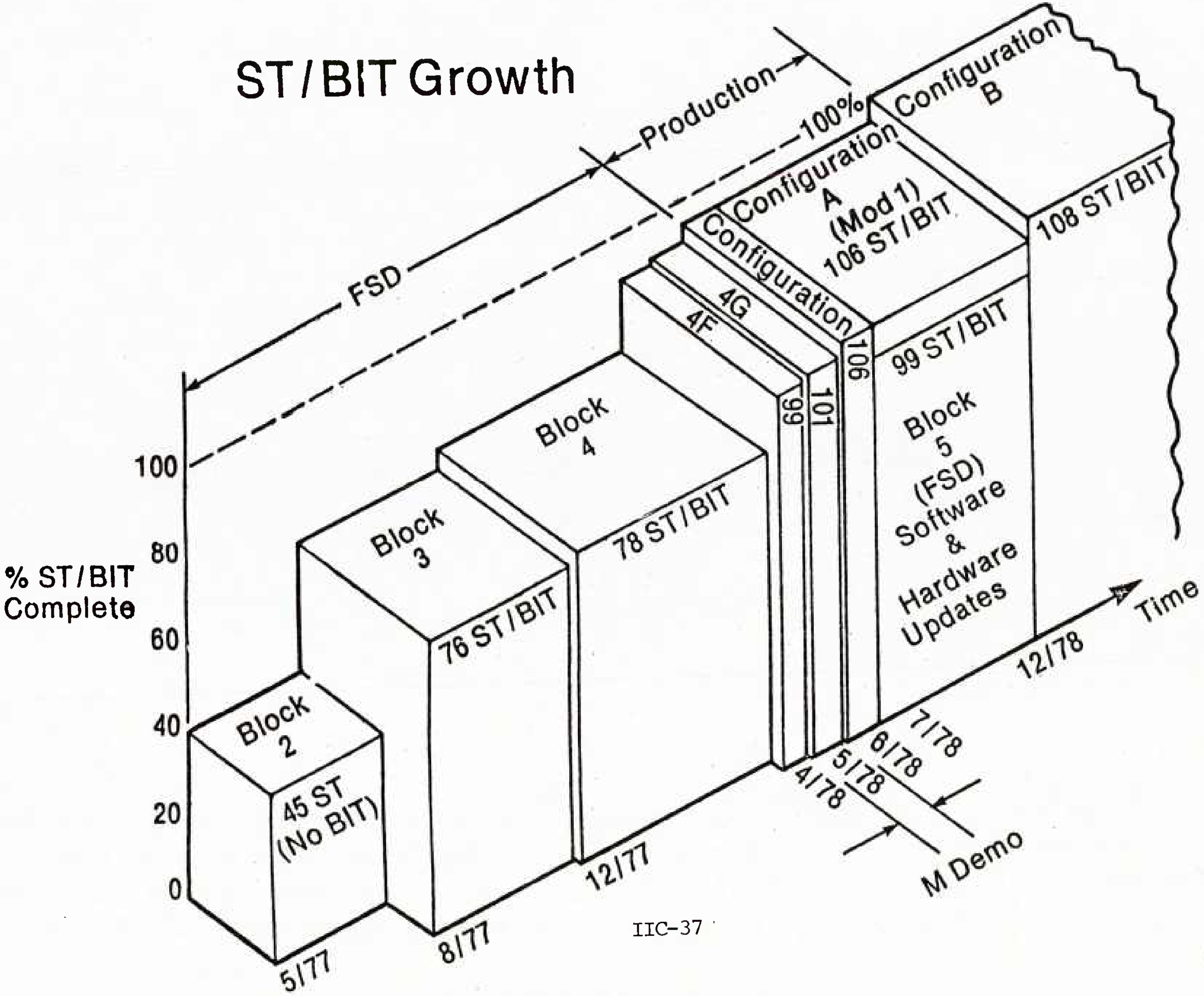


77-0328-V-4

ST/BIT GROWTH AND DEVELOPMENT

ST/BIT design, development, integration and check-out was developed in parallel with system design and mode development. The facing diagram shows the growth and development of the ST/BIT as a function of time. This concurrent development approach provided the opportunity to obtain early data on ST/BIT effectiveness and also provided additional test capability to other engineering test programs such as RQT, RGT, EQT, and flight tests.

ST / BIT Growth



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PRE-DEMO FAULT INSERTION

In an effort to get an early evaluation of ST/BIT effectiveness, a fault insertion program was instituted. The results of these incremental tests are included in the attached figure. These test results are prior to any formal MIL-STD-471 demonstration and many test/fix/retest occurrences resulted from this self-imposed WEC program.

Pre-Demo Fault Insertion Status

	No. of SRUs Faulted	Faults Detected Faults Inserted	No. of Tests Exercised
Antenna	5	54/56	13
LPRF	11	80/120	30
Transmitter	8	27/33	14
DSP	27	958/1090	19
Computer	13	86/103	17
RCP	3	43/60	6
Total	67	$\frac{1248}{1462} = 85\%$	99

FEATURES TO FACILITATE MAINTENANCE

The Avionic Systems on the F-16, including the Radar, are designed around the standard Air Force three-level maintenance concept: Organizational, Intermediate and Depot. At the Organizational level (aircraft), Self Test and Built-In-Test are used as the primary tool to checkout, detect and isolate malfunctions to a Line Replaceable Unit (LRU). The system is functionally partitioned to facilitate isolating malfunctions to an LRU at the aircraft level. At the Intermediate level (Avionics Intermediate Shop-AIS), sufficient test points and access to internal circuits are designed into the system to allow position fault isolation to a single Shop Replaceable Unit (SRU). The third level of maintenance like the AIS uses automatic test equipment and special features designed into the circuits to provide positive fault isolation to components on the SRUs. Additional features listed on the facing page are designed into the hardware and software to accommodate the maintenance concept.

FEATURES TO FACILITATE MAINTENANCE

- DESIGNED FOR EASE OF MAINTENANCE
  - LRU ACCESSIBILITY
  - NO LRU BLIND CONNECTORS
  - NO ADJUSTMENTS/CALIBRATIONS (ONLY 1 ADJUSTMENT AT I-LEVEL)
  - NO PREVENTIVE MAINTENANCE
  - DESIGN EMPHASIS TO PRECLUDE IMPROPER INSTALLATION
  - LRU/SRU INSTALLATION HARDWARE IS CAPTIVE
  - NO ON-AIRCRAFT BORESIGHTING
- ST/BIT RESULTS DISPLAYED IN COCKPIT
  - STORED IN NON-VOLATILE MEMORY
  - RECALLABLE BY PILOT OR MAINTENANCE PERSONNEL

MAINTENANCE CONCEPT

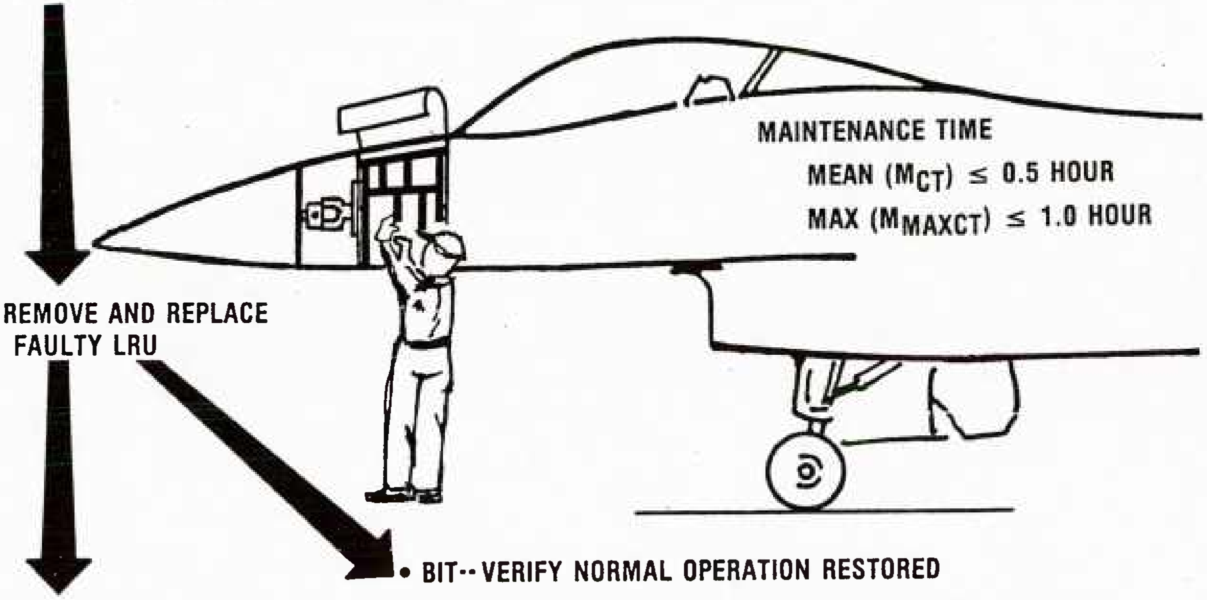
This system was designed for ease of maintenance and compatibility with the standard three-level maintenance policy.

Organizational Level

Radar fault detection is provided by self-test features integral to the system design, and reported to the pilot or maintenance personnel via cockpit displays. Self-test is a continuous, non-interruptive process that requires no operator interaction. Upon detection of a fault, the operator may initiate built-in-test which provides fault isolation to the failed line replaceable unit (LRU). This LRU is then removed from the aircraft, replaced with a like serviceable unit, and system operation verified. The maintenance time requirements specified for these functions are: <0.5 hour mean corrective task time and 1.0 hour maximum corrective task time.

ORGANIZATIONAL LEVEL MAINTENANCE CONCEPT

- SELF TEST 95% DETECTION OF MALFUNCTIONS OR OUT-OF-TOLERANCE CONDITIONS
- ST/BIT 95% ISOLATION TO FAULTY LRU



MAINTENANCE TIME

MEAN (M_{CT}) $\leq$ 0.5 HOUR

MAX (M_{MAXCT}) $\leq$ 1.0 HOUR

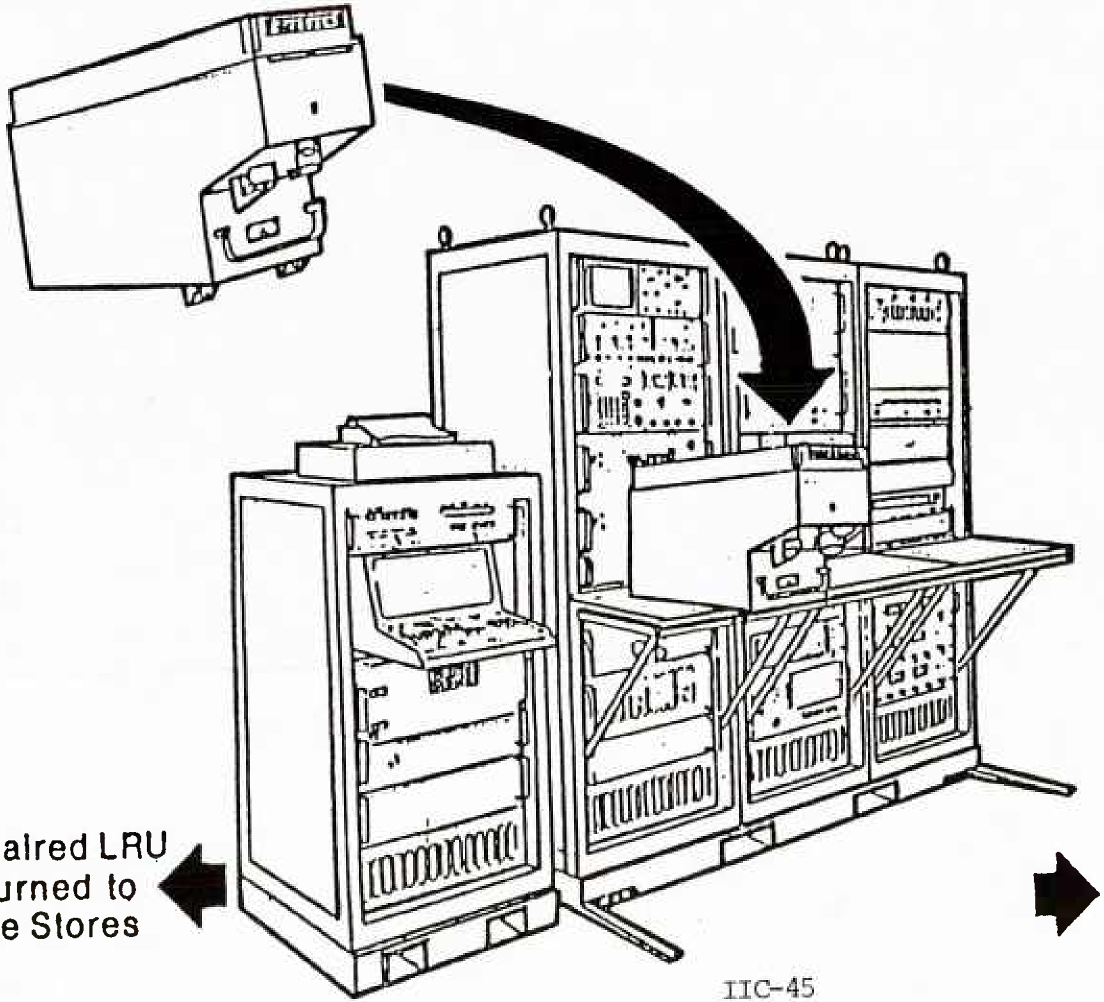
- REMOVE AND REPLACE FAULTY LRU
- BIT--VERIFY NORMAL OPERATION RESTORED
- LOW SKILL LEVEL REQUIRED--GENERALLY LEVEL THREE
- FORWARD TO INTERMEDIATE SHOP FOR REPAIR

2-9-83-9

Intermediate Level

Intermediate level maintenance consists of LRU checkout and fault isolation to a shop replaceable unit (SRU). This is accomplished on the avionics intermediate shop test equipment. LRU repair consists of removal and replacement of SRUs. Mean and maximum corrective maintenance task times are specified at 1.0 hour and 2.0 hours, respectively.

Intermediate Level Maintenance Concept



- LRU Maintenance Time
  - Mean (M_{Ct}) ≤ 1.0 Hour
  - Max (M_{Maxct}) ≤ 2.0 Hours
- Avionics Intermediate Test Station (AIS)
  - 96% Isolation to Faulty SRU
  - Remove and Replace Faulty SRU
  - Verify Repair of LRU
- Within Skill Level Five Capability

- Repaired LRU Returned to Base Stores

- Faulty SRU Forwarded to Depot for Repair

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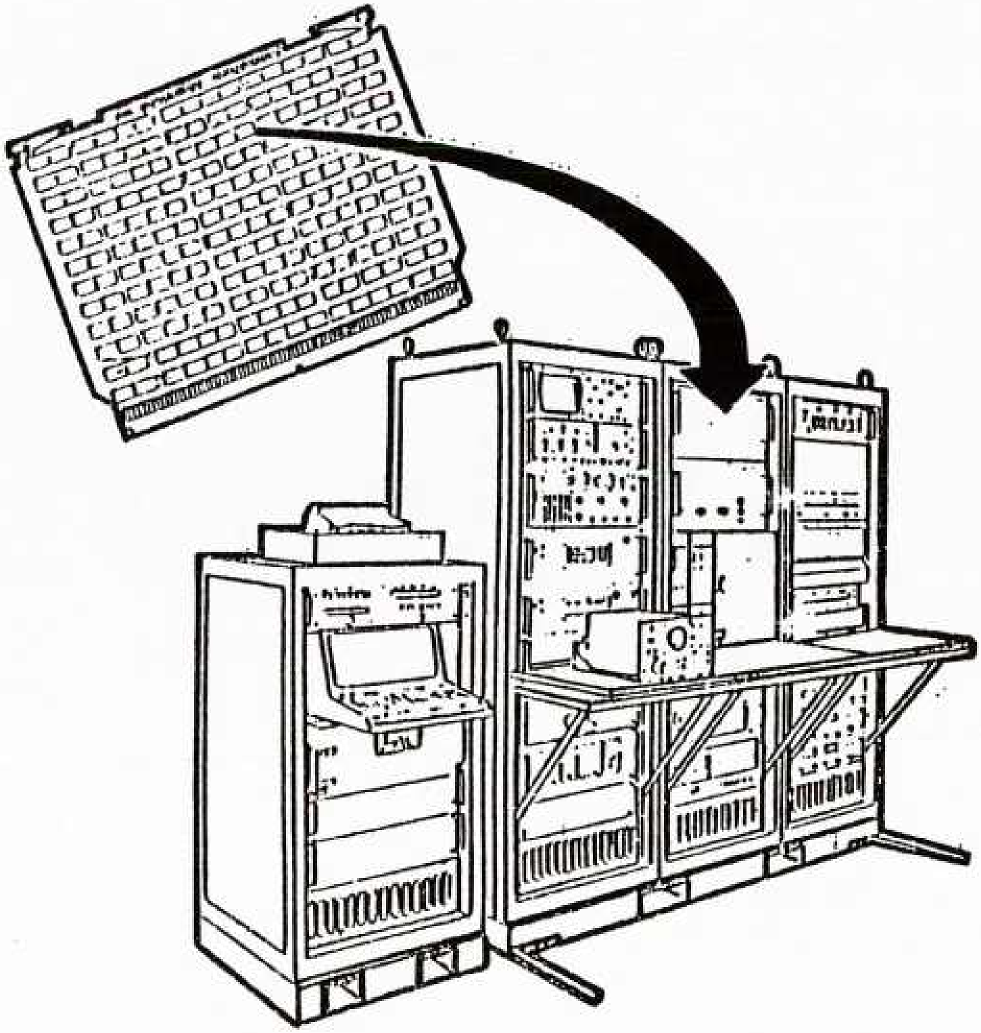
Depot Level

Depot level maintenance consists of SRU checkout and fault isolation to the failed component(s), and includes all maintenance activity necessary to restore the unit to serviceable condition. Additionally, any LRUs received from I-level due to NON-SRU failures (i.e., chassis failures) are repaired at the depot.

DEPOT LEVEL MAINTENANCE CONCEPT



- SRU FAULT ISOLATION REQUIREMENTS
  - SINGLE ELEMENT >80%
  - TWO ELEMENTS >85%
  - THREE ELEMENTS >90%
- DEPOT TEST STATION
  - ISOLATION TO COMPONENT
  - REMOVE AND REPLACE FAULTY COMPONENT
  - VERIFY REPAIR OF SRU
- REPAIRED SRU RETURNED TO STORES

MANUFACTURING

MANUFACTURING

The fourth area identified as important to producing high quality military equipment is in manufacturing or the actual production of the system. A number of techniques were used by WEC in the production of the APG-66 radar. Key techniques are shown on the following page.

MANUFACTURING

- EXTENSIVE USE OF ENVIRONMENTAL STRESS SCREENING (ESS)
  - ✓ SUPPLIERS
  - ✓ INCOMING PIECE PARTS
  - ✓ PRINTED CIRCUIT BOARDS
  - ✓ SUB-ASSEMBLIES
  - ✓ LINE REPLACEABLE UNITS
- SYSTEM LEVEL SAMPLE TEST
  - ✓ RQT ENVIRONMENTS
  - ✓ SELF IMPOSED BY WEC
- PARTS SUBSTITUTION BOARD
  - ✓ PART OF PARTS CONTROL PROGRAM
  - ✓ ASSURE USE OF RELIABLE SUBSTITUTE PARTS WHEN SUBSTITUTIONS ARE NECESSARY TO SUPPORT PRODUCTION LINE

ENVIRONMENTAL STRESS SCREENING

Westinghouse followed a screening process they called "Environmental In-Line Testing." This program was implemented throughout the production test cycle and was required of all production systems with the objective of minimizing reliability defects and test escapes on delivered systems.

The program attempted to test at the lowest practical level to avoid rejection at higher levels (which is always more expensive and time consuming). Environmental testing is also accomplished at the LRU level for each deliverable LRU. The following environmental tests were performed in-line: Vendor Assemblies, subjected to thermal cycling; Burn-in and Selected Special Parameter Tests; and Active Components, from suppliers, undergo performance tests over a range of temperatures including the extremes specified in MIL-STD-883.

Multiple Chip Hybrid Packages (MHPs) were tested environmentally per MIL-STD-883. After initial acceptance, the MHPs were baked for 24 hours at 125°C, cycled through ten repetitive exposures for ten minutes at -55°C, five minutes at room ambient and ten minutes at 125°C followed by high g acceleration in a centrifuge for one minute. The number of g's, from 5,000 to 15,000, varied with component size. Leak test and burn-in followed to remove marginal performers. Burn-in was accomplished using normal dc voltages, applied for 168 hours at 125°C, followed by the final electrical test at -54°C and +71°C, in addition to the normal ambient test.

Printed Circuit Boards (PCBs) were tested as follows:

1. Active thermal cycling (-54°C and +71°C)
2. Subassemblies. Two subassemblies, the STALO and the receiver, were designated for environmental testing with chamber temperature at -40°C and +71°C with electrical tests occurring at the stabilized temperatures. After the temperature test the PCB was exposed to random vibration. On completion of one failure-free cycle, these subassemblies were installed in the LPRF LRU.

MANUFACTURING

- ENVIRONMENTAL STRESS SCREENING USED EXTENSIVELY
    - ASSEMBLY VENDORS - THERMAL CYCLING; BURN-IN; GROSS/FINE LEAK; OTHER SPECIAL SCREENS
    - W INCOMING - MIL STD SEMICONDUCTOR AND ICs PERFORMANCE OVER TEMPERATURE EXTREMES
    - W MHPs - THERMAL SHOCK; THERMAL CYCLING; HI TEMP STORAGE; ACCELERATED BURN-IN
    - PRINTED CIRCUIT BOARDS - HI-LOW THERMAL CYCLING, PERFORMANCE TEST
    - SUB-ASSEMBLIES - HI-LOW THERMAL CYCLING; RANDOM VIBRATION (COMBINED) ONE FAILURE FREE CYCLE
    - LRUs - HI-LOW THERMAL CYCLING, RANDOM VIBRATION (COMBINED); PERFORMANCE TESTS, ONE FAILURE FREE CYCLE
    - FAILURE RESOLUTIONS--ESS FAILURE DATA PROVIDED BY TEST ENGINEERING TO PROBLEM ACTION TEAMS FOR INVESTIGATION AND TO PROBLEM ACTION BOARD FOR RESOLUTION

41/33-1

All LRUs receive environmental tests as described above. In the event of a part failure at the LRU level, the failure and associated corrective action was examined and if it was determined that the integrity of the particular LRU performance had been affected, the environmental testing was repeated.

All burn-in data on deliverable LRUs was continuously evaluated to ensure reliability control and to avoid increasing failure trends. Each LRU must demonstrate one failure-free cycle prior to delivery (Test Level F). Failure data was provided to the problem action teams for investigation and to the problem action board for correction.

SYSTEM LEVEL SAMPLE TEST

Beginning in 1983, one radar system per month was selected to undergo combined environmental testing including thermal cycling, random vibration and power on-off cycling in accordance with the RQT environmental profile.

The system level sample test was initiated by Westinghouse after completion of Reliability Acceptance Test to assure that any new problems are identified and corrected. Benefits derived from RAT testing provided the motivation for incorporation of the system level sample tests.

SYSTEM LEVEL SAMPLE TEST

- SELF-IMPOSED BY WESTINGHOUSE STARTING JANUARY 1983
- SAMPLE: ONE RADAR PER MONTH
- ENVIRONMENT: SAME AS RQT
  - ✓ TEMPERATURE CYCLING
  - ✓ RANDOM VIBRATION
  - ✓ POWER ON-OFF CYCLING
- LENGTH OF TEST: 5 DAYS/SYSTEM
- OBJECTIVE: TIMELY IDENTIFICATION AND CORRECTION OF ANY NEW PROBLEM AREAS

F-16 PARTS SUBSTITUTION BOARD

In 1977, the demand for parts exceeded the supply. Lead time for selected military standard parts was running 26 weeks to 28 weeks. To ensure that production manufacturing lines at the contractor and subcontractor were not shut down due to parts shortage, a formal Part Substitution Board was authorized by the customer and established.

- The Air Force member of the board was selected from the local Air Force Program Resident Office (AFPRO) and designated the Air Force agent.
- The Chairman of the Board was appointed from the Fort Worth Division Parts Advisory Council to represent Fort Worth Division management.
- The technical advisor to the board was selected from the Fort Worth Division Parts Engineering to serve as technical advisor on the acceptability of the part. The Defense Electronic Supply Center was available for consultation as needed to assure the best part available was used in the hardware.
- The material member of the board had access to the Fort Worth Division Material Department to establish facts about the shortage, best available sources and the implementation of the substitution authorization. The Material Board member was also the point of contact for subcontractors' request for substitutions.

Parts Engineering establishes best alternate part by coordination with part suppliers, DESC and Air Force.

The Part Substitution Board reviewed each substitution request for schedule impact.

The Part Substitution Board examines all part deviations. The board reviews these deviations to ensure that the best part available is used.

F-16 PARTS SUBSTITUTION BOARD

- FORMAL BOARD ESTABLISHED TO REVIEW ALL PART SUBSTITUTIONS (CONTRACTOR AND SUBCONTRACTOR)
- FOUR MEMBERS ON BOARD AT GD/FW
  - AIR FORCE (LOCAL)
  - CHAIRMAN (MEMBER OF PARTS ADVISORY COUNCIL)
  - PARTS ENGINEER
  - MATERIAL REPRESENTATIVE
- PARTS ENGINEERING ESTABLISHES BEST ALTERNATE PART OR PARTS
- BOARD APPROVES BEST PART THAT IS AVAILABLE FOR A LIMITED QUANTITY BUY
- BOARD ALSO REVIEWS PART DEVIATIONS

MANUFACTURING YIELD AND FIELD RELIABILITY

The APG-66 Parts Control Board established the dual-in-line package as the preferred package for manufacturing and field repairing. The flat pack was being phased out by many microcircuit manufacturers. Also, the dual-in-line provided the best solution for multi-layered printed circuit boards.

Studies of the APG-66 manufacturing lines revealed that microcircuits were exhibiting higher than expected failures during the manufacturing cycle. A check of as-received stock also confirmed the problem. Management elected to have all APG-66 microcircuits rescreened. A dramatic reduction of microcircuit failures in manufacturing and field returns resulted.

Industry research revealed that electrostatic discharge was affecting manufacturing and field reliability. The APG-66 Parts Control Board participated in the industry studies and the subsequent DOD standards for electrostatic-sensitive devices (ESD). The APG-66 subcontractors were alerted to the problem and corrective action was taken to install ESD prevention systems.

MANUFACTURING YIELD AND FIELD RELIABILITY IMPROVED

- ESTABLISHED DUAL IN-LINE MICROCIRCUITS AS STANDARD
- ESTABLISHED MICROCIRCUIT RESCREEN TO IMPROVE MANUFACTURING YIELD AND FIELD RELIABILITY
- ESTABLISHED ELECTROSTATIC DAMAGE PREVENTION SYSTEM TO IMPROVE MANUFACTURING YIELD AND FIELD RELIABILITY

TEST & EVALUATION

TEST EVALUATION SUMMARY

A SUMMARY OF THE FSD AND PRODUCTION ASSETS AND SCHEDULES FOLLOW.

TEST & EVALUATION SUMMARY
APG-66 RADAR

	ASSETS		SCHEDULE	
	PLANNED	ACTUAL	PLANNED	ACTUAL
<u>FSD</u>				
RGT	4	1	5-10/77	7-12/77
PRE-RQT	2	2		
RQT			7-10/77	
#1	3	2		3-4/78
#2	2	2		4-6/78
<u>PROD</u>.				
RGT	0	1	7-11/78	7-11/78
RQT				
#1	5	2		3-5/79
#2	5	3		11/79-2/80
#3	3	3		8-10/80
RAT				
#1	4	4		11/80-1/81
#2	2	2		7/81
#3	8	8		11/81-10/82

The fifth area is Test and Evaluation. A great many different kinds of tests were used to identify and correct problem areas and verify compliance with specified requirements. These tests and evaluations are grouped into the following four categories and are described in more detail in the following pages.

TEST AND EVALUATION

LABORATORY TEST (DEVELOPMENT)

DT&E FLIGHT TEST (DEVELOPMENT)

MOT&E (OPERATIONAL)

IN-SERVICE ASSESSMENT

LABORATORY TESTS

Laboratory testing played a vital role in the maturation of the APG-66 radar. The combined test activities have resulted in an MTBF, measured in the field, that is closer to that measured in the laboratory than experienced on previous systems.

The extensive testing not only ferreted out failures but also provided a tool for verifying the effectiveness of corrective actions. Reliability engineering was responsible for the reliability testing while maintainability engineering monitored for effectiveness of ST/BIT, and the hierarchy of tests, and added failure modes above those required in maintainability demonstration tests. During the testing, a system acceptance test procedure was run for each mode, and BIT was activated subsequent to each mode text.

Westinghouse management felt strongly that the tests were beneficial since, although they had met their contractual commitments for formal testing demonstration, they committed to continue testing one system per month under the reliability test environment to identify any problems that result from the production process.

Extensive laboratory tests were conducted using FSD and production hardware. Tests conducted are shown.

LABORATORY TEST

RELIABILITY TEST

FULL SCALE DEVELOPMENT (FSD) TESTS

- THERMAL VERIFICATION TEST
- RELIABILITY GROWTH TEST
- RELIABILITY QUALIFICATION TEST
- RELIABILITY GROWTH/RELIABILITY QUALIFICATION TWT TEST

PRODUCTION TESTS

- RELIABILITY GROWTH TEST
- RELIABILITY QUALIFICATION TEST
- RELIABILITY ACCEPTANCE TEST

MAINTAINABILITY TEST

- MAINTAINABILITY DEMONSTRATION TEST
- ACCEPTANCE TEST: UTILIZES ST/BIT CONTINUOUSLY
- AIS COMPATIBILITY TEST

LABORATORY RELIABILITY TESTING

Reliability testing was performed during development and production in the laboratory under combined environments including random vibration, rapid temperature excursions and power on-off cycling with limited use of humidity and altitude environments. The purpose of the testing was early detection and correction of problem areas and demonstration of compliance with specified MTBF.

Types of testing included reliability growth and reliability qualification during full-scale development and reliability growth, reliability qualification and reliability acceptance testing during production.

Reliability growth testing was performed at the system and equipment level and at the component level for critical components such as the TWT. An example of the effectiveness of growth testing is the 23 corrective actions identified during 420 hours of development growth testing.

Reliability, qualification and acceptance testing was performed at the radar system level in compliance with MIL-STD-781 test plans. In each case incorporation of extensive corrective action followed by retests were necessary prior to successful completion. Corrective action was incorporated for all identified problem areas.

APG-66 RADAR LABORATORY RELIABILITY TESTING

PROGRAM APPROACH

- PERFORM RELIABILITY GROWTH TESTING FOR EARLY DETECTION AND CORRECTION OF PROBLEM AREAS -- COMBINED ENVIRONMENTS
  - TEMPERATURE CYCLING
  - ALTITUDE CYCLING
  - HUMIDITY
  - POWER ON-OFF CYCLING
  - RANDOM VIBRATION
- PERFORM EXTENDED TIME REL-QUAL TESTS UNDER TEMPERATURE AND RANDOM VIBRATION ENVIRONMENT FOR EARLY DETECTION/CORRECTION OF PROBLEM AREAS AND DEMONSTRATION OF COMPLIANCE WITH SPECIFIED MTBF
- PERFORM EXTENDED-TIME REL-ACCEPTANCE TEST UNDER TEMPERATURE AND RANDOM VIBRATION ENVIRONMENT TO VERIFY RELIABILITY CONTROL

TEST SUMMARY

PHASE	TYPE TEST	MIL-STD-781B		SPECIFIED MTBF (θ_0)	SYSTEM QUANTITY	TOTAL TEST HOURS	NUMBER OF CORRECTIVE ACTIONS
		PLAN	LEVEL				
FSD	GROWTH	-	-	-	1	420	23
FSD	PRE-RQT	-	F*	-	2	470	19
FSD	RQT	III	F*	60	2	730	22
PROD.	GROWTH	-	-	-	1	230	6
PROD.	RQT	III/IV	F*	97	3	720	56
PROD.	RAT	V	F*	97	8	420	48

*TEST LEVEL F EXCEPT LOWER TEMPERATURE LIMIT OF -40°C AND RANDOM VIBRATION IN LIEU OF SINUSOIDAL.

TEMPERATURE AND RANDOM VIBRATION PROFILES

Pictorial representation of temperature and random vibration for RQT and RAT is shown. For the temperature cycling, the following conditions apply:

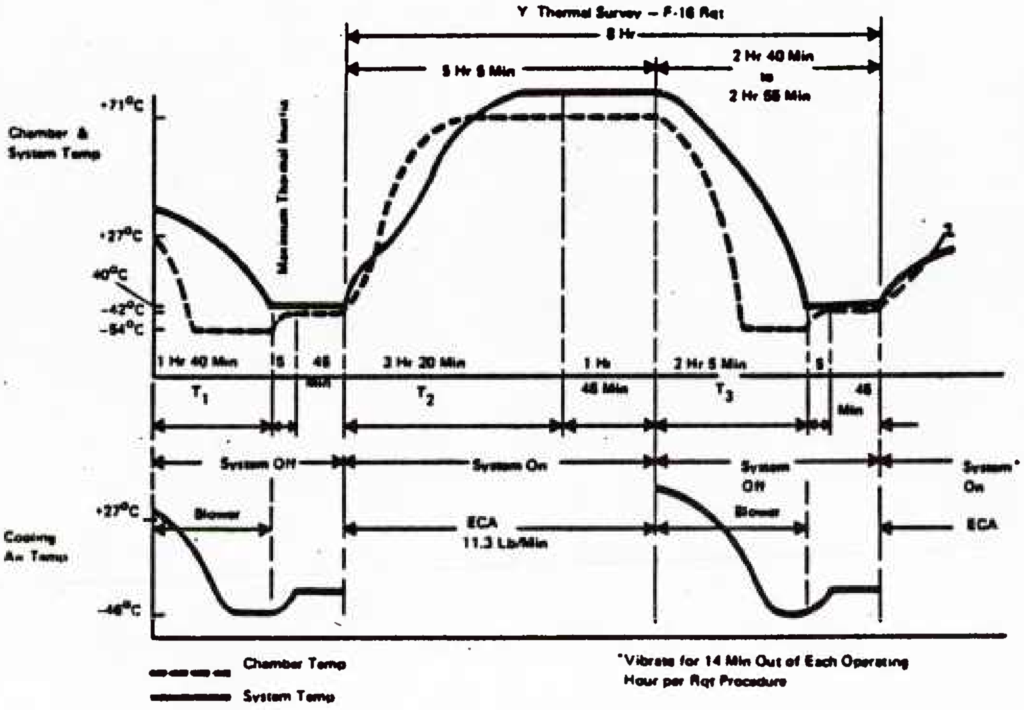
- During the cooling portion of each cycle the chamber was stabilized at -54°C. When the point of maximum thermal inertia (as determined by thermal survey) of the equipment under test reached -40°C, the chamber was then stabilized and maintained at that temperature for 45 minutes.
- Equipment power, cooling air, and chamber heating were then applied to initiate the heating portion of the cycle.
- Test time following stabilization at high temperature was one hour and 45 minutes.
- Any cooling air to enhance transition to cold temperature was applied at a temperature no greater than the existing chamber ambient temperature. Any cooling air applied to enhance transition from -54°C to -40°C was applied at -40°C. Cooling air at +27°C was applied at the beginning of the heating portion of each cycle and was maintained throughout the high temperature portion of the cycle.
- All references to "test time," "test duration," and "equipment operation" are understood to mean equipment "on-time" for the purpose of calculating MTBF.

Random vibration was performed during the tests. The duration and test levels were maintained within ±10% of the values identified in the figure. Vibration was applied normal to the plane for the majority of the circuit boards contained in the equipment.

The equipment was turned on and operated at -40°C at the start of the high temperature cycle. After stabilization at high temperature, the equipment was operated at least 1-3/4 hours. The total system operation time was five hours, five minutes for each temperature cycle. During equipment test time the equipment was cycled through its various modes of operation.

RQT AND RAT WERE ACCOMPLISHED USING COMBINED ENVIRONMENTS OF TEMPERATURE AND RANDOM VIBRATION

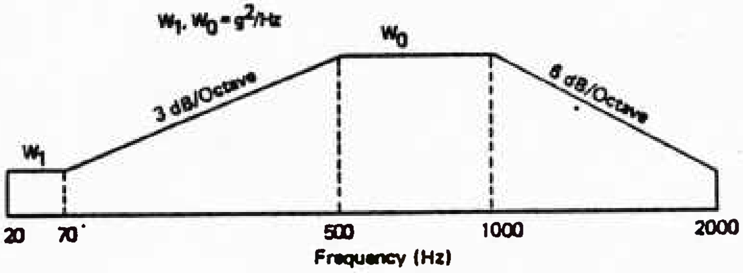
TEMPERATURE



*Vibrate for 14 Min Out of Each Operating Hour per Rqt Procedure

T_1 Stabilization from room to -40°C
T_2 Stabilization from -40°C to +71°C
T_3 Stabilization from +71°C to -40°C

RANDOM VIBRATION



	Test Level		
Test Time *	W_1 (g^2Hz)	W_0	0_A rms
8 min	0.0002	0.0014	1.32G
4 min	0.00042	0.0030	1.94G
2 min	0.0010	0.0070	2.96G

*Expressed as Min Out of Each Operating Hour

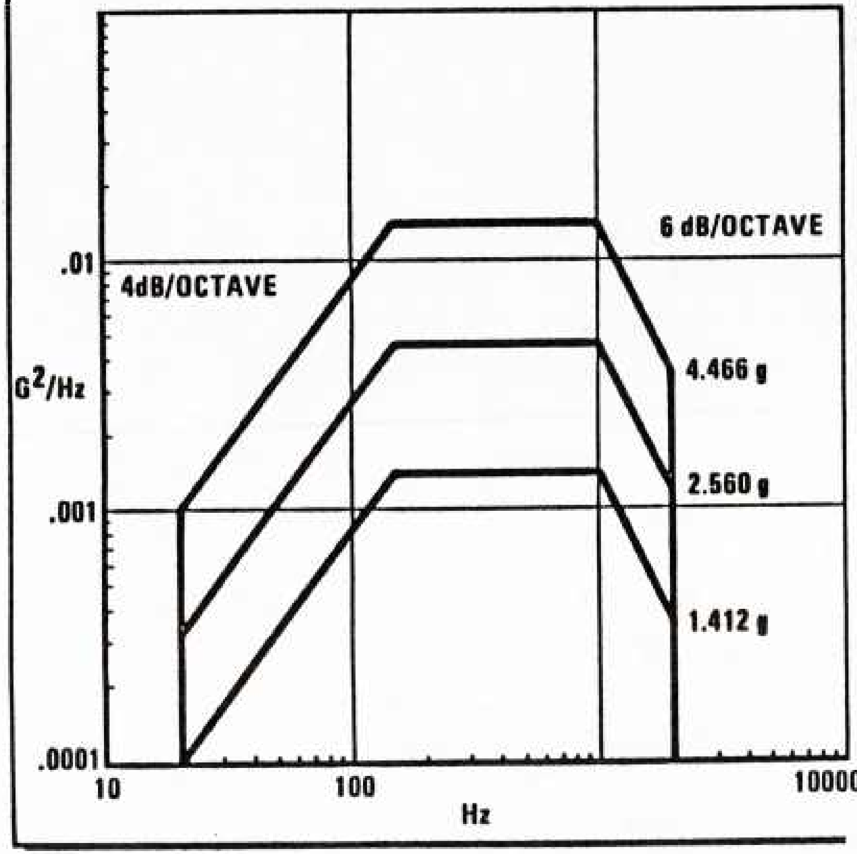
RANDOM VIBRATION TEST REPRESENTATIVE OF ACTUAL FLIGHT CONDITIONS

Extensive random vibration was used. The vibration test levels specified in 16PS002 were to be used unless actual data became available. The charts depict both the specified level from 16PS002 and the current requirement based on measured aircraft vibration levels.

CURRENT RANDOM VIBRATION SPECTRUM IS REPRESENTATIVE

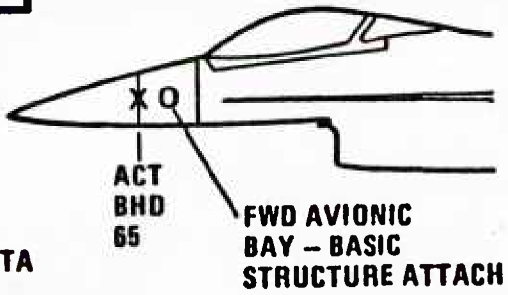
ORIGINAL

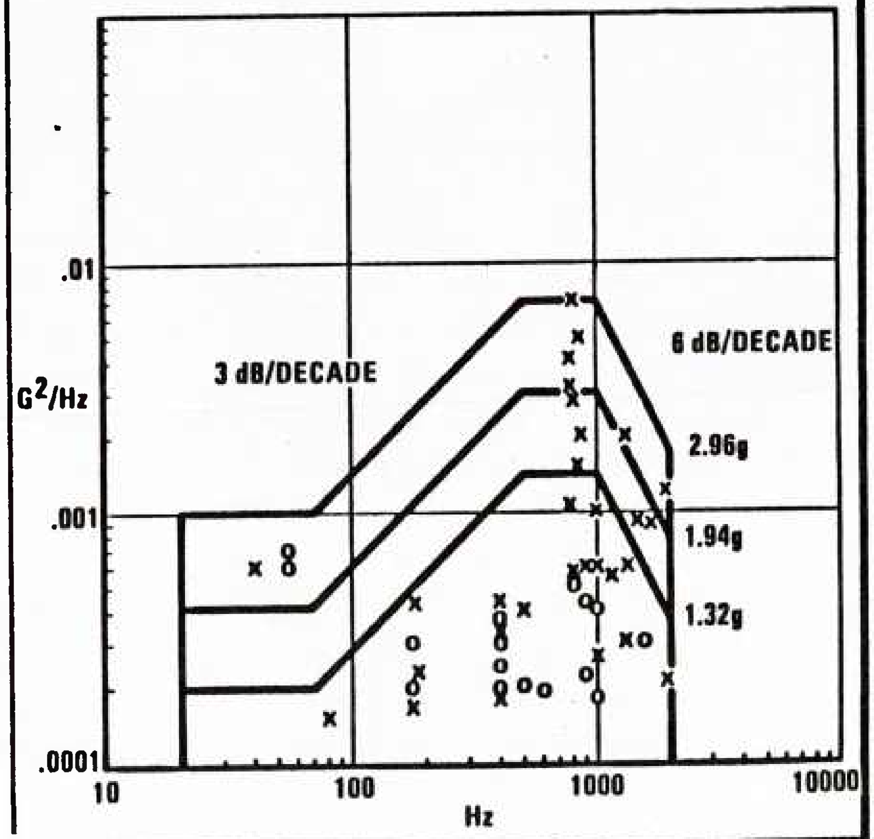
- 16PS002 STATES – "F-16" DERIVED VIBRATION LEVELS WILL BE USED IF LESS SEVERE THAN THIS SPECTRUM"



CURRENT

- DATA PLOTS ARE PEAK G^2/Hz POINTS FROM FLIGHT TEST DATA

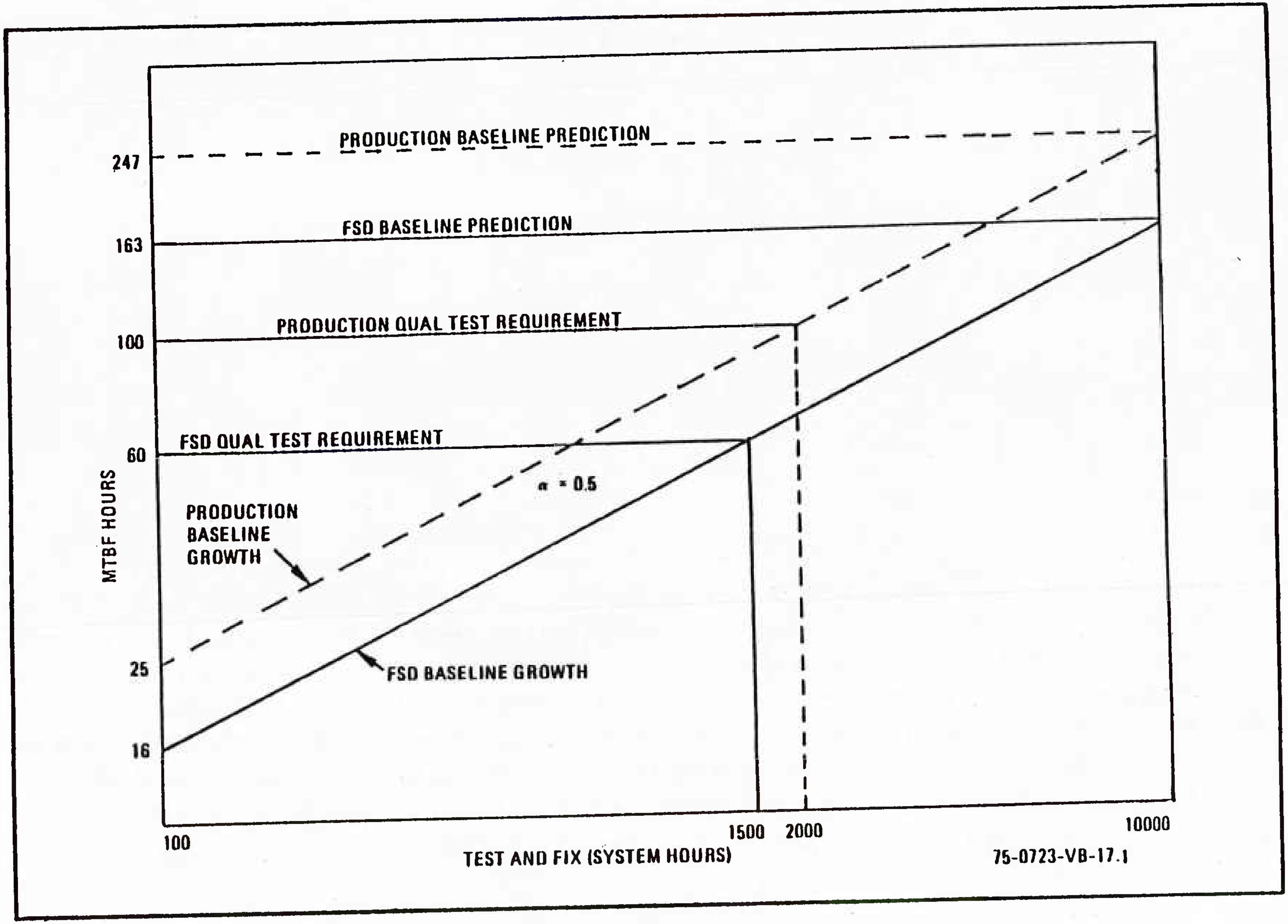




RELIABILITY GROWTH PREDICTION

Westinghouse instituted a reliability growth "test-and-fix" effort as an integral part of the overall growth program. It was planned that this effort would mature the APG-66 production radar to a demonstrable 100 hours MTBF. The test involved cycling a sample in a simulated use environment to accelerate the occurrence of failures and then to identify, analyze, and correct the causes of such failures in a closed-loop cycle. The figure following shows the intended reliability growth as a function of the program milestones. The starting point is assumed to be 10% of the predicted inherent MTBF (163 hours for the FSD system). The first inflection point of this curve represents the level of growth expected to occur during the early part of FSD as a result of environmental testing and screening at and below the LRU level. The second inflection point on this chart represents the level of MTBF expected to be achieved by learning from the combination of environmental qualification tests and the dedicated reliability growth test.

RELIABILITY GROWTH PREDICTION

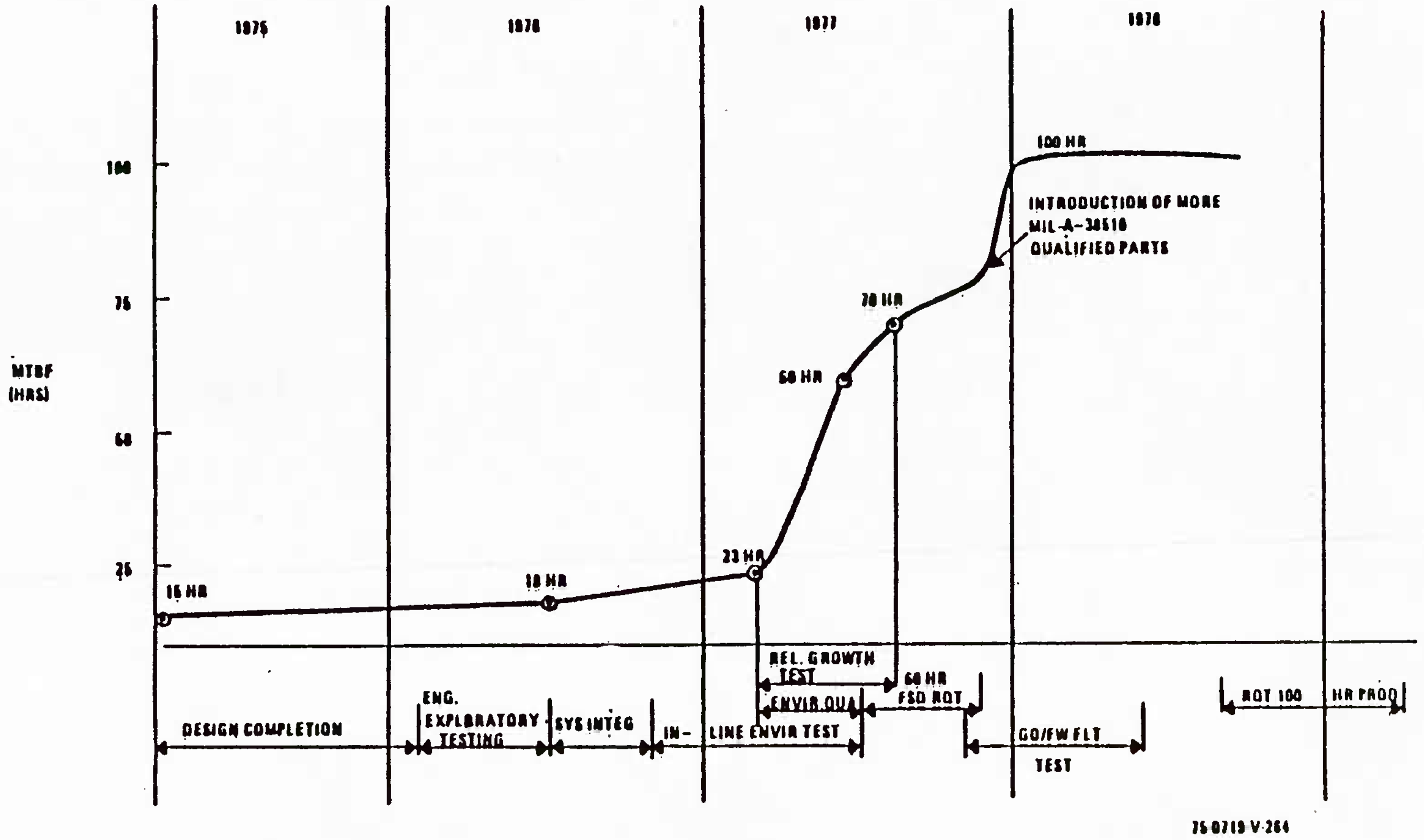


RELIABILITY GROWTH

A dedicated reliability growth program was planned for a simulated F-16 environment. Expected values are illustrated. The initial reliability value was assumed to be 10% of the predicted inherent reliability, and was predicated on a growth rate (α) of 0.5. This prediction was based on equipment growth rates attained by Westinghouse on earlier systems.

It was expected to take about 1500 Test & Fix hours to mature the FSD model to achieve the 60-hour MTBF required. Following this milestone, FSD RQT and continuation of the dedicated growth test for an additional 500 hours would be accomplished. As illustrated in the figure on the previous page, 2000 hours of growth testing was expected to mature the production model radar to the 100-hour MTBF level. Growth predictions relative to program events are shown in the following figure.

APG-66 RELIABILITY GROWTH PREDICTIONS



FSD RELIABILITY GROWTH TEST (RGT)

One system (#6) was used for RGT. The system was tested a total of 420 hours and 23 corrective actions were subsequently taken as a result. Examples of resultant changes are shown.

RELIABILITY GROWTH TESTING LED TO DESIGN IMPROVEMENTS

EQUIPMENT AND ENVIRONMENT

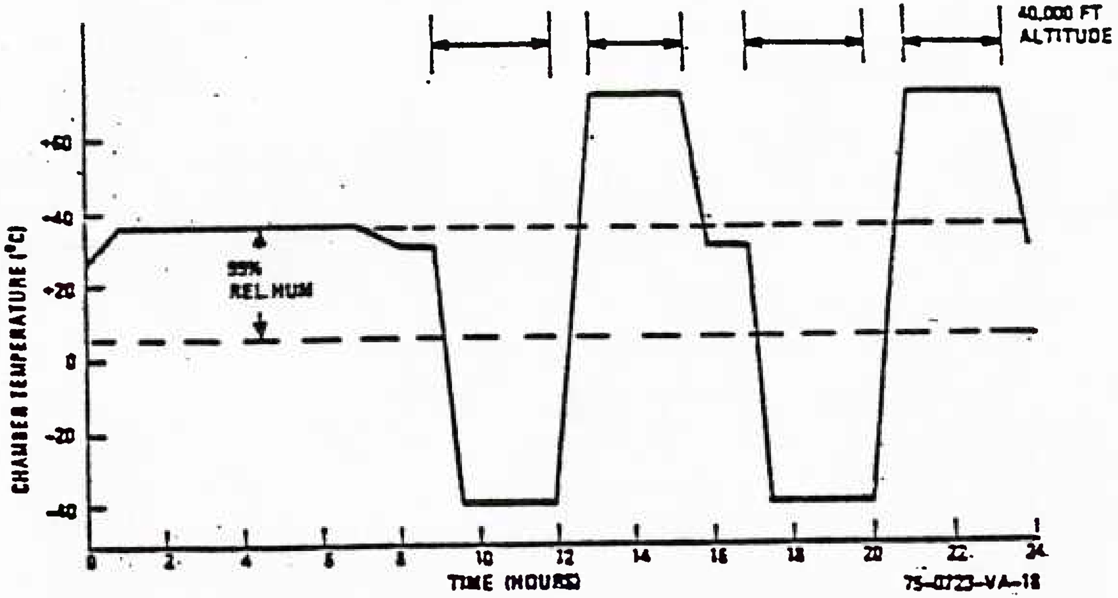
- BLOCK II SYSTEMS – 651 HOURS OF TEMPERATURE VARIANCE, HUMIDITY AND FROST, RANDOM VIBRATION, AND ALTITUDE CYCLING
- TRANSMITTER – 425 HOURS OF TEMPERATURE CYCLING, ALTITUDE CYCLING AND RANDOM VIBRATION
- LPRF – 30 HOURS OF RANDOM VIBRATION AND ACOUSTIC NOISE
- TWT – 950 HOURS OF RANDOM VIBRATION AND TEMPERATURE CYCLING

EXAMPLES OF RESULTANT CHANGES

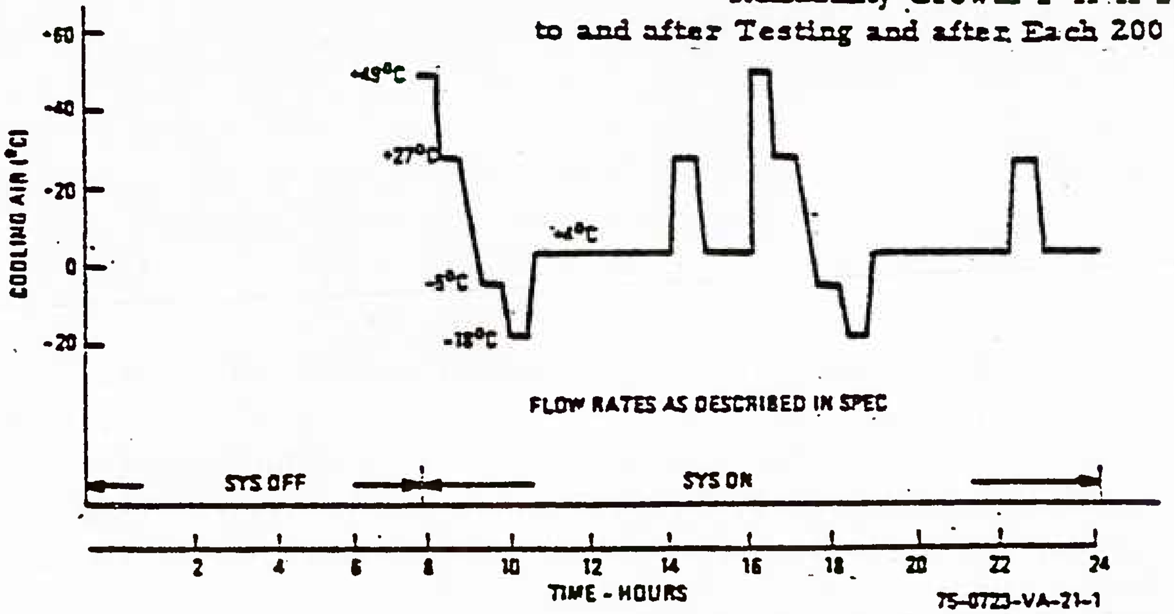
- VIBRATION
  - Component Adhesive Added to Prevent Breaking Leads
  - Special Mounting for Larger Components
  - Special Cable Tie-Downs
  - Specified Internal Torque Requirements
- TEMPERATURE RELATED
  - DSP Power Supply Redesign
  - Computer Power Supply Redesign
  - Computer EPROM and Auxiliary Board Redesign
  - Increased Screening of Microcircuits
  - Purging of Bad Lots of Ceramic Capacitors and Microcircuits
- OTHER
  - Redesign of Mission Phase Circuit
  - Redesign of Antenna Band Holding Fixture
  - Redesign of Transmitter Pressure Vessel

FSD RELIABILITY GROWTH (Continued)

Typical test cycles used during RGT are shown.



Reliability Growth T-A-H Test Cycle - 2 Cycles Prior to and after Testing and after Each 200 Hours of Operation



System Cooling Air Cycle for Reliability Growth T-A-H Test Cycle

FSD PRE-RQT TESTING

Prior to the initiation of Reliability Qualification Testing, Westinghouse performed environmental integration testing to identify and resolve problems. This pre-RQT testing was expected to improve the probability of passing the RQT. Two systems were tested (SYS 9 & 10) for a total of 470 hours. Nineteen corrective actions were subsequently incorporated. Failure types and corrective action taken are shown on subsequent charts.

FSD PRE-RQT FAILURES AND CORRECTIVE ACTION

NO.	LRU	TYPE FAILURE	CORRECTIVE ACTION INCORPORATED	
			CONFIGURATION "A"	CONFIGURATION "B"
1	DSP	Power Supply-Tripped Breakers (Cold)	YES – Design	YES
2	COMPUTER	Power Supply-Automatic Shutdown "Volts Good" Up Before 5V Up (Cold)	YES – Design	
3	ANTENNA	Bit III (Circos)-Cold-Op Amp Slew Rate	YES – Design & Screen	
4	ANTENNA	Waveguide Leak-Cold	YES – Design One Vendor	
5	ANTENNA	ST/Bit "Azelon"-Cold-Thermistor Impedance	RQT Selected Systems-Design	
6	ANTENNA	Rotary Joint Leak-Cold	YES – Design	
7	LPRF	Microprocessor Fails to Start-Cold	YES – Test Procedure Change	
8	LPRF	Excessive False Alarms-Cold Resistor Pack	YES – Part Purge	
9	COMPUTER	Capacitor Short-Power Supply-Hot	YES – Part Purge	
10	LPRF	ST/Bit Xmit Cal-Hot	YES – Design SW Patch	
11	TRANSMITTER	Bit 4434-Hot-Ion Pump Power Supply	YES – Design	

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FST PRE-RQT SYSTEMS 9 AND 10 FAILURES AND CORRECTIVE ACTION (CONTINUED)

NO.	LRU	TYPE FAILURE	CORRECTIVE ACTION INCORPORATED	
			CONFIGURATION "A"	CONFIGURATION "B"
12	LPRF	False Alarms-Hot-Resistor Pack	YES – Part Purge See 8	
13	COMPUTER	R2 Broken Loose-Vibration	YES – Application Proced	
14	ANTENNA	Boresight Shift-Vibration	YES – Design	
15	ANTENNA	Drive Band Broke-Vibration	YES – Design	
16	DSP	ST/Bit "Ext Wat"-Vibration Power Supply	YES – Adjust Procedure	
17	ANTENNA	Broken Lead Digibus MHP-Vibration	YES – Assembly Spec	
18	TRANSMITTER	Pressure Vessel Leak at Cover	YES – New Test Equip	
19	ANTENNA	Flex Cable Damage	YES – Design	

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FSD RELIABILITY QUALIFICATION TEST

At the completion of FSD growth testing, Westinghouse was required to demonstrate full compliance with the specified APG-66 radar reliability requirement of 60 hours MTBF (70 hours excluding ground modes). The test was conducted in accordance with MIL-STD-781B, Test Level F as modified by the contract. Three radar systems were required to be tested. The test duration depended on the number of failures, and the environmental schedule including vibration as contractually specified was to be followed. The results of the RQT are shown in the following table.

APG-66 RADAR RELIABILITY QUALIFICATION TEST (RQT)

Test Type	Attempt No.	Test Hours	Relevant Failures	Corrective Actions*
RQT	1	33	3 (failed)	3
	2	721	13 (passed)	23
				26

---

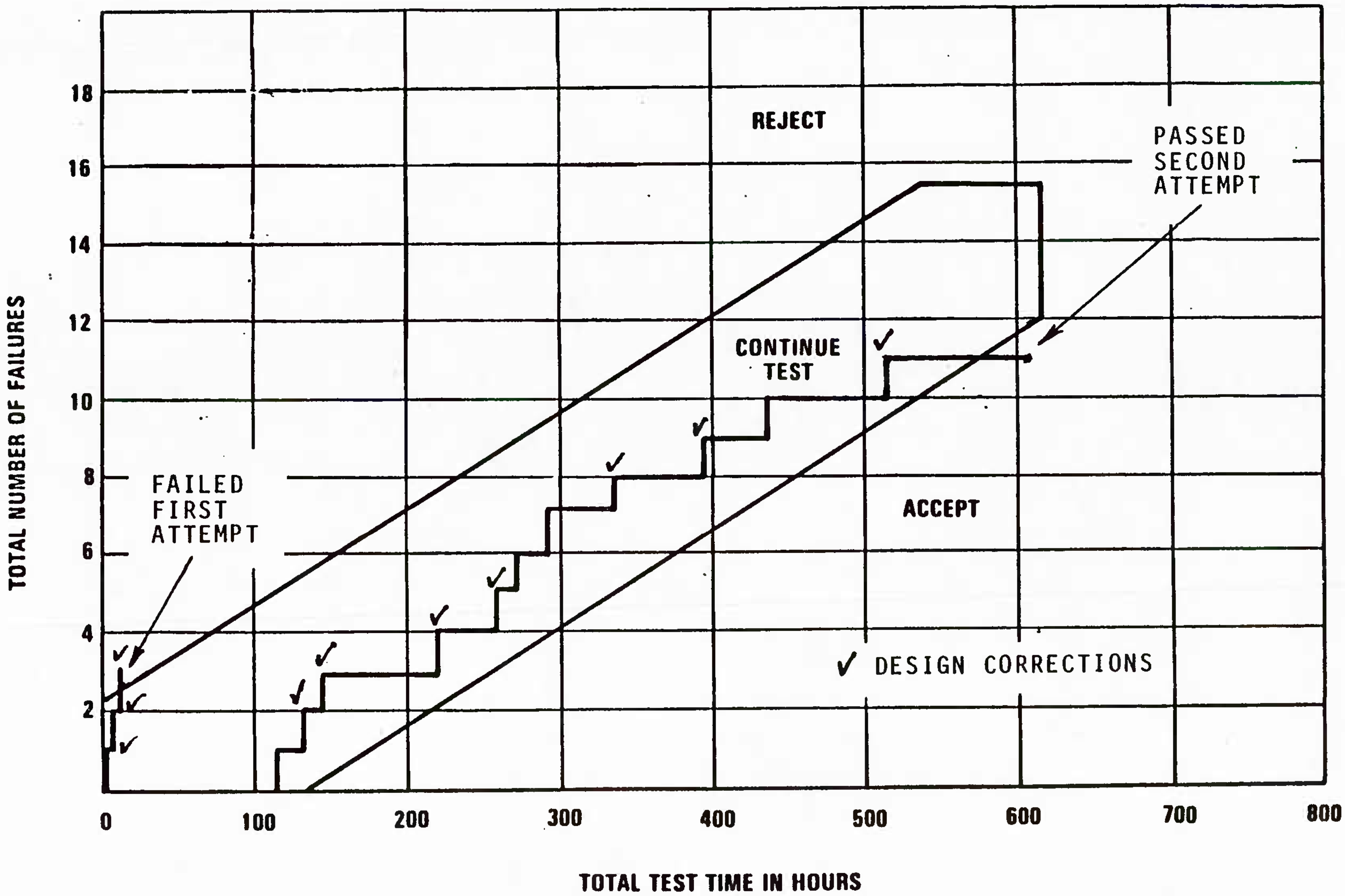
*Corrective actions were taken for failures that occurred during set-up for RQT, RQT and troubleshooting periods.

Relevant failures and subsequent corrective actions are itemized on subsequent charts.

APG-66 RADAR FSD RELIABILITY QUALIFICATION TEST PASS/FAIL CRITERIA

SPECIFIED MTBF(Θ_o) = 60HRS

TEST PLAN III



INITIAL FSD RQT

FAILURES AND CORRECTIVE ACTIONS

NO.	LRU	TYPE FAILURE	CORRECTIVE ACTION INCORPORATED CONFIGURATION "A"	CORRECTIVE ACTION INCORPORATED CONFIGURATION "B"
1	LPRF	Bit PLOKFL - Vibration	YES – Design	
2	COMPUTER	Broken Lead Power Supply Vibration	YES – Design	
3	DSP	False Alarms	YES – Design	

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RQT FOR THE TWT

During the competition for a radar supplier it became evident that the TWT was a high-risk item and likely to be a cost driver. The Air Force and GD jointly devised a reliability test for the TWT and included this test as a requirement in the RFP. Westinghouse, as the successful contractor, then further imposed a reliability growth test on their subcontractors for TWTs. Up to this time no production air-cooled TWT had ever been flown. But for reasons of weight and simplicity, WEC decided that an air-cooled TWT would be desirable for the F-16 application. Their specification for potential suppliers included the need for a reliability growth program. As a result of the subsequent performance of the TWT in field use, the next generation of TWT on the improved APG-66 also has a similar reliability program specified. The resulting design currently has demonstrated four times the MTBF that had originally been predicted and three suppliers have been qualified to provide such a TWT. The high reliability is even more impressive when one considers that the failures of a number of TWTs were maintenance-induced, i.e., waveguides were not connected properly and the subsequent loss of pressurization caused repeated arcing that cracked the TWT window.

TWT RELIABILITY QUALIFICATION TEST

PURPOSE

DEDICATED RELIABILITY TESTING BECAUSE THIS IS THE FIRST PRODUCTION AIR COOLED TWT FOR AIRBORNE USE AND IS A MAJOR LIFE-CYCLE COST DRIVER

REQUIREMENT

- 3 TUBES FOR A TOTAL OF 3000 HOURS
- 1 ALLOWABLE FAILURE
- TEST LEVEL "F" OF MIL-STD-781B EXCEPT LOWER TEMPERATURE -40°C AND RANDOM VIBRATION

RESULTS

3 TUBES COMPLETED 3080 OPERATIONAL HOURS, 300 COLD STARTS, 35 HOURS RANDOM VIBRATION TO 4.9 G's (RMS)

NO FAILURES

PRODUCTION RELIABILITY GROWTH TEST

One production system (#20) was used to accomplish production reliability growth testing. Production growth testing was implemented to further mature radar reliability after development RQT and prior to production RQT. Environments included temperature cycling, power on-off cycling and random vibration. RQT performance measurement procedures were used. However, temperature and vibration profiles were used to increase stress levels and radar power-on time efficiency.

PRODUCTION RELIABILITY TEST

EQUIPMENT & ENVIRONMENT

- ONE SYSTEM - PRODUCTION SYSTEM #20
- 230 TEST HOURS
- TEMPERATURE CYCLING
  - ✓ PROFILE A EMPHASIZED TURN-ON STRESS AT COLD TEMPERATURE (-40°C)
  - ✓ PROFILE B EMPHASIZED HIGH TEMPERATURE STRESS (+71°C)
- RANDOM VIBRATION - 14 MINUTES/OPERATE HOUR FROM 20 TO 2000 HZ
  - ✓ 8 MINUTES AT 1GRMS
  - ✓ 4 MINUTES AT 2.6GRMS
  - ✓ 2 MINUTES AT 4.6GRMS

EXAMPLES OF RESULTANT CHANGES

- VIBRATION
  - ✓ DEDICATED GROUND WIRE ADDED
  - ✓ ASSEMBLY AND INSPECTION IMPROVEMENTS INCORPORATED
- TEMPERATURE
  - ✓ CAPACITANCE INCREASED ON POWER TRANSFORMER
- OTHER
  - ✓ DIGITAL SIGNAL PROCESSOR TESTS ADDED
  - ✓ PROCESS AND DESIGN CHARGES INCORPORATED TO CORRECT TRANSMITTER HIGH VOLTAGE DIODE BLOCK PROBLEM

40B/2-26

PRODUCTION RQT

Westinghouse was required to demonstrate full compliance with the specified requirement of 100 hours MTBF (125 hours excluding ground mapping modes). This production RQT was to be conducted in accordance with the test plan used for FSD, and was performed on 5 of the first 25 deliverable production radars. Compliance with MIL-STD-781B was demonstrated when Test Plan III accept criteria for number of failures versus operating times were met. The results of the Production RQT are also shown in the following table.

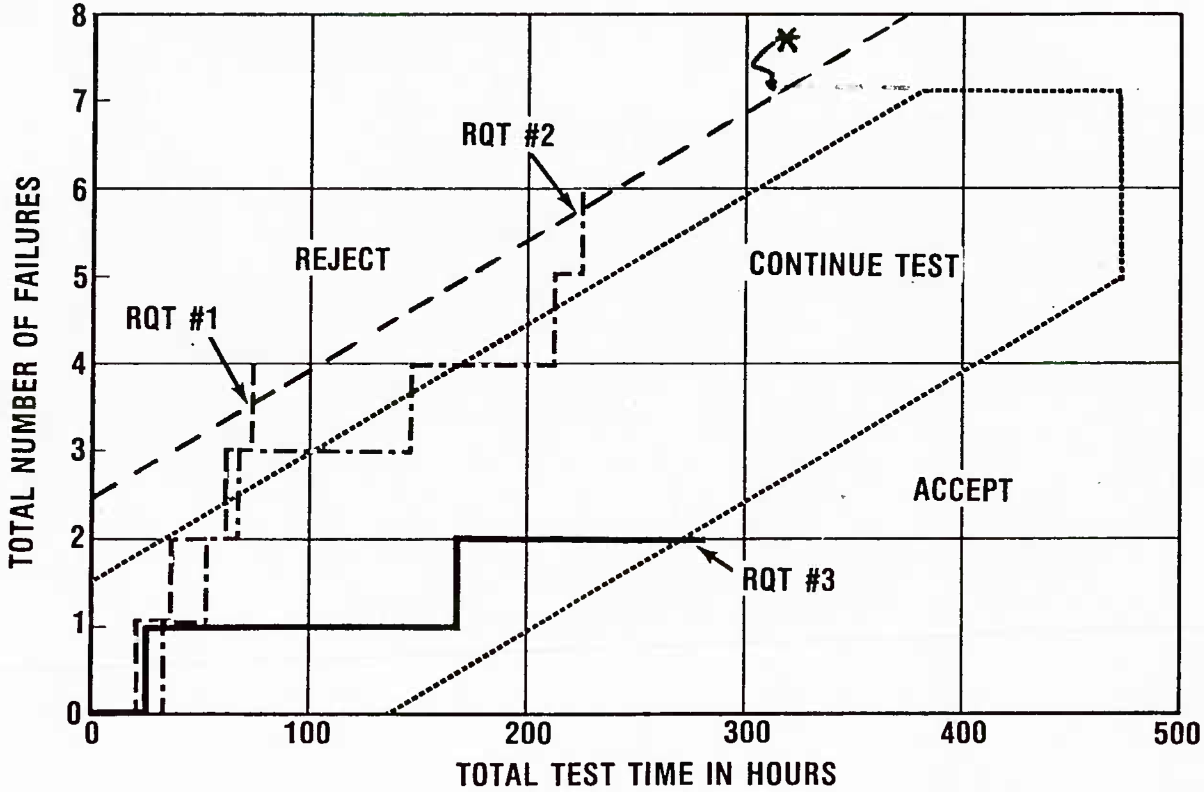
	Attempt No.	Test Hours	Total Hours	Relevant Failures	Corrective Actions
Prod RQT	1	80	192	4 (failed)	21
	2	229	364	6 (failed)	24
	3	271	400	2 (passed)	10
					55

Sixty-five corrective actions were made for failures that occurred during RQT as well as for problems identified while troubleshooting.

RADAR PRODUCTION RQT PASS/FAILURE CRITERIA

SPECIFIED MTBF (θ_0) = 97 HOURS

TEST PLAN IV*

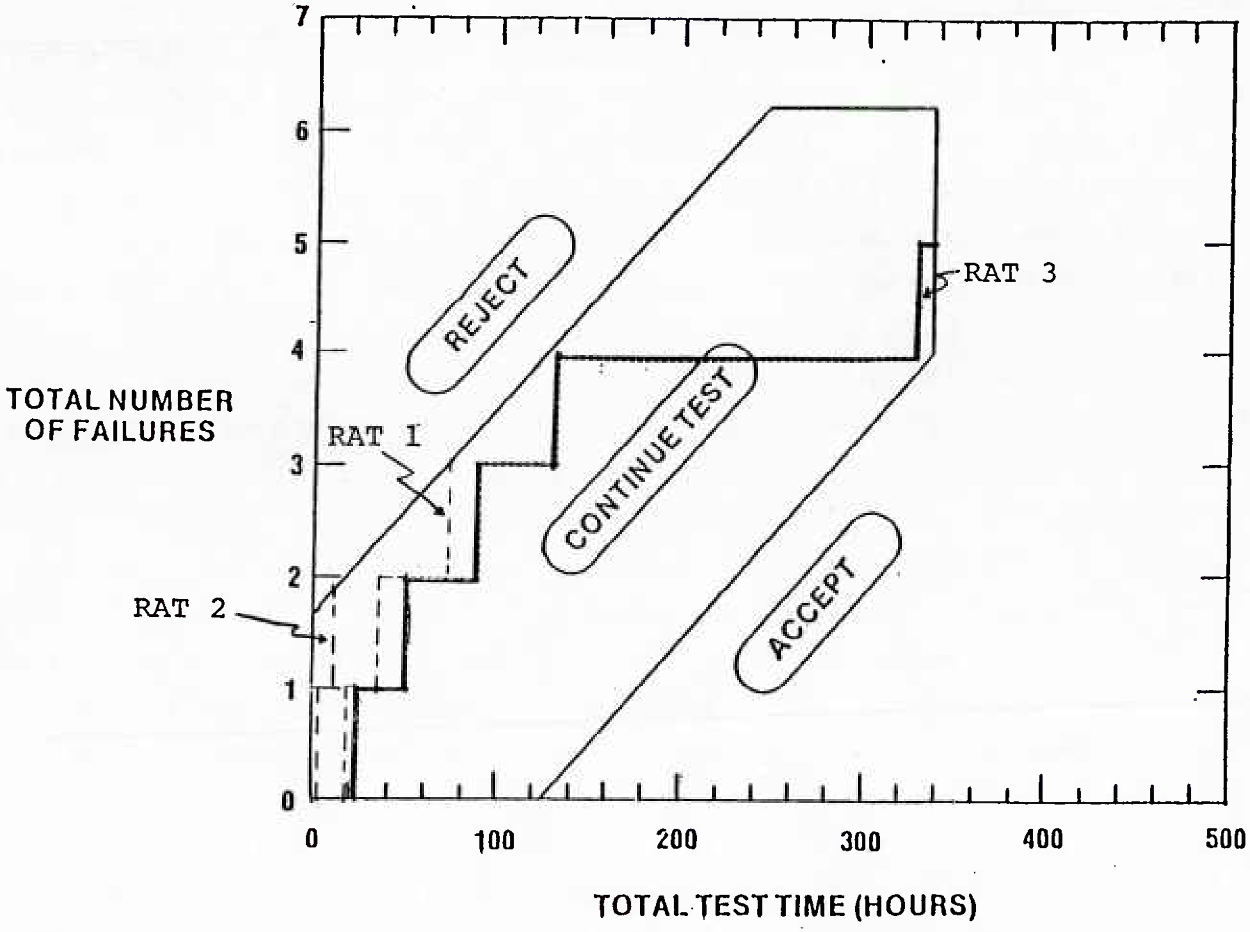


2-9-83-7 *RQT #1 and #2 were conducted using Test Plan III.

PRODUCTION RELIABILITY ACCEPTANCE TESTS

Reliability acceptance testing (RAT) began on November 17, 1980 and was completed on September 30, 1982. Two attempts resulted in reject decisions. Testing was conducted in accordance with MIL-STD 781B, Test Plan V, Level F, amended to include random vibration and a lower test temperature of -40°C. RAT 3 demonstrated that the radar meets the specified MTBF (θ_O) of 97 hours.

APG-66 PRODUCTION RELIABILITY ACCEPTANCE TESTS



RELIABILITY ACCEPTANCE TEST

The first Reliability Acceptance Test was initiated on November 17, 1980 and was stopped on January 28, 1981. Four systems were used for the test.

A test reject condition was reached when the fifth test failure occurred at the 75-hour test point. During the 161 hours of reference testing and troubleshooting (non-test hours), 18 additional failures were identified. All failures were evaluated for cause and possible corrective action. For the total of 23 failures, the causes of failure were identified for 14 failures, while 9 were for unknown causes. Twelve corrective actions were taken to correct the 14 failures for which the causes of failure were known.

The second RAT attempt began on July 2, 1981 and was stopped on July 18, 1981. Two systems were tested. A test reject condition was reached when the second test failure occurred at the twelve-hour test point. During the 49 hours of reference testing and troubleshooting (non-test hours), nine additional failures were identified. All failures were analyzed for cause and possible corrective action. For the total of 11 failures, the causes of failure were identified for 10 failures while one was for unknown causes. Nine corrective actions were taken to correct the 10 failures for which the causes of failure was known.

The third attempt of the RAT was started on November 20, 1981 and was successfully completed on 30 September 1982. During this period, 335 test hours were accumulated with five relevant failures. This test demonstrated that the radar meets the specified MTBF (θ_O) of 97 hours. Eight systems were used for the test. During the 85 hours of reference testing and troubleshooting (non-test hours) 25 additional failures were identified.

All failures were analyzed for cause and possible corrective action. For the total of 30 failures, the causes of failure were identified for 26 failures while 4 were for unknown causes. Twenty-six corrective actions were taken to correct the 26 failures for which the causes of failure were known.

RELIABILITY ACCEPTANCE TESTS

		HOURS[A]			FAILURES		
	SYSTEM NO.	TEST	NON-TEST	TOTAL OPERATING	TEST	NON-TEST	TOTAL
TEST #1	1R	15	52	67	2	5	7
	2R	22	37	59	1	4	5
	3R	17	31	48	1	6	7
	4R	21	41	62	1	3	4
	TEST 1 TOTALS	75	161	236	5	18	23
TEST #2	1A	0.1	27	27	1	3	4
	2A	12	22	34	1	6	7
	TEST 2 TOTALS	12	49	61	2	9	11
TEST #3	1	21			0	2	2
	2	21			1	1	2
	3	31			1	3	4
	4	61			1	1	2
	5	81			1	4	5
	6	76			0	2	2
	7	21			0	10	10
	8	23			1	2	3
	TEST 3 TOTALS	335	85	420	5	25	30

[A] HOURS MAY NOT ADD DUE TO ROUNDING.

RELIABILITY ACCEPTANCE TEST CORRECTIVE ACTION SUMMARY

A summary of the corrective actions taken as a result of the three reliability acceptance tests is shown. The failures for which the corrective actions were taken identify the most probable cause of failure by failure type. The three types of failures used here are component, design and workmanship.

RELIABILITY ACCEPTANCE TESTS CORRECTIVE ACTION SUMMARY

	LRU	XMTR			COMP			LPRF			ANT			DSP		
	FAILURE TYPE	C	D	W	C	D	W	C	D	W	C	D	W	C	D	W
TEST #1 ●	# OF CORRECTIVE ACTIONS	0	1	0	0	0	0	2	1	0	2	4	1	1	0	0
TEST #2 ●	# OF CORRECTIVE ACTIONS	0	0	0	0	0	1	2	0	3	1[A]	1	0	1	0	0
TEST #3 ●	# OF CORRECTIVE ACTIONS	0	1	0	1	0	0	1	6	4	0	6	2	4	0	1

C = COMPONENT D = DESIGN W = WORKMANSHIP

[A] VENDOR WAS DISQUALIFIED

40A/23-1

MAINTAINABILITY DEMONSTRATION

A maintainability demonstration was performed on the radar system to verify that O-Level and I-Level requirements were met. The demonstration was based on Method 9 of MIL-STD-471 and utilized tools, test equipment, personnel and technical data closely approximating that to be used for operational support. This exercise verified the self-test/built-in-test capabilities of the system and provided a measure of corrective task times associated with system repair. One hundred and fifty simulated faults were inserted into the system. Quantitative distribution of the faults (to the LRU/SRUs) was based on the predicted relative failure frequency of each unit, with a minimum of one fault being inserted on each SRU.

Dedicated test articles were required for R&M. Often not enough assets are provided in the development phase to accomplish the planned tasks in a timely manner. In this program, two systems were planned for growth testing and three for development RQT; however, because of additional modes hardware and software requirements, two systems were released for other purposes and the maintainability demonstrations were delayed.

F-16 O-LEVEL MAINTAINABILITY DEMONSTRATION REQUIREMENTS AND RESULTS

- MAINTAINABILITY DEMONSTRATION REQUIREMENTS
  - 150 FAULTS TO BE INSERTED INTO SIX LRUs
    - DISTRIBUTED ACCORDING TO RELATIVE FAILURE RATES
    - SELECTED VIA RANDOM NUMBER GENERATION
  - EACH SRU (79 TOTAL) SHALL HAVE AT LEAST ONE FAILURE INSERTED

- MAINTAINABILITY DEMONSTRATION RESULTS

	O-LEVEL		I-LEVEL	
	SPEC REQ.	DEMO RESULT	SPEC REQ.	DEMO RESULT
FAULT DETECTION	94%	94%	-	-
FAULT ISOLATION	95%	98%	96%	96%
MEAN TASK TIME	.5 HR	<15′/50″	1 HR	58′/0″
MAX. TASK TIME	1.0 HR	15′/50″	2 HR	1 HR/48′/3″

MAINTAINABILITY GROWTH PLAN

Westinghouse initiated a maintainability growth program in the very early stages of the development phase to track the growth of ST/BIT and other maintainability features of the APG-66 radar. The growth plan established procedures for data collection, failure reporting, problem area review, and corrective action. This plan provided a method of tracking the growth and effectiveness of maintainability features and test philosophy of the F-16 radar.

MAINTAINABILITY GROWTH PLAN

- ≈ 45 MONTHS OF SYSTEM TEST TIME AT WESTINGHOUSE EXCLUDING FACTORY ACCEPTANCE TEST
- FAILURE REPORTS
- ST/BIT/M EFFECTIVENESS DATA COLLECTED VIA TAPE RECORDED TELECONS
- ABOVE REPORTING PROVIDES:
  - LARGE DATA BASE
  - REPAIR/RETEST CONCEPT IMPLEMENTED EARLY IN FSD
  - MEASURED EFFECTIVENESS OF: FACTORY TEST EQUIPMENT
    ACCEPTANCE TEST SPECIFICATION
    SYSTEM TEST SPECIFICATION
    ST/BIT/M

PRE-DEMO FAULT INSERTION

A fault insertion program was instituted by Westinghouse during the development phase of the program in an effort to achieve early visibility in the area of ST/BIT effectiveness. This testing, conducted prior to any formal MIL-STD-471 demonstration, provided valuable insight relative to potential improvements in ST/BIT mechanization. The results of these incremental tests are included in the attached figure.

PRE-DEMO FAULT INSERTION STATUS

	NO. OF SRUs FAULTED	FAULTS DETECTED FAULTS INSERTED	NO. OF TESTS EXERCISED
ANTENNA	5	54/56	13
LPRF	11	80/120	30
TRANSMITTER	8	27/33	14
DSP	27	958/1090	19
COMPUTER	13	86/103	17
RCP	3	43/60	6
TOTAL	67	1248/1462 = 85%	99

DT&E FLIGHT TEST

The DT&E (FSD) flight test effort was accomplished using several airplanes over a 2-1/2 year period. Several organizations and bases were involved. Most of the testing was done at Air Force bases with contractor support in varying degrees.

The pre-FSD testing began during the Air Force sponsored flight test model evaluation, first by the two radar competitors--Hughes and Westinghouse, and later by the winner--Westinghouse. The purpose of this testing was to gather engineering data to evaluate end-to-end radar performance in the air-to-air modes. Testing was in a relatively benign environment using F-4 air vehicles with non-F-16 avionics.

The FSD flight test program tested the radar in the F-16 air vehicle with a full complement of avionics. Radar performance data were gathered during this period. Included in the data were evaluations of the self test and built-in-test, reliability and maintainability. As the testing procedures progressed, design changes were incorporated and tested. This progress soon resulted in the installation of production hardware into the FSD flight test program, and later, design changes to the production equipment. The testing satisfied all the formal requirements of the air vehicle and procurement specifications.

Reliability and maintainability engineering personnel followed the DT&E flight test through all phases. During the F-4 flights at fly-off competition at General Dynamics, failure data were analyzed and utilized in the selection process. During F-16 radar flights for development and R&M demonstration at General Dynamics and Edward AFB, R&M personnel from GD and Westinghouse were assigned for data gathering, analysis and corrective action. Hands-on maintenance was accomplished and maintenance times verified.

A large amount of the testing and evaluation was accomplished by the Multinational Operational Test and Evaluation (MOT&E) group. This special Air Force testing organization was located at Hill AFB, the first operational TAC base for F-16. The testing at Hill had a heavy emphasis on self test/built-in-test evaluation, as well as overall radar usability in the F-16 aircraft in a field environment using standard Air Force maintenance personnel, facilities, and procedures.

DT&E FLIGHT TEST

- TEST AIRCRAFT

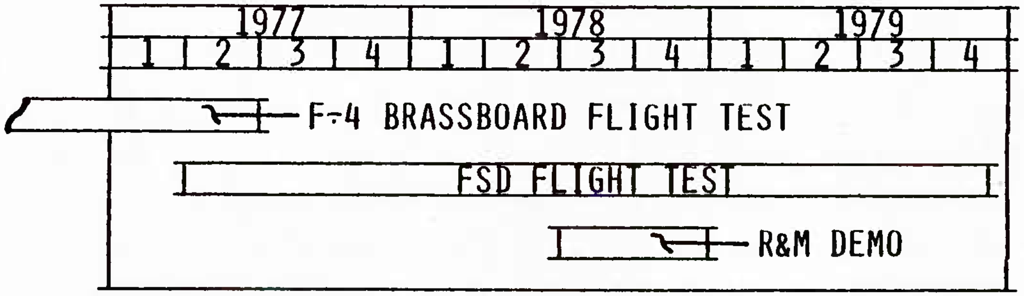
  ONE F-4 -- RADAR DEVELOPMENT

  FOUR F-16s -- RADAR DEVELOPMENT

  TWO F-16s -- R&M DEMONSTRATION

• 181 FLIGHTS USING BRASSBOARD RADAR	~1.2 HRS/FLT =	217
• 441 FLIGHTS USING FSD RADARS	~1.5 HRS/FLT =	662
• 1241 FLIGHTS USING PRODUCTION RADARS	~1.5 HRS/FLT =	1862
	~ TOTAL	2741

••• PLUS AN ADDITIONAL ~254 FLIGHT HOURS SPECIFICALLY FOR RELIABILITY AND MAINTAINABILITY



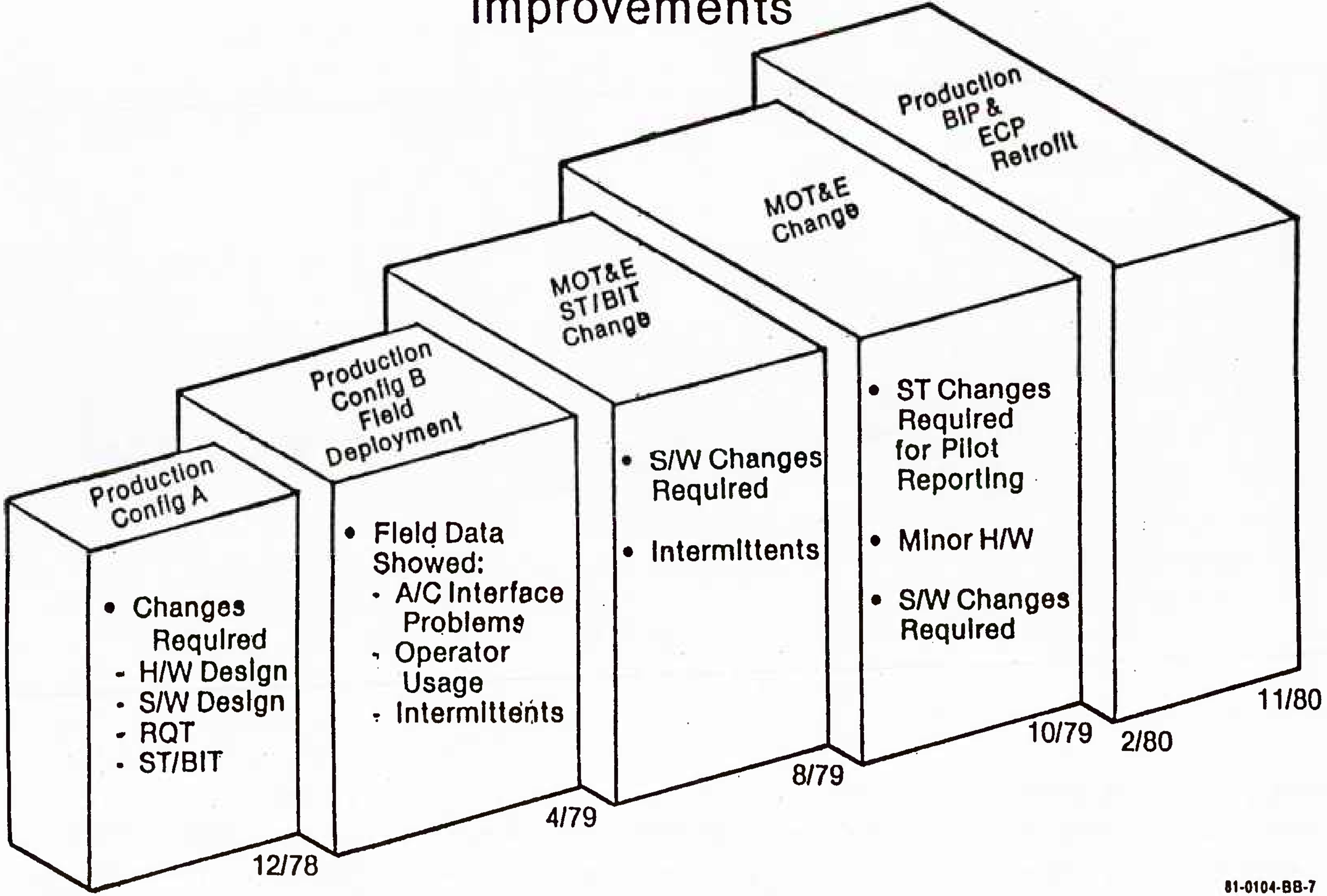
AN/APG-PRODUCTION IMPROVEMENTS

Initial APG-66 radar production deliveries to the F-16 aircraft started in June 1978. As a result of these aircraft integration tests, RQT, and other engineering tests, a number of hardware and software changes were instituted as depicted in the chart.

The first fleet activation occurred in January 1979 at Hill AFB, Utah. A number of design problems were revealed as a result of the operator using modes in different roles than anticipated, aircraft interface problems, and intermittent malfunctions due to system transients. Design changes to correct these problems were incorporated into Configuration B improvements.

In 1979, USAF user personnel requested additional changes in the ST/BIT mechanization. GD/W/& MOT&E personnel met and set up a task team to test and evaluate a new ST/BIT mechanization and submit a correction of deficiency system design change. The following charts reflect the new ST/BIT mechanization. These design changes were flight tested at Hill AFB, Utah, by MOT&E personnel and approved for fleet retrofit by SPO in the fall of 1979. After these changes, the number of flights occurring without an MFL increased from 35% in 1979 to 92% in the fall of 1982.

AN/APG-66 Production Improvements



Production Config A

- Changes Required
  - H/W Design
  - S/W Design
  - RQT
  - ST/BIT

12/78

Production Config B Field Deployment

- Field Data Showed:
  - A/C Interface Problems
  - Operator Usage
  - Intermittents

4/79

MOT&E ST/BIT Change

- S/W Changes Required
- Intermittents

8/79

MOT&E Change

- ST Changes Required for Pilot Reporting
- Minor H/W
- S/W Changes Required

10/79

Production BIP & ECP Retrofit

2/80

11/80

81-0104-BB-7

AN/APG-66 PRODUCTION IMPROVEMENTS

The overall objective of the team effort (GD/W/MOT&E) was to logically approach the problems being experienced with ST/BIT on the Radar. The approach included three phases to adequately define the problems based on field data collected at the time, evaluate potential corrections and assure that they were consistent with USAF maintenance philosophies and then develop an implementation approach to incorporate the changes into the F-16 aircraft fleet.

MOT&E COMMITTEE PLAN FOR EVALUATING ECP 30 ST/BIT PROGRAM

COMMITTEE MEMBERS: AFTEC, SPO, GD AND W

PHASE I

- COLLECTION OF DATA FROM EAFB AND COMMITTEE EVALUATION
- MODIFY MOT&E A/C
- COLLECT AND EVALUATE DATA FROM MOT&E AND ESTABLISH M CONCEPT POLICIES AND PROCEDURES (2-4 WEEK INTERVAL)

PHASE II

- REAFFIRM GROUND RULES AND POLICIES EMPLOYED ON M CONCEPT AND PROCEDURES
- PERIODIC COMMITTEE EVALUATION OF RESULTS
- UPDATE GROUND RULES AND DATA COLLECTION TECHNIQUES

PHASE III

- DECISION ON THE IMPLEMENTATION OF ST/BIT PROGRAM INTO THE FLEET

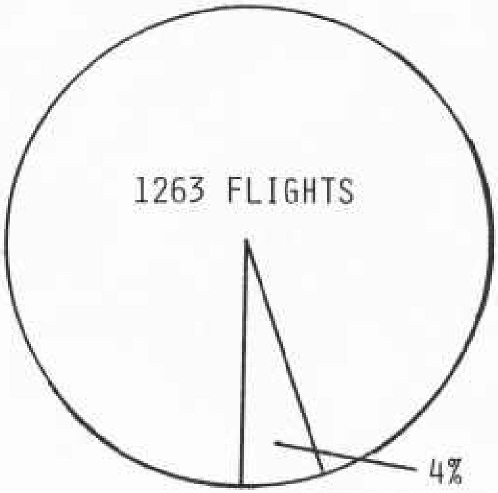
MOT&E DATA ANALYSIS

The MOT&E conducted between March and December 1980 consisted of 1317 total flights. Only 54 flights (4%) had catastrophic fault reports which led to the conclusion that previous nuisance indicators of self test failures had been resolved.

MOT&E DATA ANALYSIS

(3/80 TO 12/80)

1317 TOTAL FLIGHTS



54 FLIGHTS WITH CATASTROPHIC FAULT REPORT

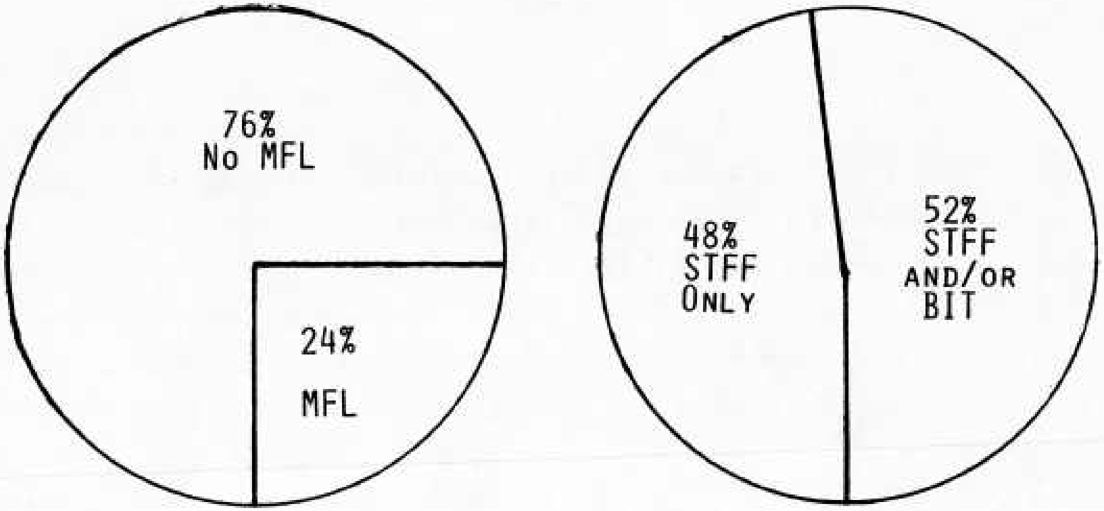
MOT&E DATA ANALYSIS

Additional analysis of MOT&E data suggest that only 11.5% of flights required Self Test Fault Flag (STFF) usage (worst case). Once the Maintenance Fault Test Report was cleared by LRU removal, everything worked. Performance, reliability, availability and ST/BIT were all good. In addition, the STFF is a good indicator of system degradation.

MOT&E DATA ANALYSIS

(3/80 THRU 12/80)

1317 FLIGHTS ANALYZED
9 A/C



MOT&E DATA ANALYSIS

The Avionic System ST/BIT concept implemented on newly developed hardware for the F-16 weapon system is characterized by two types of test(s): (1) Self-Test; automatic, non-interruptive tests intended to detect failures or out-of-tolerance conductions and (2) Built-In-Test; interruptive of normal operation and are used primarily to supplement ST in isolating faults to an LRU. Further, the concept includes provisions to report malfunctions to the pilot that: (1) require his attention or (2) reduce capabilities. The requirements imposed on F-16 avionic subsystems include detection of 95% of malfunctions and isolation of 95% of detected malfunctions to a single LRU.

The APG-66 Radar, instead of implementing ST/BIT at the LRU level (which may not have been practical) implemented it at the system level which consisted of six (6) LRUs. This coupled with the nature of Radar systems, in general, makes setting of sensitivity thresholds for ST/BIT criteria difficult in a dynamic environment. The charts shown on the next two pages indicate the results of early testing and the need for additional development and refinement of ST/BIT for the Radar System.

WHAT WERE THE PILOT-NOTED PROBLEMS AFFILIATED WITH SELF-TEST AND BUILT-IN TEST? (BLOCK B)

- SELF-TEST REPORTS OCCURRED IN-FLIGHT TOO OFTEN, ILLUMINATED THE MASTER CAUTION LIGHT, AND THE PILOT DEBRIEF REPORT STATED:
  - FREQUENTLY THE RADAR WORKED OK
  - FREQUENTLY, CAN'T RUN BIT DURING FLIGHT, PARTICULARLY AT TIME OF SELF-TEST FAILURE REPORT
  - FREQUENTLY NO FAILURES NOTED WHEN BIT WAS RUN
  - CONCLUSION: FAULTS REPORTED IN-FLIGHT BY SELF-TEST WERE OF LIMITED VALUE TO THE PILOT

40A/29-2

PILOT-NOTED PROBLEMS

For the Radar system, redefining the objectives of Self Test and Built-In Test in view of the problems experienced in the field became necessary.

In that the Radar performed essentially end-to-end self-test of the system, fault isolation to a single LRU by built-in-test proved to be difficult without additional system level information. Many of the in-flight out-of-tolerance conditions detected (either correctly or erroneously) were not duplicatable back on the ground in a non-dynamic Radar environment. Because of the problem experienced early, confidence in ST/BIT test as a measure of acceptable performance of the Radar was considerably reduced and resulted in numerous manhours being expended in trying to duplicate problems. When the Radar experienced hard failures/non-dynamic situations, Built-In-Test satisfactorily detected and isolated the problems during ground testing.

APG-66 ST/BIT PROBLEMS INCURRED AT HAFB
WITH BLOCK B CONFIGURATION

- SELF-TEST REPORTS DO NOT PROVIDE AN INDICATION OF WHICH LRU IS DEFECTIVE
- FREQUENTLY POSTFLIGHT MAINTENANCE FAILS TO REPRODUCE IN-FLIGHT ST REPORTS
- SELF-TEST PROBLEM CREATED THE FOLLOWING SITUATIONS:
  - PILOT HAS LITTLE CONFIDENCE IN SELF-TEST OR BUILT-IN TEST
  - MANY MAINTENANCE HOURS SPENT TRYING TO DUPLICATE SELF-TEST/BUILT-IN TEST REPORTS
  - MANY CNDs AND RTOKs DUE TO "SHOT-GUN" REMOVAL OF LRUs
- BUILT-IN TEST IS NOT A PROBLEM
  - LRUs REMOVED FOR BIT REPORT ARE USUALLY DEFECTIVE

F-16 APG-66 RADAR IMPROVEMENTS IN ECP-331

At the ECP 331 change block point several changes were made to the self test (ST) and built-in-test (BIT) implementation. A number of detailed problems were uncovered and corrected. These are listed on the facing chart. The corrections consisted of software changes to permit proper sequencing and timing to prevent false reports. In a few isolated cases, certain tests were masked when a failure was detected in other related tests.

A major re-mechanization was implemented for the ST. A separate radar list was generated for reporting only radar self tests. These data were sent to the FCC for storage and future recall. Additional technical order data were generated to enable maintenance crews to utilize the ST data on the ground in conjunction with BIT reports and pilot comments to better isolate failures to specific LRUs or to prevent the removal of LRUs when the report was initially intermittent. The re-mechanization also increased the number of catastrophic fault reports which are reported to the pilot via the master caution light (MCL). And, in addition, a general report (ST fail) was removed from the MFL to prevent nuisance occurrences to the pilot. As a result of this re-mechanization, the cannot duplicate (CND) rate was reduced by approximately 3:1 from aircraft with the old mechanization.

F-16 APG-66 RADAR IMPROVEMENTS
IN ECP-331 THAT CORRECT
BLOCK B ST/BIT PROBLEMS

- ST/BIT SOFTWARE CORRECTIONS AND IMPROVEMENTS SUMMARY:

- TRANSMITTER PEAK DETECT FAILURE
- TRANSMITTER HIGH VOLTAGE FAILURE
- TRANSMITTER CALIBRATION FAILURE
- MSL 2001 REPORT
- ANTENNA DRIVE DEFECTIVE
- SYNCHRONIZER TEST FAILURE
- T_X PEAK, DETECTOR FAILURE AT TOF
- ST REPORTS BEFORE REQUIRED WARM-UP
- BIT 6450 REPORTS AT INITIAL TURN-ON
- TRANSMITTER PEAK DETECT FAILURE IN DBS MODE
- MSL 2001 REPORTR AT RADAR TURN-ON
- MSL 2001 REPORTS DURING ST
- INTERMITTENT RECEIVER VERIFICATION FAILURE
- SELF-TEST FAILURES NOT DUPLICABLE ON GROUND
- ONLY CATASTROPHIC FAULT REPORTS ILLUMINATE MCL

F-16 APG-66 RADAR IMPROVEMENTS
IN ECP-331 THAT CORRECTED
BLOCK B ST/BIT PROBLEMS (CONT'D)

- COMPUTER HARDWARE CHANGES TO ELIMINATE HANG-UP CONDITION (1005)
- ANTENNA FLIPPER HARDWARE CHANGE AND RETROFIT
- SYSTEM OFP SOFTWARE CHANGES THAT AFFECT ST/BIT
  - SYSTEM CALIBRATION ROUTINES MODIFIED TO MEET OPERATIONAL SCENARIO
  - TRANSMITTER PROTECTION AND CONTROL LOGIC MODIFIED
  - ANTENNA OVERTEMPERATURE LOGIC MODIFIED
  - A/C INTERFACE MODIFICATIONS
    - SQUAT SWITCH BOUNCE
    - ECS SHUTDOWN
    - INU DOWN ACCOUNTED FOR
  - DSP INITIALIZATION HEADER WORD FIX
  - COMPUTER HANG-UP RESTART LOGIC MODIFIED

APG-66 RADAR IMPROVEMENTS

During and after the evaluation phase of field testing, a number of candidate changes were identified (some flight tested) for inclusion in the hardware and software to improve Radar ST/BIT reliability and utility.

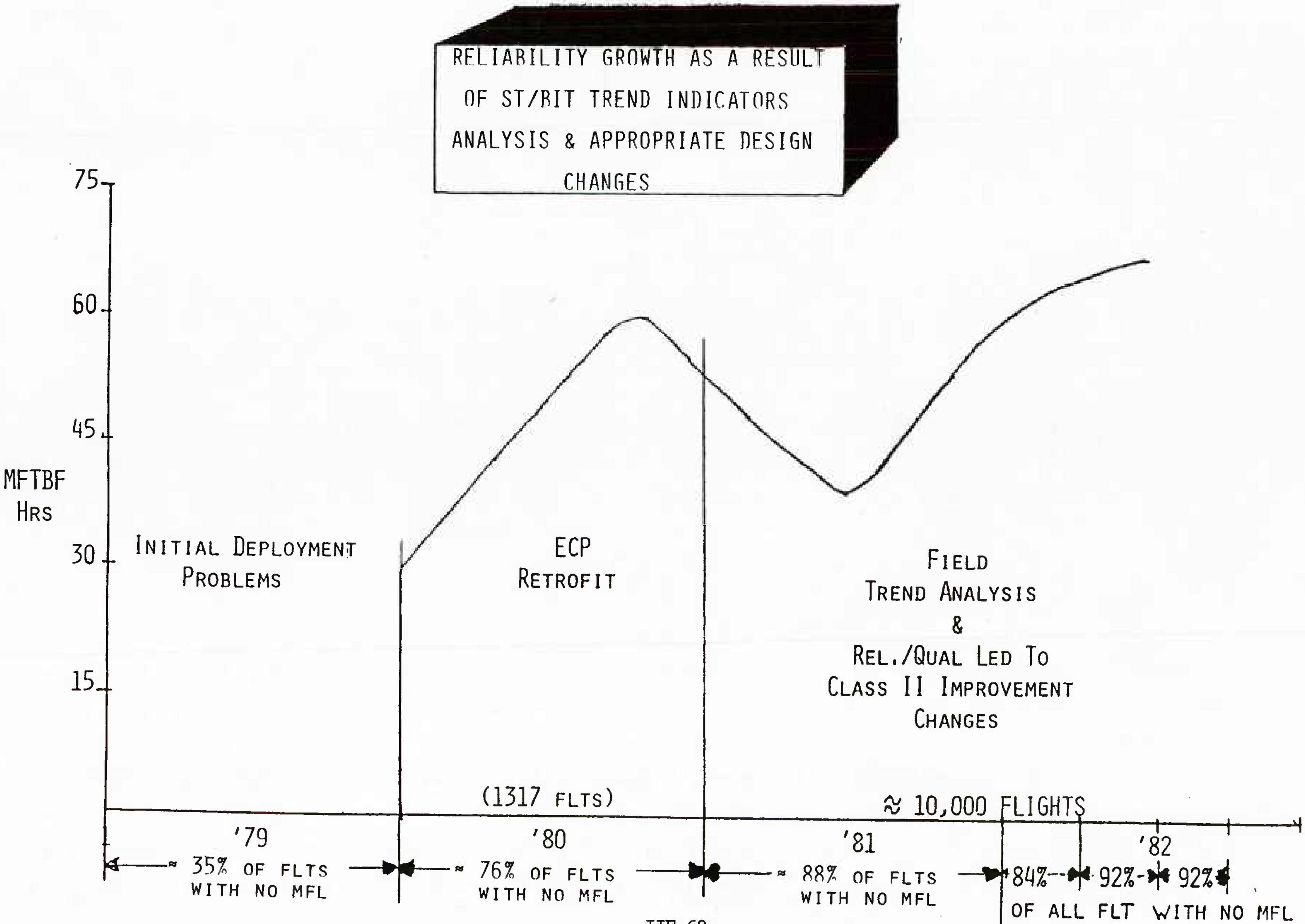
A joint GD/W/AF decision was made with regard to incorporating needed changes into the airborne hardware. The items listed on the facing page regarding ST/BIT were included in ECP 331. The ST/BIT restructuring minimized the possibilities of CNDs while at the same time improved the meaningfulness of faults reported to the pilot. The changes subsequently restored pilot and ground maintenance crew confidence in Radar ST/BIT as a reliable maintenance tool.

CHANGES INCLUDED IN ECP-331 REGARDING SELF-TEST REPORTING SYSTEM

- CATASTROPHIC FAULT REPORTS INCREASED TO 31 TESTS
- 6 WORDS (80 BITS) SENT TO THE FCC IN SELF-TEST, INDICATING THE FAILED PARAMETER
- LOGIC CHANGE TO ELIMINATE ST REPORT FLAG FROM ILLUMINATING THE A/C MASTER CAUTION LIGHT
- MASTER CAUTION LIGHT ILLUMINATES AS A FUNCTION OF CATASTROPHIC FAULTS, ONLY (1010)
- MAINTENANCE FAULT LIST (MFL) CONTINUES TO STORE 1010's, 6002's, BIT REPORT NUMBERS, AND THE NEW ST FAULT FLAG REPORTS
  - NEW ST FAULT FLAG REPORTS STORED IN SEPARATE LIST (RST)

RELIABILITY GROWTH THROUGH ST/BIT

Performance and fault circumstance data obtained through the self test/built-in-test capability of the radar allowed identification and correction of problem areas in field use. The availability of the self test/built-in-test data permitted ST/BIT performance analysis. This identified design improvements which improved reliability growth.



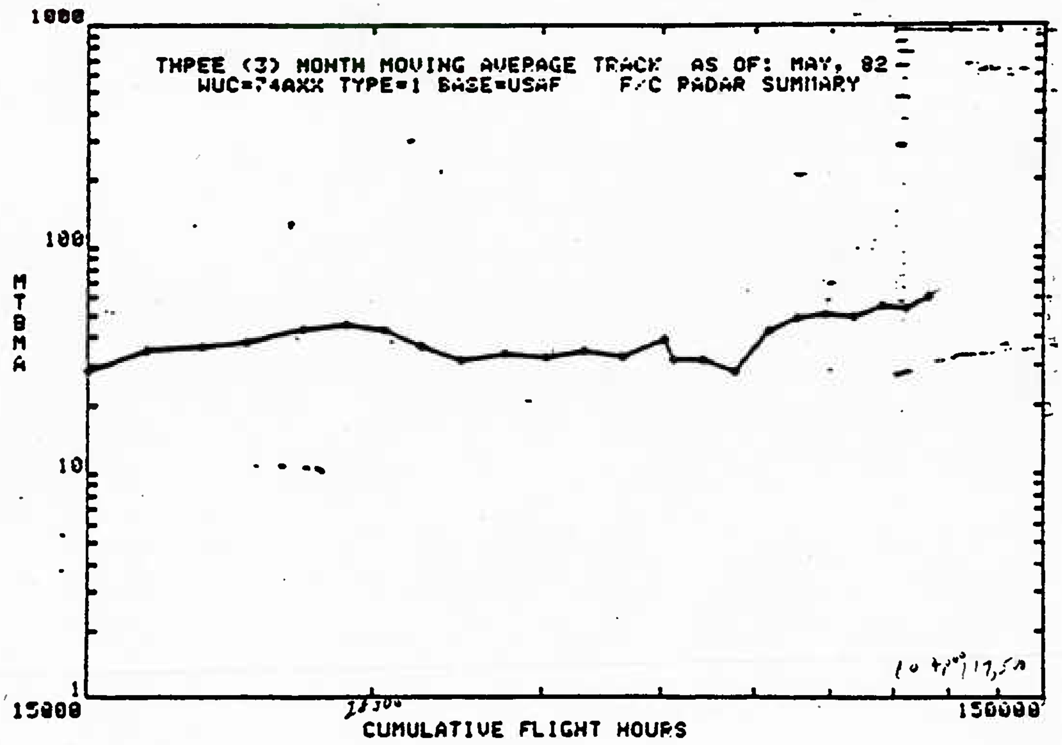
RELIABILITY GROWTH AS A RESULT OF ST/BIT TREND INDICATORS ANALYSIS & APPROPRIATE DESIGN CHANGES

RBP 11/29/82

IN-SERVICE ASSESSMENT

These figures show some selected data from in-service operations of the F-16 APG-66 radar. The chart shows MTBMA as a function of cumulative flight hours. Problems such as the radar drive band breakage, chafing of the wire harness, and transistor failures in the AZ compensation assembly prevented the results from attaining higher levels. As a result of field data and laboratory evaluation of these problem areas, corrective action has been identified and is being incorporated. The MTBMA trend is upward as the number of flight hours passes 104,000. The 3-month moving average MTBMA by May 1982 is better than 60 hours.

APG-66 RADAR MTBMA
VS. CUMULATIVE FLIGHT HOURS



LESSONS LEARNED

Competition has many benefits--the most obvious being cost. When performance of the requirements is linked with incentive (either monetary or assignment of additional liability), the resolve to perform is emphasized early and stressed throughout the development and subsequent production phases.

The generation of requirements should follow a controlled logic supported by sufficient rationale to justify the requirements. Contribution by all participants who can ultimately agree on the requirements normally adds to the commitment that must be followed.

Good results are obtained when the government engages in cooperative efforts with the reputable contractors to develop requirements, thereby avoiding unacceptable extensions of the technological state of the art and causing unwarranted performance and reliability expectations as well as high costs. Support requirements should also be a primary consideration in developing a new system concept.

The ability of contractors to be flexible during early development is enhanced by a prime/sub relationship. This allows the two parties to make needed changes without having to follow a lengthy chain of command. The integration of the APG-66 into the overall weapon/aircraft system was much smoother due to the contractual arrangement used during the FSD and early production phases.

LESSONS (RE)LEARNED

- COMPETITION IS A KEY MOTIVATOR
- RELIABILITY AND MAINTAINABILITY MUST BE STATED AS REQUIREMENTS -- NOT GOALS
- INCENTIVES WORK TO EMPHASIZE REQUIREMENTS
- DEVELOPMENT OF REQUIREMENTS REQUIRES PARTICIPATION OF BUYERS AND SELLERS TO ASSURE THAT THEY ARE RATIONAL AND REASONABLE
- MIL-STD-470 NEEDS TO BE REVISED
- THE PRIME/SUB RELATIONSHIP OFFERS INTERFACE SIMPLICITY, FLEXIBILITY, AND FREEDOM TO MAKE CHANGES IN THE FORMATIVE STAGES OF THE PROGRAM

Cost and/or liability incentives have a significant impact on the attention and commitment of high-level management.

A major part of the emphasis by management is the generation of development plans for both R&M. These plans must be integrated with the system plans to be sure that the proper attention is given to R&M. Without such planning the R&M functions may tend to become satellite activities.

In order to implement the R&M plans, the initial design team must include engineers to fold maintainability and reliability into the inherent design and development process. It is through their activities that the requirements will be visible to the whole team.

The need for management of concurrent activities is normally dictated by reduced acquisition cycles. The need to maintain follow-up of the various results of concurrent activities requires an integrated knowledge of those results. All of the data from the activities such as environmental qualification, reliability qualification, maintainability demonstrations, etc., should be combined to form the appropriate corrective actions.

Asset management is a critical facet of concurrency. It is crucial that plans include dedicated hardware for R&M testing and development. As the need for hardware always exceeds the amount of hardware that is available, allocations must be planned and made. The exact number of sets of hardware required is dependent on many factors. Data from hardware use is needed for evaluation of the need for and adequacy of corrective action. Thus, the more hardware actually in use, the better the analysis data base becomes.

LESSONS (RE)LEARNED

- MANAGEMENT EMPHASIS, INFLUENCED BY COST INCENTIVES, IS A SIGNIFICANT DRIVING FORCE IN R&M SUCCESS
- R&M DEVELOPMENT PLANS MUST BE INTEGRATED WITH SYSTEM DEVELOPMENT PLANS
- THE DESIGN TEAM MUST CONTAIN AS INTEGRAL MEMBERS ST/BIT/MAINTAINABILITY ENGINEERS AND RELIABILITY ENGINEERS
- CONCURRENCY CAN BE MANAGED
- DEDICATED HARDWARE FOR R&M GROWTH AND TEST MUST BE PLANNED AND ALLOCATED

40A/28-3

Parts selection and control are of prime importance in achieving high reliability and keeping low levels of maintenance.

The inclusion of the suppliers of the parts as members of the team is one way to maintain their support. The main incentive for these suppliers is volume. Other types of incentives are difficult to apply to piece part suppliers.

The specifications outlined for MIL-M-38510 parts are not sufficiently defined or controlled for parts which must operate in high data rate applications. The screening requirements for these devices are also inadequate. As a result, Westinghouse has imposed 100% testing of all such components over temperature to ensure that they will operate in the specific application.

While much effort and attention is being focused on higher technology for digital devices very little attention is being focused on analog components for improved reliability and performance. RF devices are components which deserve particular attention.

The ability to pass down R&M requirements is in many cases difficult to accomplish because of the ability of many suppliers to accept such requirements without excessive capital investments. Small businesses are of particular concern. In most cases significant assistance is required to bring their manufacturing and quality capabilities up to their design capabilities. The assistance from government personnel is also vital.

LESSONS (RE)LEARNED

- MANUFACTURERS OF MILITARY PARTS MUST BE A PART OF THE TEAM--VOLUME IS THE KEY INCENTIVE
- SCREENING AND CHARACTERIZATION OF PARTS IS NECESSARY IN CURRENT AND FUTURE HIGH DATA RATE ELECTRONICS. MIL-M-38510 AND MIL-STD-883 ARE NOT ENOUGH
- MAJOR EMPHASIS ON TECHNOLOGY IMPROVEMENTS IS ON DIGITAL COMPONENTS--ANALOG DEVICES RECEIVE LESS ATTENTION--PARTICULARLY RF DEVICES
- DOLLAR PERCENTAGES ARE SPECIFIED FOR SMALL BUSINESSES--PASS DOWN OF REQUIREMENTS (MIL Q 9859, ETC.) ALSO SPECIFIED--TWO EXTREMES DICTATE ASSISTANCE

40A/28-4

The application of development through IR&D in advance of firm requirements was of significant importance toward the development of the APG-66. A major part of the activity on the Westinghouse WX series radar was aimed at improved reliability and maintainability.

The tools of computer designs, thermal analyses, maintainability/reliability predictions, trade-offs, etc., if properly applied, will provide a baseline design which has a fundamental R&M capability. Without such a baseline the management of subsequent problems becomes intolerable. The APG-66 has a sufficient base inherent in the early design to allow for the management of problems and the subsequent corrective actions for those problems.

The development of the ST/BIT during the development of the radar was key to ensuring that the maintainability requirements could be achieved. ST/BIT has proven to be an important tool in evaluating the reliability of the radar. This is due largely to the fact that the ST/BIT development was integral with the overall radar development.

The continuation of design support after development is important in determining corrective actions throughout the production and operational phase. An understanding of this by cost analysts on production quotes is important.

LESSONS (RE)LEARNED

- INDEPENDENT R&D IS A FEEDING FUNCTION FOR FUTURE IMPROVEMENTS
- USE OF PRUDENT DESIGN TOOLS, ANALYSES, TRADE-OFFS, ETC., PROVIDE AN INHERENTLY GOOD DESIGN--A MUST FOR MANAGEMENT OF PROBLEMS THAT OCCUR
- ST/BIT DEVELOPMENT, INTEGRATION AND CHECK-OUT MUST BE CONCURRENT WITH SYSTEM PERFORMANCE DEVELOPMENT
- DESIGN SUPPORT THROUGHOUT PRODUCTION IS ESSENTIAL FOR CORRECTIVE ACTION

Exposure to environment and insertion of faults prior to formal R&M tests is an effective means of identification of problem areas which require corrective action. Incorporation of such corrections prior to the tests provides for a thorough evaluation during the testing.

For many years there has been concern about the differences between laboratory and field reliability. The application of random vibration over environment has provided a more accurate simulation of field conditions and allowed for corrective action which can influence the field performance.

Continuous acceptance test procedure was accomplished during all reliability testing at all environmental conditions with BIT activated at the end of each mode. The performance measurements of the ATP can then be correlated to ST/BIT performance and each checked against the other. Simulation of interfaces can also be accomplished to identify problem areas.

Follow-on reliability testing on a periodic basis is an effective means of identifying new problem areas. From the development phase through completion of reliability acceptance testing new problems were identified in each test. Although the required reliability tests have been completed, Westinghouse planned for and is continuing testing on a monthly basis to assure that any new problems are identified and corrected.

The true evaluation of R&M requirements and their effectiveness is how well they are being met in operational usage. Programs for this evaluation must be planned.

LESSONS (RE)LEARNED

- RELIABILITY GROWTH AND MAINTAINABILITY PRE-DEMO ARE INVALUABLE TOWARD GETTING EARLY LOOK AT POTENTIAL PROBLEMS AND IS AN INTEGRAL PART OF TEST AND FIX
- RANDOM VIBRATION DURING ENVIRONMENT BRINGS LABORATORY CLOSER TO FIELD CONDITIONS
- USE OF ATP RATHER THAN ABBREVIATED TEST DURING RELIABILITY TESTING ENSURES ALL ELEMENTS ARE ASSESSED
- FOLLOW-ON RELIABILITY TESTING PERIODICALLY DURING PRODUCTION IS EFFECTIVE TOWARD IDENTIFYING NEW PROBLEMS AS WELL AS MAINTAINING CONTROL
- VALIDATION OF R&M REQUIREMENTS/EFFECTIVENESS MUST INCLUDE OPERATIONAL USAGE

A key element of achieving continued reliability after development and qualification is improving factory yields. Improved yield results in lower rework and handling which are potential causes of failures. Additionally, Westinghouse experience has shown that factory problems tend to show up again in the field. Productivity improvements also affect yield and provide better field performance.

The monitoring of all in-house problems makes use of ST/BIT. This in turn allows for changes to testing based on significant trends. By using ST/BIT to identify factory problem a continuous evaluation of the effectiveness of ST/BIT is maintained.

Testing in the factory must be continually evaluated to determine that problems are not only detected but the detection is at the lowest level possible. Since most tests are controlled by approved documents, some flexibility must be allowed.

LESSONS (RE)LEARNED

- YIELD/PRODUCTIVITY IMPROVEMENTS ARE A DEFINITE FACTOR IN OBTAINING GOOD RELIABILITY
- MONITORING OF IN-HOUSE PROBLEMS CAN MEASURE EFFECTIVENESS OF ST/BIT AND ASSIST IN DETERMINING PROBLEM TRENDS
- MANUFACTURING TESTING MUST HAVE SOME FLEXIBILITY TO ALLOW FOR REDUCTION OF PROBLEMS AT HIGHER LEVELS

40A/28-7

The introduction of hardware into the operational environment introduces new variables which can affect the R&M performance. Because of these variables it is vital that a continuous evaluation of the field performance be maintained.

The normal government data are insufficient to allow for trend evaluation and subsequent corrective action. In order to obtain such data it is important that planning be made to obtain the field results.

Contractor engineering support in the field is critical to operational problem understanding, feedback and correction. Engineering support in the field has been provided by both GD and Westinghouse since the beginning of the program and has significantly assisted in solving interface problems, test equipment problems, T.O. problems, hardware and operational problems. When the Air Force decided to eliminate contractor support in late 1982, Westinghouse management felt strongly that this support was necessary in the solution of field problems and provided personnel at no additional cost to the government.

I-level testing is most critical from the point of view of accurate fault determination and verification. Results of factory test and field experience dictate modification of some tests and tolerances. Without this iterative process good units are tested bad and bad units are tested good.

The training of maintenance personnel needs to be strengthened. This is particularly important in light of the high turnover rate of technicians at a given location. Identification of aircraft interface problems is sometimes a last resort. This at times results in abnormal pull rates on specific aircraft.

The identification of a field problem and incorporation of corrective actions is impeded by the flow of technical orders. Up to 12-18 months can elapse between the identification of a problem and some relief getting to the user.

LESSONS (RE)LEARNED

- FIELD PERFORMANCE EVALUATION IS MANDATORY FOR IMPROVING R&M
- NORMAL DATA ARE INADEQUATE
- RIW PROVIDED ONE POINT OF EARLY IDENTIFICATION OF FIELD PROBLEMS
- CONTRACTOR ENGINEERING SUPPORT IN THE FIELD IS CRITICAL TO OPERATIONAL PROBLEM UNDERSTANDING, FEEDBACK AND CORRECTION
- ITERATION OF I-LEVEL TESTING IS CRITICAL TO EFFECTIVE AND ACCURATE IDENTIFICATION OF FAULTS. SITE-TO-SITE VARIATIONS IN GROUNDING AND POWER CREATE DIFFERENT TEST RESULTS
- TRAINING IS INADEQUATE; TURNOVER IS HIGH
- THE FLOW OF FORMAL TECHNICAL DATA IS TOO SLOW. NO RAPID VEHICLE EXISTS TO ALERT THE FIELD TO SPECIFIC PROBLEMS OR METHODS FOR IMPROVING MAINTENANCE

40A/28-8

An improved method to incorporate required changes, particularly early in field operations, is needed to rapidly incorporate those changes to avoid unnecessary costs and mature the systems earlier. The ECP route is very slow and costly to incorporate and unnecessarily costly in maintenance actions required before incorporation. The RIW program on the radar set the stage for a quicker change. However, it still proved very slow and a means was found to incorporate quasi-Class II changes in production and retrofit if the test equipment (AIS) was not affected. Commercial industry is far better in timeliness in correcting some deficiencies at no cost to the customer.

A key element in overcoming some of the current inhibitors is a cooperative atmosphere between the hardware contractor, the T.O. and I-level contractor, the aircraft contractor, the SPO, and the users.

LESSONS (RE)LEARNED

- CORRECTIVE ACTION IS KEY TO IMPROVING R&M
- CURRENT PRACTICES INHIBIT CORRECTIVE ACTIONS DUE TO STRICT INTERPRETATION OF MIL-STD-483
- IN-LINE BREAK INTO PRODUCTION OF CORRECTIVE ACTION WITH INCORPORATION INTO FIELD RETURNS HAS BEEN MOST EFFECTIVE
- TEAM WORK BETWEEN ALL PARTIES IS A PREREQUISITE TO ACHIEVING SUCCESS

Lessons Learned

Cost incentives are significant driving forces for obtaining management emphasis to ensure R&M success. Cost incentives operative early in the program, structured to produce significant R&M effort, can reduce life-cycle cost. Management must constantly be aware of all problems in a program and be a driving force in the solution of those problems in order to plan effectively to meet incentive objectives. Management emphasis is also a key factor in working as a team rather than in an adversary relationship. The team effort was a major contribution to the success of this program.

Contractor engineering support in the field is critical to operational problem understanding, feedback and correction. Engineering support in the field has been provided by both GD and Westinghouse since the beginning of the program and has significantly assisted in solving interface, test equipment, T.O., hardware and operational problems. When the Air Force decided to eliminate contractor support in late 1982, Westinghouse management felt strongly that this support was necessary in the solution of field problems and provided personnel at no additional cost to the government.

LESSONS (RE)LEARNED

- COST INCENTIVES ARE DRIVING FORCE FOR MANAGEMENT EMPHASIS SIGNIFICANT TO ENSURE R&M SUCCESS
- COMPETITION IS A KEY MOTIVATOR
- CONTRACTOR ENGINEERING SUPPORT IN THE FIELD IS CRITICAL TO SOLVING OPERATIONAL PROBLEM

An improved method is needed to incorporate required changes, particularly early in field operations to avoid unnecessary costs and to mature the systems earlier. The ECP route is too slow and costly in maintenance actions required before incorporation. The RIW program for the radar should have provided for quicker change, but the ECP approvals were so slow that their purpose was circumvented by other actions.

Electrostatic sensitive devices are a problem that must be dealt with not only in the manufacturer's plant but in field use as well. Early in the program it was discovered that many electrostatic sensitive devices were not marked or packaged properly in normal practice. RNC resistors were a case in point, wherein the specification had to be changed to have them marked and packed properly, which in turn made them a non-standard part. Special attention was required by Westinghouse in setting up the manufacturing area to cope with this problem in providing conductive materials in packaging work areas, grounding and the control of humidity and operating procedures. The growth in new technology with smaller and more sensitive devices will likely magnify this problem.

LESSONS (RE)LEARNED

- AN IMPROVED METHOD TO INCORPORATE REQUIRED CHANGES IS NEEDED (EXPEDITE)
- ELECTRO-STATIC DISCHARGE CAN CAUSE DAMAGE TO MICROELECTRIC PARTS AND ASSEMBLIES DURING MANUFACTURE AND REPAIR ACTIVITIES
  - SOME DEVICES TODAY ARE NOT TREATED AS ELECTRO-STATIC SENSITIVE THAT NEED TO BE
  - ADDITIONAL PRECAUTIONS ARE NEEDED FOR I LEVEL AND DEPOT LEVEL ACTIVITIES

Financial incentives, when appropriately applied, have the effect of motivating management to act in the best interests of the government because they will also be acting in their own best interests. The kinds of financial incentives that seemed to work effectively in the case of the APG-66 radar are the following: Reliability Improvement Warranty (RIW), guaranteed MTBF for selected subsystems, and reward or penalty sharing for surpassing or falling short of requirements. Such sharing was extended contractually to the major subcontractor. The proportions of sharing are shown on page IIA-9 of this report.

The APG-66 was highly concurrent in the sense that production started before full-scale development was completed. The success seems to stem partly from the fact that WEC had done a considerable amount of relevant design work before winning the contract for the APG-66.

The amount of the financial incentive necessary to produce that extra bit of top management interest is unclear. In the case of the APG-66, evidence supports the hypothesis that top management will press to achieve each incentive since it tends to reflect on the overall program and on their company reputation.

LESSONS (RE)LEARNED (CONTINUED)

- GOOD UP-FRONT DESIGN MAKES LATER PROBLEMS MANAGEABLE
  - CONTINUING ENGINEERING SUPPORT IS A LEGITIMATE AND NECESSARY ACTIVITY AFTER PRODUCTION BEGINS
- CONCURRENCY CAN BE MANAGED
- DEDICATED TEST ARTICLES ARE REQUIRED FOR R & M
- RELIABILITY MUST BE STATED AS A REQUIREMENT -- NOT A GOAL
- SCREENING AND CHARACTERIZATION OF PARTS IS NECESSARY IN CURRENT AND FUTURE HIGH DATA RATE ELECTRONICS APPLICATIONS. MIL-38510 IS NOT ENOUGH (MIL STD 883)
- FOLLOW-ON RELIABILITY TESTING ON A PERIODIC BASIS IS AN EFFECTIVE MEANS OF IDENTIFYING NEW PROBLEM AREAS AND OF MAINTAINING QUALITY THROUGH PRODUCTION
- RUN CONTINUOUS ATP DURING RELIABILITY TESTING

Lessons Learned

Development for the APG-66 did not originate at the moment that a military requirement was stated for it. It originated considerably before that time, partly through IR&D that resulted in developing a prototype of the system. This "pre-development" activity reduced risks by helping to train the designers for the specific kind of equipment that would become the APG-66.

It also is apparent that competition produces better equipment at lower cost. Hence proposals should be sought from as many potential contractors as are available.

LESSONS LEARNED

- CONTRACT
  - SUPPORT IR&D
  - ENCOURAGE COMPETITION
  - DEVELOP SYSTEM REQUIREMENTS COOPERATIVELY (GOVERNMENT & INDUSTRY)
  - REQUIREMENTS SHOULD REFLECT SUPPORT CONSIDERATIONS
- FINANCIAL INCENTIVES CAN BE USED TO PROMOTE R&M
- KEEP CONTRACTS SIMPLE, ALLOW FLEXIBILITY TO MAKE CHANGES EARLY IN PROGRAM
- THE LEVEL OF FINANCIAL INCENTIVE APPEARS TO BE SECONDARY IN IMPORTANCE

Management commitment to quality is important to producing a good product. Moreover, the commitment must be at a high enough level of management to influence all relevant operations (i.e., no conflict must arise between the company components that are required to produce high-quality installed equipment and those components whose job is to sell spares).

In the F-16 program, both WEC and GD set up parallel project organizations. Another factor was that teamwork among the prime and subcontractors and their suppliers was established early and maintained throughout the program. In the final analysis, people resolve problems.

LESSONS LEARNED

- MANAGEMENT
  - MANAGEMENT MUST SUPPORT R&M IF R&M IS TO BE ACHIEVED
  - THE MANAGEMENT ORGANIZATION SHOULD PROVIDE THE Q&RA MANAGER AUTHORITY TO GET THE JOB DONE
  - EMPHASIS MUST INCLUDE THE INTEGRATION OF R&M AS A REQUIRED CHARACTERISTIC OF THE EQUIPMENT UNDER DEVELOPMENT
  - PRIME CONTRACTOR AND SUBCONTRACTORS AND THEIR SUPPLIERS WORKING AS A TEAM HAVE THE BEST CHANCE OF PRODUCING RELIABLE EQUIPMENT

LESSONS LEARNED

- DESIGN
  - EMPHASIZE GOOD DESIGN UP FRONT (EARLY)
  - SCREEN AND CHARACTERIZE ALL PARTS IN ALL HIGH DATA RATE ELECTRONIC APPLICATIONS
  - EMPHASIZE THE USE OF VARIOUS ANALYTICAL TOOLS (E.G., TRADE STUDIES) BY DESIGN ENGINEERS
  - EMPHASIZE THE USE OF ALL OTHER TOOLS BY DESIGN ENGINEERS THAT ARE AVAILABLE TO SUPPORT RELIABLE AND MAINTAINABLE DESIGNS
  - ENSURE THAT DESIGN ALTERNATIVE STUDIES INCLUDE ATTENTION TO R&M CHARACTERISTICS
  - ST/BIT DEVELOPMENT, INTEGRATION, AND CHECK-OUT SHOULD BE CONCURRENT WITH SYSTEM PERFORMANCE DEVELOPMENT
  - ST/BIT DEVELOPMENT REQUIRES THE ASSIGNMENT OF PERSONNEL AND EQUIPMENT ASSETS
  - MAKE ST/BIT/MAINTAINABILITY ENGINEERS AN INTEGRAL PART OF THE DESIGN TEAM WITH SUFFICIENT ASSETS COMMITTED TO DO THE JOB

40A/27-5

Sometimes, the notion of testing is discarded after a program gets into production. Of course, testing is extremely important during the production of any system and especially during the production of high-performance electronic systems. The testing that must be done includes environmental stress screening at all levels of the production line--from parts through LRUs. The parts control program must be energetically enforced to ensure and maintain quality. And reliability acceptance tests, which usually occur early in the production program, if continued can uncover problems that might creep into the hardware. The number of systems to be tested under such a program is variable.

The damage that can be done by electrostatic discharge during normal handling of modern electronic devices mandates that the potential for damage be controlled. Through packaging and methods of discharging static electricity from workers and tools, parts and assemblies handled during manufacture, testing and repair can be protected.

Problems in the field that are environmentally related invariably appear. Additional environmental tests may be called for during early stages of production to handle problems identified in field use.

LESSONS LEARNED

- MANUFACTURING
  - THE EXTENSIVE USE OF ESS AND IMPLEMENTATION AT ALL LEVELS OF THE PRODUCTION PROCESS FROM INCOMING PARTS TO LRUs IS EFFECTIVE
  - AN AGGRESSIVE PARTS CONTROL PROGRAM PAYS BIG DIVIDENDS
  - AN ELECTROSTATIC DAMAGE PREVENTION SYSTEM IN PRODUCTION AND IN THE FIELD IS NECESSARY
  - CONTINUE RELIABILITY TESTING THROUGH THE PRODUCTION PROGRAM

Historically, ST/BIT testing always gets a lower priority than the classic performance tests. This lower priority is partly driven by the lack of assets. Therefore, systems should be dedicated to early evaluation of R&M functions. Tests should include ST, BIT, growth and environmental testing.

The presence of contractor personnel at operating bases is important in maintaining the operational availability of the fleet of aircraft, since they are capable of providing quick fixes. Moreover, they also provide an important information system for the contractor that enables the designers to effect rapid improvement in the product after it is fielded.

Environmental chambers at the Intermediate Shop level, particularly for cold soak, relatively simple and inexpensive, could help to avoid reinstalling potentially defective parts and assemblies in repaired LRUs. They would also be very helpful in finding problems associated with RETOKS with reliable fault reporting.

LESSONS LEARNED (CONT)

TEST AND EVALUATION

- EARLIER R&M TESTING IF PLANNED, FUNDED, AND IMPLEMENTED FOR FSD CAN BE BENEFICIAL TO RELIABILITY MATURATION
- GROWTH TESTING DURING FSD CAN MINIMIZE THE PROBLEMS CAUSED BY A CONCURRENT PROGRAM
- DEDICATED R&M TEST ARTICLES FOR FSD AND PRODUCTION TESTING ARE VERY IMPORTANT TO A CONCURRENT PROGRAM
- MAINTAINABILITY TESTS WITH ENOUGH SIMULATED FAULTS TO PROVIDE A RELIABLE SAMPLE OF THE EFFICACY OF THE SYSTEM FAULT DETECTION AND ISOLATION IS NECESSARY TO MATURE ST/BIT SYSTEM
- THE COLLECTION OF R&M DATA AT GOVERNMENT FACILITIES FOR THE PURPOSE OF PRODUCT IMPROVEMENT IS ESSENTIAL TO MATURING THE SYSTEM
- COLD SOAK CHAMBERS AT THE INTERMEDIATE SHOP LEVEL MAY SOLVE MANY PROBLEMS AT I-LEVEL RATHER THAN ?????

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