ICAS-82-3.5.3

F/A-18 R&M-DOES EARLY PLANNING PAY OFF?

R. D. Dighton

McDonnell Aircraft Company
McDonnell Douglas Corporation
St. Louis, Missouri 63166

Abstract

Primary objectives of the F/A-18 Hornet program are to improve operational readiness (OR) and reduce life cycle cost (LCC) relative to current Navy fighter/attack systems. This paper describes the design and management techniques used by the Navy and McDonnell Aircraft Company (MCAIR), the Hornet prime contractor, to design superior reliability (R) and maintainability (M) features into the F/A-18 to achieve these objectives. Key factors in the Hornet's establishment of new plateaus of reliability and maintainability performance are the definitive Navy R and M specification requirements which the contractor has guaranteed to demonstrate and the substantial R, M, LCC and program management incentives (totaling $39M) which MCAIR can earn. MCAIR's design and trade study process considers R and M along with weight and performance in all design decisions. An important Hornet program initiative which contributed to improve R and M was definition of a realistic Operational Mission Environment (OME) based on typical Navy and Marine Corps peacetime training and critical combat missions. This OME became the basis for most equipment design and test requirements. Key Hornet R and M design features are described in this paper. Principal reliability features include avionics equipment derating, improved avionics cooling, and fewer parts in the major subsystems such as radar, engine, and crew station. Maintainability features of the F/A-18 design include better equipment access, extensive built-in-test (BIT) and fault isolation, an auxiliary power unit (APU) for ground maintenance, and corrosion-resistant materials.

Reliability and maintainability performance of the flight test aircraft were tracked from first flight by a joint Navy/contractor team, using operational groundrules. This tracking process is discussed and R and M growth during FSD is presented. The Hornet's reliability guarantee was demonstrated by a 50-flight program utilizing realistic operational profiles. Major maintainability demonstrations included removal and replacement of the engine and radar. Operational impacts of the Hornet's demonstrated R and M performance are presented in terms of reduced number of maintenance people and reduced operating and support costs relative to the F-4J and A-7E. The paper concludes with a summary of R and M management lessons learned during the Hornet program.

I. Introduction

In the early 1970's the U.S. Navy began to plan to replace both the F-4 fighters and A-7 light attack airplanes in the fleet. The original Advanced Navy Fighter (ANF) Study program evolved into the Naval Air Combat Fighter (NACF) program which led to the F/A-18 Naval Strike Fighter. A production buy of 1366 Hornets is planned by the U.S. Navy and Marines, in addition to the eleven flight test aircraft being operated. Canada selected the CF-18 Hornet to replace its CF-101s and CF-104s and plans to procure 138 aircraft. Australia also selected the F/A-18 as its next generation fighter/attack weapon system and plans to procure 75 Hornets.

Major Hornet program objectives and milestones are summarized in Figure 1. McDonnell Aircraft Company (MCAIR), a division of McDonnell Douglas Corporation, is the prime contractor for this program. Northrop builds the center and aft fuselage for the aircraft. The Hornet is powered by two General Electric F404 engines.

Fig. 1 Hornet Program Summary

OBJECTIVES

- REPLACE F-4 NAVY FIGHTER
- REPLACE A-7 NAVY ATTACK
- REPLACE F-4 MARINE FIGHTER/ATTACK
- IMPROVED READINESS, LOWER OWNERSHIP COSTS

MILESTONES

- CONTRACT AWARD - JANUARY 1976
- FIRST FLIGHT - NOVEMBER 1978
- DSARC III - FEBRUARY 1981

CONTRACTORS

- MCDONNELL DOUGLAS - AIRFRAME PRIME CONTRACTOR
- NORTHROP AIRCRAFT - AIRFRAME MAJOR SUBCONTRACTOR
- GENERAL ELECTRIC - F404 ENGINE PRIME CONTRACTOR

The F/A-18 Hornet is a single-seat, high performance, multi-mission aircraft which will replace the F-4 in the Navy's fighter role and the A-7 in the Navy's light attack role, as well as replacing the Marines' F-4s in their fighter/attack role. It will provide the fleet with large improvements in air combat maneuvering performance and weapon system capability relative to the F-4 and better weapon delivery accuracy and greatly increased survivability relative to the A-7. For the first time, a high-performance aircraft has been designed for both fighter and attack capability at its inception. The F/A-18 is designed with full fighter and attack commonality. That is, there is only one basic aircraft configuration in both hardware and software. The aircraft in squadron service will be missionized for fighter or attack roles through the selection of external sensors and stores. In addition to the obvious life cycle cost advantages of one airplane for two different missions, the operational commander will be in control of a more versatile and flexible force than in the past.

The F/A-18 requirement was generated, in part, as a reaction to the excessive operating and support costs being experienced by the U.S. Navy's operating forces. A corollary consideration was the need to improve the operating fleet's operational readiness. Therefore, with the Hornet program the U.S. Navy initiated a "New Look," contracting for improved reliability (R) and maintainability (M) and reduced life cycle cost (LCC). This paper reviews the key elements of the "New Look" planning for improved R and M and summarizes the Hornet program achievements at the end of the development phase.

II. Reliability and Maintainability Guarantees

The Hornet contract incorporates reliability and maintainability guarantees for key parameters, all of which will be demonstrated by the prime contractor. In this program, R and M are contractual design requirements, not just desired goals as in most previous aircraft programs. By this innovation in development contracting, the Navy intended to provide R and M with the same design emphasis as weight, performance, and cost.

Principal reliability guarantees are summarized in Figure 2. These are not all of the guarantees, but they illustrate that weapon-system-level parameters are guaranteed along with critical subsystems such as the radar. The weapon-system-level guarantees are demonstrated at approximately the 2500 flight hours point during a dedicated reliability demonstration.

Fig. 2 Hornet Reliability Guarantees

	GUARANTEE	DEMONSTRATED
AIR VEHICLE MFHBF	3.7 HR	$\bar{R}$ DEMO 50 2-HR FLIGHTS
MISSION RELIABILITY	$\leq$7 MISSION FAILURES	
EQUIPMENT MFHBF	$\leq$33 EQUIPMENT FAILURES	
RADAR MTBF 50th PRODUCTION UNIT	80 HR	MIL-STD-781 TEST
125th PRODUCTION UNIT	100 HR	

Key maintainability parameters are also guaranteed for the Hornet. Principal parameters are summarized in Figure 3. Again, this is not the complete list of M guarantees. The aircraft-level guarantees will be demonstrated at Fleet Supportability Evaluation (FSE) after approximately 25,000 flight hours have been accumulated. This demonstration will occur in a U.S. Navy environment with Navy maintenance personnel. The equipment replacement time and fault isolate time demonstrations occurred as part of the Maintenance Engineering Inspection (MEI).

Fig. 3 Hornet Maintainability Guarantees

	GUARANTEE	DEMONSTRATED
DIRECT MMH/FH	11	FSE
MEAN TIME TO REPAIR	1.78 HR	FSE
TURNAROUND TIME	15 MIN	FSE
MEAN TIME BETWEEN MAINTENANCE	0.49 HR	FSE
ENGINE REPLACEMENT	21 MIN	MEI (COMP)
RADAR REPLACEMENT	20 MIN	MEI (COMP)

These R and M guarantees have been taken very seriously by MCAIR and major subcontractors. Top-level numbers have been allocated to subsystems and major equipment items. All subcontracts contain R and M guarantees based on reasonable allocations of the prime contract guarantees. Also, major subcontracts contain specific R and M demonstration programs.

III. Reliability and Maintainability Incentives

As a further indication of the Navy's emphasis on improved R and M, an incentives program was established to motivate the contractor to meet or exceed the R and M guarantees. This incentive program is summarized in Figure 4. Reliability incentives totaling $12 million could be earned at 1200 flight hours and at the completion of the 50-flight R demonstration. Maintainability incentives, also totaling $12 million, could be earned during the first 9000 flight hours. A potential of $15 million in incentives could also be earned by exceptional performance in LCC and program milestone management. These awards were based, at six-month intervals, on qualitative evaluations of the contractor's performance in such areas as LCC reductions achieved during FSD, effective tradeoffs, control of subcontractor's LCC, meeting critical milestones, achieving DTC goals, and management responsiveness to program problems.

Fig. 4 Hornet LCC Incentives
Potential Award Fee = $39 M

	1200 FH	50 FLT $\bar{R}$ DEMO	2500 FH	9000 FH
MEAN FLIGHT HR BETWEEN FAILURE	$4 $\bar{M}$	$8 $\bar{M}$		
MMH/FH, "O" LEVEL UNSCHEDULED	$1.5 $\bar{M}$		$2.5 $\bar{M}$	
DIRECT MMH/FH			$1.5 $\bar{M}$	$2.5 $\bar{M}$
MEAN FLIGHT HR BETWEEN MAINTENANCE ACTION			$1.5 $\bar{M}$	$2.5 $\bar{M}$
LCC AND PROGRAM MANAGEMENT	$15 $\bar{M}$ AWARD FEE BASED ON QUALITATIVE EVALUATIONS AT 6-MO INTERVALS THROUGH 1980			

Since the Hornet's reliability is largely determined by the performance of its subsystems, MCAIR decided to provide incentives for major subcontractors and equipment suppliers. A total of $17 million was available to these subcontractors. Prior to the accumulation of 1200 flight hours, most award payments were based on qualitative factors, such as LCC management. Beyond 1200 flight hours, most incentive payments were based on quantitative values of demonstrated R and M. Some subcontractors also had part of their incentives based on laboratory demonstrations of their equipment.

IV. Trade Studies

Trade studies have traditionally been the designer's key tool in the evolution of a weapon system design. With the increasing emphasis on improved R and M and reduced life cycle cost, a new dimension was added to the designer's classical performance versus weight trade-off process. Most trade studies have historically been the private domain of those engineers intimately involved in the design process. In the Hornet program, added emphasis and visibility was placed on this trade-off process in the following ways:

- o Trade studies were conducted in more depth, particularly with respect to reliability, maintainability, and logistics alternatives.
- o A comprehensive planned operational scenario was established by the U.S. Navy covering such elements as flying hour program, expected operational inventory, site activation schedule, land-based/carrier-based mix, and such cost factors as personnel pay and fuel cost.
- o Trade studies were documented in greater detail to ensure adequate consideration of inter-disciplinary effects and to facilitate life cycle cost reporting.
- o Configuration management was tied to the trade study process since Design Decision Memo's were used to summarize trade study results as well as to document changes to the configuration baseline.

Formal trade studies were started much earlier in the Hornet program than in previous Navy programs, being triggered by both U.S. Navy and contractor-suggested alternatives to the design baseline. More than 100 formal trade studies had been started at FSD contract go-ahead and over 400 formal studies had been completed by the end of 1978. These formal trade studies resulted in a LCC avoidance of at least $260M.

Some examples of trade studies which emphasized R, M, and LCC considerations are summarized in Figure 5. The common wheel and tire trade-off is discussed later in this paper. The wing pylon jettison trade-off was basically whether to jettison the pylon with the tanks and armament racks or retain it with the airplane if it became necessary to jettison external stores. The decision was to retain the pylons due to the cost and weight avoidance. Cost and weight can be avoided and R and M improved because of a simpler pylon design and less complex pylon mounting attachments in the wing. Performance is degraded slightly, of course, in combat or emergency situations because of the additional pylon weight and drag. The flight control system (FCS) simplification study resulted in significant cost and weight reductions and reliability improvement by providing minimum essential redundancy through redesign of the computer and some actuators. Hughes Aircraft, the APG-65 radar supplier, found that it would be difficult to achieve its reliability guarantees with a radar designed to fit within the allocated space in the Hornet's nose. A trade study increasing this volume 0.5 ft^3 resulted in a relatively large LCC avoidance, as well as a small weight savings. The radar WRA support trade study evaluated alternatives of VAST, modified VAST, and new-design test equipment to support the radar. The selected new Radar Test Station resulted in an almost $20M LCC avoidance.

Fig. 5 Example Life Cycle Cost Trades

ITEM	COST SUMMARY Δ FSD ($ M)	Δ UNIT PROD ($ K)	Δ LIFE CYCLE ($ M)	Δ WEIGHT (LB)	PERFORMANCE
COMMON F-18/A-18 WHEEL/TIRE	−0.8	+0.4	−7.5	+89	DEGRADED
WING PYLON JETTISON	−2.1	−4.0	−23.8	−40	DEGRADED
FCS SIMPLIFICATION	−0.8	−33.0	−33.2	−60	IMPROVED
INCREASED RADAR VOLUME	−0.5	−18.4	−31.4	−3	NEGLIGIBLE
RADAR WRA SUPPORT	−5.2	N/A	−19.8	0	NO CHANGE

NAVAIR asked MCAIR, in early 1976, to conduct a trade study addressing the issue of whether both the F-18 and A-18 could utilize a common wheel and tire (Figure 6). At that time, several hardware differences existed between the F-18 and A-18 including a smaller wheel and tire on the F-18. It was known that installing the larger tire on the fighter would result in a larger cross-sectional area and higher drag. Also, unit cost and weight of the fighter would increase. However, the fighter's brake and tire life would be lengthened because its lower operating weight would impart less stress on the larger brakes and tires. The trade study showed that the Hornet program's R and M would be improved and LCC reduced by selection of the alternative approach. The larger wheel and tire was selected for both the F-18 and A-18 and was the key decision leading to a common F/A-18 configuration. The details of the O&S cost reduction are shown in Figure 7. The major cost savings can be seen to accrue from the elimination of 1370 brake stack replacements throughout the Hornet's life cycle.

Fig. 6 Common F/A-18 Wheel/Tire Study

ISSUE:

SHOULD FIGHTER AND ATTACK VERSIONS UTILIZE COMMON WHEELS AND TIRES?

BASELINE:

FIGHTER · 30 x 9.5 x 14.5 TIRE
ATTACK · 30 x 11.5 x 14.5 TIRE } **MIN REQUIREMENT**

RESTRAINT:

ATTACK VERSION MUST USE LARGER TIRE/WHEEL

CONSIDERATIONS:

LARGE TIRE ON FIGHTER

— DEGRADES PERFORMANCE
— INCREASES UNIT COST $400
— ADDS WEIGHT - 89 LB (40 kg)
— IMPROVES BRAKE LIFE
— DECREASES LIFE CYCLE COST

COMMON TIRE SELECTED

Fig. 8 F/A-18 Procurement · LCC Savings
Based on 46 Percent of Procured CFE Cost

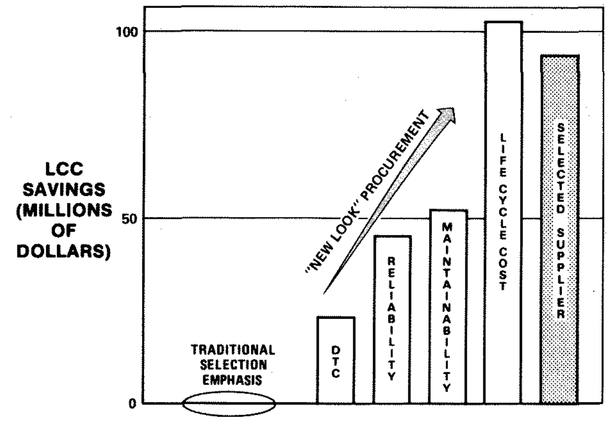


Fig. 7 Common Wheel/Tire LCC Analysis

			COST CHANGE FOR COMMON WHEEL/TIRE $M
FSD			−0.788
PRODUCTION			+0.319
O&S			
	DIFFERENT	**COMMON**	**ΔCOST ($ M)**
REPLACEMENT TIRES			
FIGHTER	59,888	85,908	(−0.381)
ATTACK	36,910		
REPLACEMENT BRAKES			
FIGHTER	4,104	5,830	(−5.064)
ATTACK	3,096		
OTHER O&S			
LABOR, FUEL, ETC.			(−1,541)
TOTAL O&S			−6.986
TOTAL LCC SAVINGS			−$7.455M

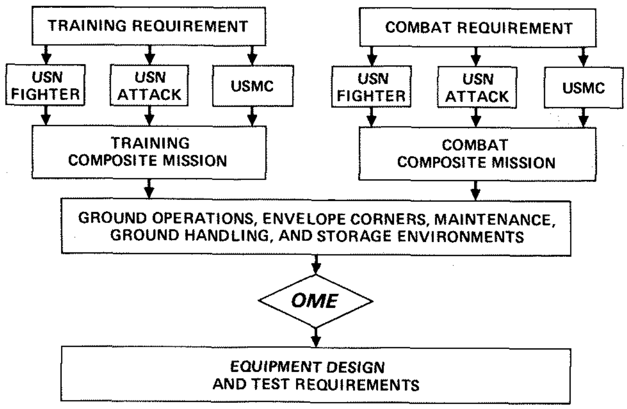
A significant portion of the Hornet is procured from equipment suppliers and, therefore, careful attention to improved R and M and reduced LCC must also be given to the source selection process. Life Cycle Cost evaluations were made of all bidder's proposals in the source selection of major F/A-18 equipment. The impact of the "New Look" on the equipment procurement process is illustrated in Figure 8. LCC savings are shown relative to supplier selection based on only performance and weight, the traditional selection basis. A small savings could accrue if the supplier selection had been based strictly on a DTC bias to the lowest unit production cost. Larger savings result if the supplier had been selected on the basis of best R or best M. The largest savings occur if the supplier expected to provide the lowest life cycle cost was selected. The actual supplier selected, for those major equipments considered in this evaluation, was judged to provide the lowest LCC in all cases but one, and in this case the supplier was rated second in LCC. For these major equipment items, LCC savings of about $90M were realized by conscientiously considering all of the elements of the "New Look" in LCC control in the procurement process.

V. Operational Mission Environment

A key Hornet program initiative which promises to contribute significantly to achieving greatly improved equipment reliability is implementation of a realistic Operational Mission Environment (OME) as a basis for design and test requirements. Traditional design and test requirements often have been found to be inadequate in representing fleet operating stresses. As a result, the real-world operating environment contributes to failure modes that were not considered during design, nor discovered and corrected during demonstration tests. To solve this problem, the U.S. Navy and MCAIR defined realistic training and combat mission profiles as the basis for a detailed expected operating environment of the airplane. A comprehensive analysis of the Hornet flight, ground operating, storage, and maintenance handling environment was then used to tailor procurement specifications for design and test requirements of major systems.

As the first step in the OME process, outlined in Figure 9, twelve training missions were defined based on training syllabus requirements, squadron surveys, and pilot experience. Six critical combat missions were based on the Hornet's Operational Requirement. A frequency of occurrence for each mission was established for Navy Fighter, Navy Light Attack, and Marine Fighter/Attack squadrons, as well as ship/shore and combat/training sortie ratios. The Hornet OME builds on the foundation of the mission environment, based on mission profiles, but also includes combat maneuvers, occasional transient excursions beyond the design flight envelope, ground operation, and handling and storage conditions. This comprehensive OME definition formed the basis for establishing expected flight loads, vibration, temperature, altitude, humidity, acoustics, salt, and dust design-to-requirements. Critical design points from the OME became design-to requirements for all Hornet equipment. Thus, design and test conditions tailored to the expected environment of this equipment were derived and were imposed in the procurement specifications, replacing testing to less severe conditions of classical military specifications.

Fig. 9 Hornet Mission Profiles in Design and Test



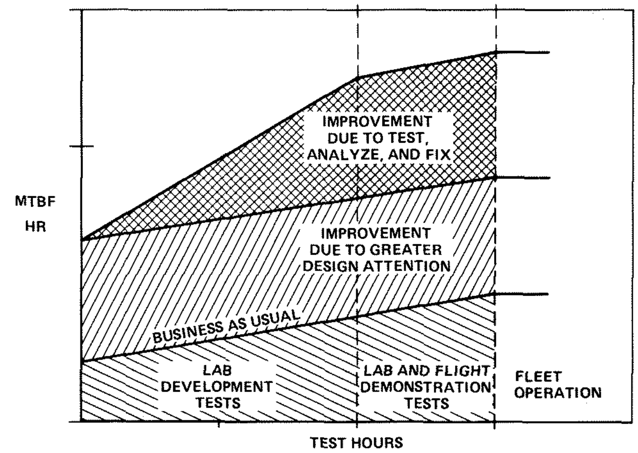
Accelerated testing approaches were developed to time-compress the design life testing for test span reductions and cost economies. Addition of temperature cycling, random and sinusoidal vibration, and humidity are the major changes from the MIL-STD-781B test specifications for most equipment. For certain critical mission equipment, such as the APG-65 radar, temperature, humidity, and vibration cycling are combined. A comparison of OME and MIL-STD-781B testing requirements for avionics equipment is presented in Figure 10.

Fig. 10 Major Avionics Testing Changes with OME

PARAMETER	BASELINE MIL-STD-781B	OME
– TEMP EXTREMES		
CHAMBER	–54° TO +71°C	–54° TO +85°C
COOLING AIR	–54° TO +49°C	–54° TO +63°C
– TEMP SHOCK		
COOLING AIR	5°C/MINUTE	33°C/MINUTE
– VIBRATION		
TYPE	FIXED SINE	RANDOM + FIXED SINE
INTENSITY	±2.2 g	MAX PERFORMANCE
– HUMIDITY	NONE	TYPICAL MISSION
– ALTITUDE	SEA LEVEL	SEA LEVEL TO 15,250 m

A key part of the F/A-18's "New Look" approach to designing for improved reliability is an integrated test program. This test program emphasizes two separate phases, development and demonstration tests. The expected improvement in equipment reliability during these test phases is illustrated in Figure 11.

Fig. 11 Reliability Improvement with the "New Look"



A primary objective of the development phase is early assessment of mission-critical environments and translation into equipment design requirements. It emphasizes Test, Analyze, and Fix (TAAF) with closed loop failure reporting. An improvement in initial equipment reliability (at the start of development testing) is expected due to the more realistic OME design conditions. A further improvement in the reliability growth curve slope is predicted because of the improved realism of the OME test environnent and the TAAF approach.

The objective of the demonstration phase is the traditional verification of design requirements in laboratory and flight tests. A new requirement in the Hornet program was a 50-flight dedicated reliability demonstration. This test program simulated the spectrum of operational mission conditions, including realistic equipment operations. More than 7 mission failures or 33 equipment failures would constitute failure to pass the demonstration.

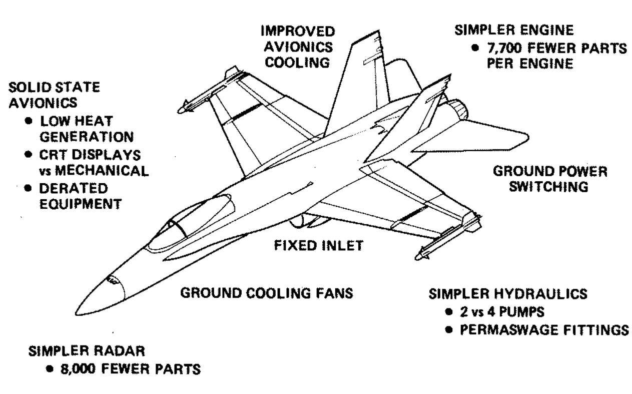
VI. Designing in Reliability

MCAIR accepted the Hornet reliability requirements as being especially challenging and implemented many actions in the management, design, and test areas to assure that these requirements would be achieved. The subsystem manager's responsibilities in the R and M areas were emphasized and R and M engineers were integrated into the design process. By co-locating these R and M specialists with the subsystem managers and designers they supported, all design details were reviewed for R and M impact with maximum influence on the evolving design. An extensive formal trade study process was also used to evaluate any significant proposed changes to the baseline design. All trade studies were evaluated for R and M impacts, along with the usual performance, weight, and cost impacts. Over 400 formal trade studies were performed during the Hornet's FSD design phase. Periodic design reviews, both internally and with the Navy, provided final assurance that R and M was being adequately considered in the design process.

Many of the standard approaches to ensuring high equipment reliability were utilized in the Hornet program. Lack of emphasis on these techniques in this paper does not imply that they are ineffective. Examples of these techniques include reliability design-to-allocations, periodic assessment of status for each subsystem manager, failure modes and effects analysis, an approved parts list, and use of a Closed Loop Evaluation and Reporting (CLEAR) system to report and track all equipment failures from the initiation of equipment testing.

Some of the Hornet design features to enhance reliability are summarized in Figure 12. Much of the Hornet avionics is solid-state, thus providing low heat generation. Nevertheless, heat is one of the primary contributors to avionics failures and we have emphasized better cooling in the design. A new water separator is used in the environmental control system to provide cooler air without condensation. Ground cooling fans supply air for ground operation, and ground power switching circuits prevent equipment from operating automatically when ground power is applied. The APG-65 radar is significantly simplified from the F-4J radar through digital processing and extensive use of solid-state circuits. Also, an electric antenna drive is used in the APG-65 instead of a hydraulic drive. It has 8000 fewer parts than the F-4J radar, all of them expected to be more reliable. Most of the pilot's flight and weapon system information is displayed on versatile CRT displays instead of individual electro-mechanical instruments. Although in the same general thrust class, the F404 engine has fewer compressor and turbine stages than the J79 engine in the F-4. A major improvement has been transfer of the engine accessories to an Airframe Mounted Accessory Drive (AMAD). Also, the F404 fuel controls are much simpler than those of the J79 as is the air inlet system which is fixed versus previous systems with several movable surfaces and associated controls. Hydraulic system reliability is improved by the use of Permaswage line fittings and high response pumps of proven reliability. The Environmental Control System turbine compressor incorporates air bearings, which have provided almost flawless service.

Fig. 12 Improved Reliability Through Design
F/A-18 Compared to F-4J



One of the major contributors to improved avionics reliability is derating of the components from their rated current, voltage, power, and temperature operating specifications. Used extensively on spacecraft and commercial home electronic devices, this technique greatly prolongs the life of almost all electronic components. The NASA "Long Life Assurance Study for Manned Spacecraft Long Life Hardware" was used as a guide to establish derating levels. The examples presented in Figure 13 illustrate that, in many cases, more stringent derating specifications were imposed on Hornet equipment suppliers than those used by NASA in its manned spacecraft programs. To date, Hornet suppliers are achieving these levels in 98% of the component applications. Another contribution to component improvement has been in the area of Quality Assurance. Most Hornet suppliers have implemented 100% receiving inspection of semiconductors. This has had a stabilizing influence on component quality, allowing Hornet equipment to achieve high reliability levels. A side benefit has been an overall cost savings because of the reduced rework required during manufacturing tests, and a significantly reduced life-cycle cost is projected.

Fig. 13 F/A-18 Parts Derating Examples

PART TYPE	PARAMETER	MANUFACTURES' SPEC ALLOWABLES	NASA*	F/A-18A HORNET
GENERAL PURPOSE TRANSISTOR	JUNCTION TEMPERATURE	125°C	110°C	100°C
	POWER	100%	50%	15%
GENERAL PURPOSE/ SWITCHING DIODE	JUNCTION TEMPERATURE	125°C	110°C	100°C
	POWER	100%	30%	15%
DIGITAL MICRO-CIRCUITS	JUNCTION TEMPERATURE	125°C	110°C	90 - 110°C

*Reference NASA Report CR-128905, long life assurance study for manned spacecraft long life hardware.

Avionic component failure rates are also adversely affected by high operating temperatures. This phenomenon is illustrated in Figure 14 for microcircuit junction temperatures. Mean junction temperatures are typically about 103°C for current-generation fighter electronics. Derating criteria established for the Hornet program reduced the mean junction temperature of the F/A-18 radar and HUD to 70°C, dramatically reducing the relative failure rates. Most of the F/A-18 electronic equipment was similarly derated for junction temperature, as well as current, power, and voltage.

The F404 engine, manufactured by General Electric, contributes to the Hornet's reduced LCC through its design simplicity and ease of maintenance. It has two-thirds the parts of the J79 engine and produces about the same thrust. Also, it is built in modules for ease of maintenance and can be borescoped without removal from the aircraft. The F404 features which contribute to a predicted reliability four times better than the J79 are summarized in Figure 15.

Fig. 14 Better Cooling Improves Reliability

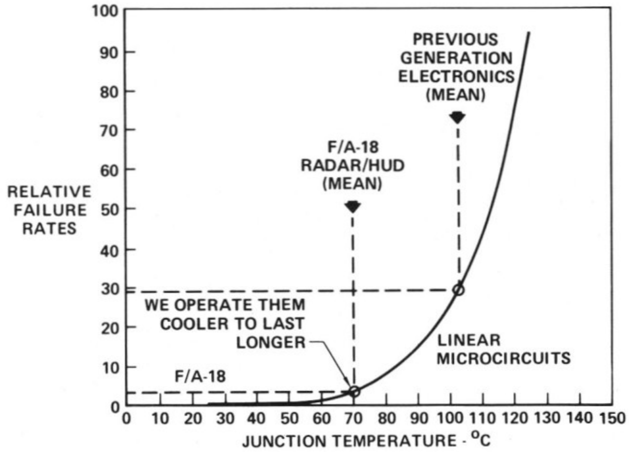
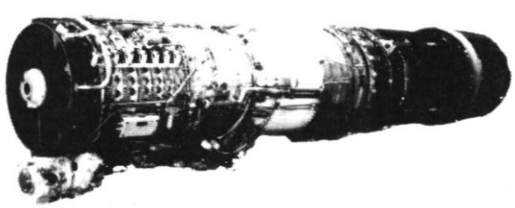


Fig. 15 Engine Design Simplicity for High Reliability

J79 (PHANTOM) 22,000 PARTS



SAME THRUST CLASS
- 3/4 THE LENGTH
- 1/2 THE WEIGHT
- 7,700 FEWER PARTS

8 FEWER STAGES
- 7 COMPRESSOR
- 1 TURBINE

3 FEWER VARIABLE STRATORS

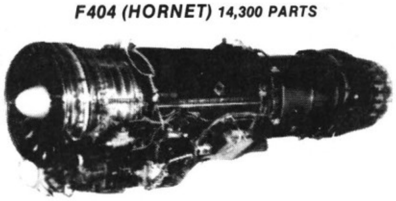
SIMPLE GEAR BOX
- 38 FEWER BEARINGS
- 28 FEWER SHAFTS

SIMPLE FUEL SYSTEM
- 29 FEWER PIPES

ONE COMBUSTOR
- LINER vs 10 CANS

PROVEN BASE
- OVER 2,500 HR (FACTORY AND FLIGHT) ON YJ101

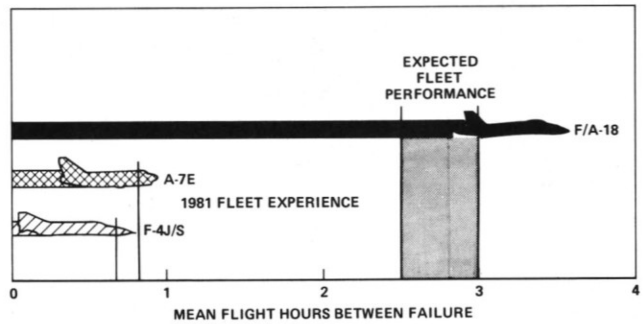
F404 (HORNET) 14,300 PARTS



AND FOUR TIMES THE RELIABILITY

The end result of all this emphasis on design and testing for improved reliability of the Hornet is an expected fleet MFHBF about three times that of the currently-operational F-4J and A-7E, as shown in Figure 16. The first year of fleet operations by VFA-125 at NAS Lemoore indicates that the Hornet will achieve this improved MFHBF.

Fig. 16 Hornet Expected Reliability is 3 Times the Fleet Average



VII. Designing for Improved Maintainability

The primary objective of the F/A-18 Maintainability Program is to reduce the number of man-hours and elapsed time to perform preventive maintenance, inspect and service the aircraft, and repair any failures which occur. Of course, maintainability benefits from the Hornet's great strides in reliability, which leads to fewer unscheduled maintenance actions. The same management approach was followed for M as previously discussed for R. Trade studies and day-to-day design activities were fully supported by M engineers. The M program also used design-to allocations at the subsystem manager level of the organization. Maintainability impact on design was organizationally supported by their reporting to the same engineering manager responsible for reliability. This organizational setup provided maximum influence on the evolving design while allowing M engineers to retain their functional Product Support integration with the Logistic Support Analysis process.

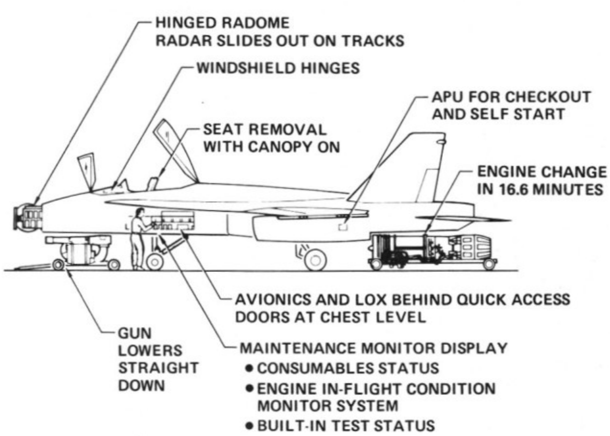
Achieving the Hornet's challenging M guarantees requires some significant advances in the state-of-the-art in such areas as BIT, as well as attention to all design details. Principal Hornet M features are summarized in Figure 17.

Fig. 17 Hornet Maintainability Features

- BUILT-IN TEST FOR MOST AVIONICS AND HYDRO-MECHANICAL EQUIPMENT
- RAPID FAULT ISOLATION
- CORROSION RESISTANT MATERIALS - COMPOSITES AND 7050 ALUMINUM - IVADIZED STEEL COMPONENTS
- RAPID WRA REPLACEMENT
- SCHEDULED MAINTENANCE MINIMIZED
- NO TURNAROUND OR DAILY GSE

A key contribution to reduced maintenance requirements is quick and easy access to all equipment which requires other than rare attention. The Hornet's major access provisions are identified in Figure 18. Even engines can be changed in less than 17 minutes because of rapid access and quick-disconnect features. An APU provides power for quick systems checkout and self-start. Ground cooling fans also reduce the need for cooling carts during maintenance and pre/post flight checks. Most major equipment has built-in test (BIT) and fault isolate test (FIT) to greatly reduce troubleshooting time.

Fig. 18 Designed for Easy Access



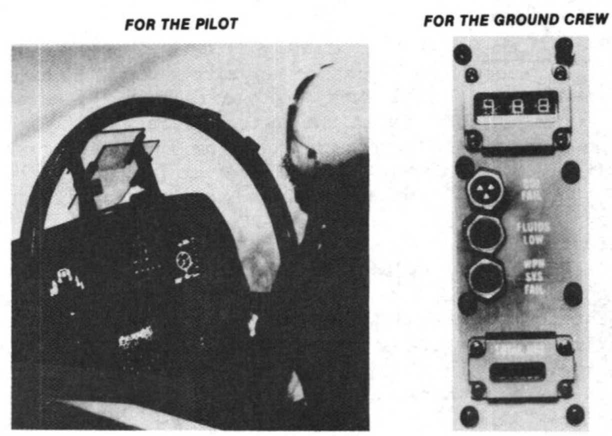
Easy accessibility is provided by all avionics components being one deep behind access doors with two to four quick-opening latches. Avionics boxes are unplugged from the front and slide out. Quick-remove, ratchet-type securing devices require no special tools. Also, no on-aircraft adjustments or alignments are necessary for avionics since alignment corrections are handled by software. Few requirements exist for workstands since the Hornet has 134 doors accessible from the flight deck and over 91 percent of the equipment can be reached without using workstands.

Engine removal is easy, the engine having only 11 connections to the aircraft. Engines are neutral and require no build-up kits. In addition, no trim runs are required following engine replacement.

Hornet maintainability depends heavily on the capability of built-in test circuits in all avionics and many non-avionics systems which provide cockpit recognition of any system degradation, verify the failure to the weapon replaceable assembly (WRA) and assist the maintenance technician in isolating and analyzing the fault. The contract requires a guaranteed fault isolation time of five minutes or less for 95 percent of the equipment and ten minutes or less for the remaining five percent. Ninety percent of the avionics BIT circuits are automatic and are utilized inflight, as well as on the ground, to assess functional performance, identify failed modes, and perform operational readiness system checks. Ninety-eight percent of the avionics system is covered by a combination of automatic and operator-initiated BIT circuits which are utilized at the organizational level to assist the technician in failure detection and isolation.

Failures of most avionics equipment and many of the hydro-mechanical subsystems are indicated in the cockpit and also displayed on a maintenance monitor panel in the nose wheel well, as illustrated in Figure 19. This maintenance monitor panel allows maintenance personnel to isolate a failure to a weapon replaceable assembly. Also, consumables status of engine oil, AMAD oil, APU oil, hydraulic fluid, radar liquid coolant, LOX and fire extinguisher bottle pressure is displayed on this indicator when interrogated by depressing a switch on the panel. A maintenance signal data recorder set is also used to help trouble-shoot systems, including recording the outputs of the engine inflight condition monitor system (EICMS) and g-levels at critical points of the structure.

Fig. 19 Built-In Test/Fault Cues

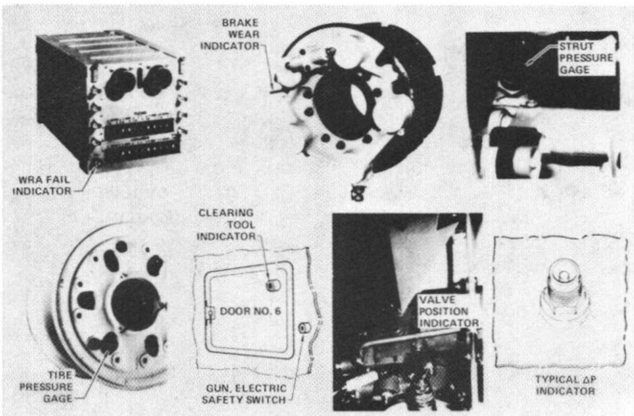


Examples of BIT indicators at the WRA level are illustrated in Figure 20. Emphasis here is on built-in detectors for relatively frequent tasks such as tire pressure gages, strut pressure gages, brake wear indicators, and clogged filter (ΔP) indicators.

Initial BIT assessments were performed following early supplier reliability development testing to assure that the BIT was correctly designed. A larger task involved integration of all the avionic and hydro-mechanical BIT into a functioning system in the aircraft. The BIT development task is now nearing completion and assessment of the Hornet's BIT capability in the first training squadron will occur in the near future.

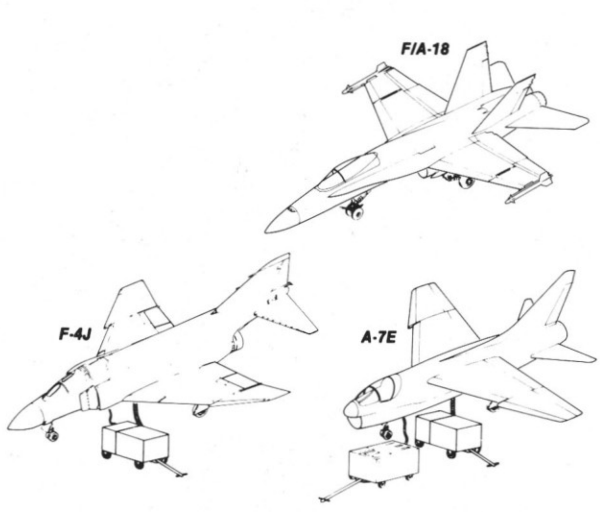
Corrosion is a major problem for the Navy. Typically, the Navy spends ten times as much effort as the USAF on corrosion control for F-4s. Therefore, major emphasis was placed on corrosion prevention in the Hornet design. Use of graphite epoxy composites for exterior skins is very beneficial. Also, 7050 aluminum is used where possible. Another major innovation is use of ion vapor deposition (IVADIZE) to electrically deposit a thin layer of aluminum on such exposed steel components as the landing and arresting gear mechanisms, horizontal tail spindles, and certain access door screws.

Fig. 20 Equipment Indicators Provide Quick Assessment



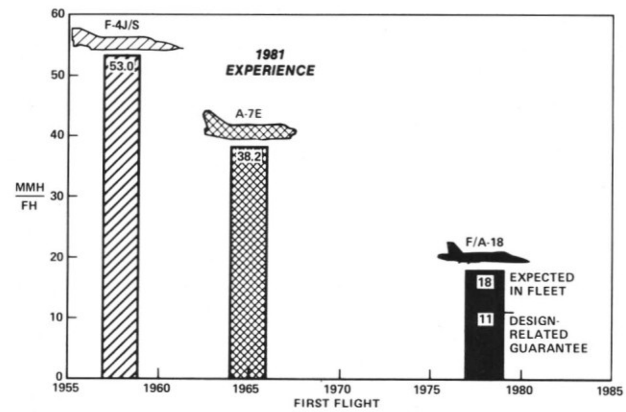
A substantial part of an aircraft's MMH/FH is expended on preflights and correction of minor defects at the Organizational maintenance level. The Hornet's APU and groundcooling fans allow preflights and minor maintenance to be performed without hooking up ground power or air conditioning carts. The Hornet's APU, operating in the ground maintenance mode, will provide adequate electrical and hydraulic power for almost all system checks and troubleshooting. In addition, the groundcooling fans provide adequate cooling for avionics subsystems up to 105°F ambient temperatures. A comparison of Hornet ground support equipment requirements with those of the F-4J and A-7E is illustrated in Figure 21.

Fig. 21 No Turnaround or Preflight GSE and No GSE for Most "On-Aircraft" Maintenance



The Hornet's maintainability index, measured in maintenance manhours per flight hour (MMH/FH), shows substantial reduction over current operational aircraft, as depicted in Figure 22. A threshold of no more than 18 MMH/FH, as reported in the Navy's 3M reporting system, was established as an F/A-18 program requirement. In order to ensure achievement of this operational value, the prime contractor is designing to a requirement of 11 MMH/FH for all direct and Support General design-related maintenance categories. This requirement is based on certain measurement criteria which will equate to about 18 MMH/FH in the 3M system.

Fig. 22 Hornet Continues the Trend to Lower Maintenance Requirements



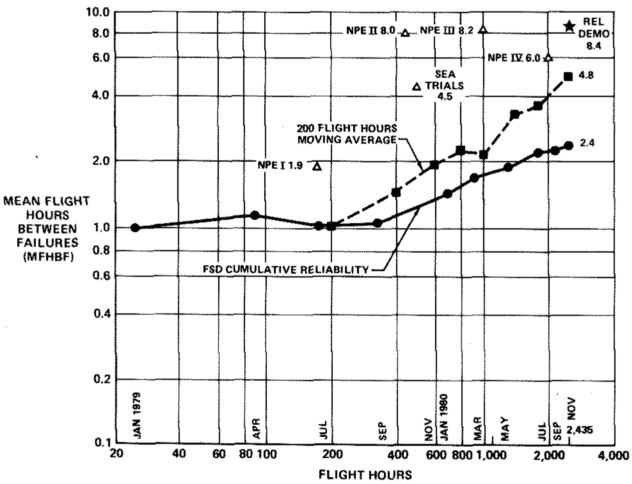
VIII. HORNET R AND M STATUS

Another new Hornet program initiative, tracking of R and M growth during the FSD development phase using operational 3M data groundrules, provided a credible data base for R and M status tracking. To implement this assessment, a joint Contractor/Navy Reliability/Maintainability Review Board (RMRB) was established at the Naval Air Test Center (NATC), Patuxent River, Maryland. This RMRB assessed all unscheduled maintenance actions during flight test operations and determined if the actions were relevant for inclusion in the data base, or were nonrelevant because they were test-equipment-related, corrected by previously approved design changes, or were non-relevant within the Navy's 3M maintenance reporting system guidelines. The few actions which could not be resolved by the RMRB were dispositioned through an appeal process to higher command.

The reliability performance of all F/A-18s in the test program at NATC was tracked from first flight. The Mean-Flight-Hours-Between-Failures (MFHBF) trend with cumulative flight hours is displayed in Figure 23. The bottom line labeled "FSD Cumulative Reliability" is the raw data from the RMRB. Since this is a cumulative line, the early flight test aircraft dominate the data base.

Therefore, a 200-flight hour moving average is considered more representative of the F/A-18's reliability performance. Reliability performance during Navy Preliminary Evaluations (NPEs) and Sea Trials also demonstrated the Hornet's capability while being flown by Navy and Marine pilots in operationally-oriented environments.

Fig. 23 FSD Reliability Trend
All Test Aircraft



The Hornet's MFHBF guarantee of 3.7 hours was demonstrated by a special 50-flight test. The demonstration was performed by MCAIR using the last of the 11 FSD airplanes. Of the 50 flights, the first 20 were dedicated to an air-to-ground profile, the second 20 to an air-to-air profile, and the last 10 to a ferry/familiarization profile. The air-to-ground and air-to-air profiles incorporated simulated combat segments near the middle of the mission and the ferry/familiarization flights incorporated a NAVAID penetration, GCA pattern, and two touch-and-go's. During two air-to-ground flights, live gunfire and bomb drops with MK-82SE inert bombs were performed on a practice target. The gun was also fired out on two air-to-air flights.

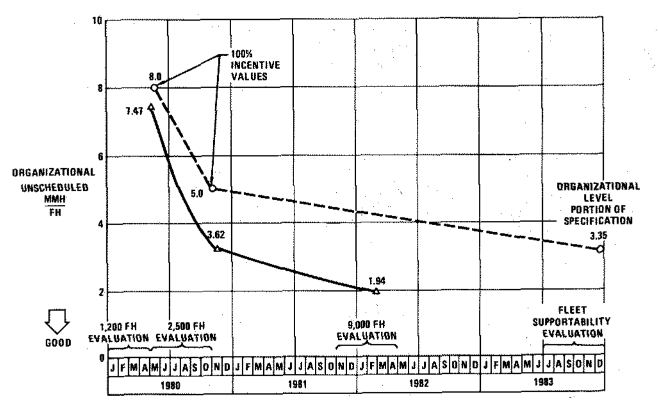
Results of this reliability demonstration are summarized in Figure 24. As can be seen, the 3.7 hour MFHBF guarantee was exceeded by a very comfortable margin and resulted in awarding of the entire incentive for this demonstration. Of the 12 equipment failures, nine occurred in Contractor-Furnished-Equipment (CFE) and three failures were charged to Government-Furnished-Equipment (GFE). The Hornet contract also specified a Mission Success (Ps) of 0.80 (7 mission failures allowed) with a goal of 0.90. Only two mission failures occurred during the 50-flight demonstration, resulting in a Ps of 0.96 which exceeds not only the requirement but the goal as well.

Fig. 24 Hornet Reliability Flight Demonstration
50 Flights/100 Flight Hours in 15 Days

- RELIABILITY DEMONSTRATED
  - REQUIREMENT MFHBF = 3.7 HR
  - DEMONSTRATED MFHBF = 8.4 HR
- ONLY 12 FAILURES (3 AVIONICS)
- FLEW 25 CONSECUTIVE FAILURE-FREE FLIGHT HOURS
- RADAR OPERATED WITHOUT FAILURE THE ENTIRE TEST
- DEMONSTRATED PROBABILITY OF MISSION SUCCESS = 0.96 (ONLY 2 MISSION FAILURES)

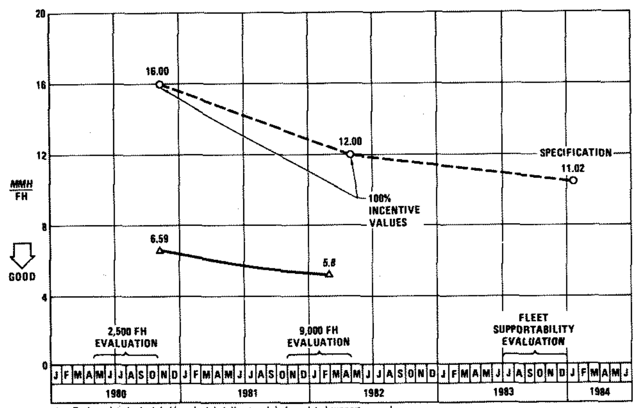
Maintainability performance during NATC operations was monitored in the same manner as R performance. Organizational-level unscheduled maintenance manhours per flight hour (MMH/FH) was the primary parameter tracked from the beginning of the flight test program. Hornet performance is compared to the design goals for this maintainability parameter in Figure 25. The design goals at 1200 and 2500 flight hours are equal to the 100% incentive values. The final requirement of 3.35 is the unscheduled maintenance portion of the 11.02 guarantee. As can be seen from Figure 25, the Hornet performance was better than the design goal (100% incentive line) during both the 1200-FH and 2500-FH evaluation periods. This excellent performance has also continued into 1982.

Fig. 25 Hornet Organizational Level Unscheduled MMH/FH



Tracking of organizational and intermediate level maintenance, including all unscheduled and design-related scheduled and support general, was initiated for the 2500-FH evaluation period. As shown in Figure 26, the Hornet also exceeded the 100% incentive requirements for this total maintainability parameter.

Fig. 26 Hornet Organizational and Intermediate MMH/FH
Includes Unscheduled + Design-Related Scheduled and Support General



dr = Design related scheduled/unscheduled direct and design related support general

Equipment remove and replace demonstrations were conducted for major subsystems. Two of the principal demonstrations covered the engine and radar with results as summarized below:

Subsystem	Remove and Replace Times Required	Remove and Replace Times Demonstrated
F-404 engine	21 minutes (4 men)	16.6 minutes (4 men)
APG-65 radar	20 minutes	11.6 minutes

Another indicator of R and M success at completion of Hornet development is the R and M incentives awarded to MCAIR. The final reliability incentives status is summarized in Figure 27. MCAIR received 68% of the $12M available for R incentives. Maintainability incentives status is summarized in Figure 28. The 9000-FH evaluation is currently in progress so the M incentives picture is not complete. However, to this point, MCAIR has received almost 95% of the available maintainability award payments.

The Navy verified the Hornet's outstanding R and M performance during their Initial Operational Test and Evaluation (IOT&E). IOT&E was conducted from 27 October 1980 to 12 February 1981 using 7 aircraft which flew 257 sorties for 367 flight hours. The IOT&E report concluded the mission reliability was adequate for this stage of the program and the F/A-18 exhibits excellent potential to meet operational readiness goals during fleet employment. Quantitative R and M results are as follows:

	IOT&E Results	IOT&E Threshold
MFHBF	2.37 hr.	1.4 hr.
MMH/FH (O-Level, unscheduled & scheduled)	9.7	9.0

Operational readiness (full system capable) was measured at 64%, as compared to a mature system requirement of 80%. This was also judged to be excellent performance for this early stage of the Hornet program.

Fig. 27 Reliability Incentives

	100% AWARD VALUE MFHBF (HR)	ACHIEVED VALUE MFHBF (HR)	MAXIMUM AWARD ($M̄)	AWARD RECEIVED ($M̄)
1,200 FLIGHT HOUR EVALUATION	4.0	1.99	4	0.15
50 FLIGHT RELIABILITY DEMO	6.25	8.9	8	8

Fig. 28 Maintainability Incentives

	100% AWARD VALUE	ACHIEVED VALUE	POTENTIAL AWARD ($M̄)	AWARD RECEIVED ($M̄)
1,200 FLIGHT HOUR EVALUATION MMH/FH (UNSCHEDULED O-LEVEL)	8.0	7.72	1.5	1.5
2,500 FLIGHT HOUR EVALUATION MMH/FH (UNSCHEDULED O-LEVEL)	5.0	3.62	2.5	2.5
DMMH/FH (TOTAL AIR VEHICLE)	16.0	6.36	1.5	1.5
MFHBMA (HR)	1.5	1.16	1.5	1.14
9,000 FLIGHT HOUR EVALUATION DMMH/FH (TOTAL AIR VEHICLE)	12.0	EVALUATION *IN PROGRESS*	2.5	TBD
MFHBMA (HR)	1.6		2.5	TBD
MAXIMUM POTENTIAL VALUE TO MCAIR = $ 12 M̄				

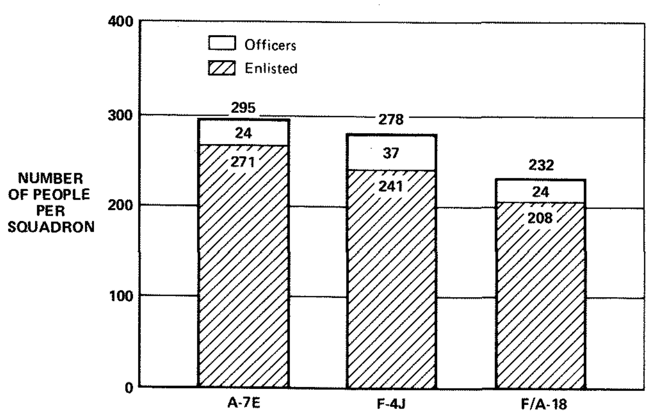
The final evaluation of the Hornet's M performance in the fleet environment will occur during the Fleet Supportability Evaluation, starting in the fall of 1983. No surprises are expected from this evaluation because the Hornet has been maintained and flown by VFA-125 at Lemoore NAS, California since February of 1981. The Hornet has shown excellent and improving R and M performance during this initial operating period. The 9000-FH evaluation is being conducted at Lemoore with Navy and Marine organization-level maintenance and is verifying the high level of F/A-18 R and M performance.

IX. Operational Impacts of Improved R&M

Primary Hornet program objectives include reduced operating and support (O&S) costs and improved operational readiness (OR) compared to the aircraft it will replace in the fleet, the F-4J and A-7E.

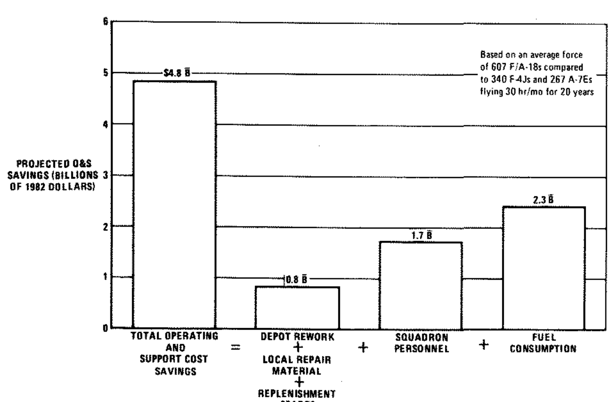
A key input to any O&S cost comparison is the number of maintenance people required in a twelve-plane squadron. A comparison of this factor in Figure 29 shows that a Hornet squadron is projected to require between 30 and 63 fewer enlisted people than an F-4J or A-7E squadron, primarily due to its greatly improved reliability and maintainability. It should be noted that the F-4J manning is based on a utilization of 21.5 flight hours per month while the A-7E manning is based on flying 34 hours per month. The F/A-18 maintenance manning is based on a planned utilization of 35 hours per month. The F/A-18's manning reduction from the F-4J level would be even larger if the F-4J were operating 35 hours per month. This reduction of enlisted maintenance personnel is especially important in this volunteer force era. The size of the male labor pool qualified for military service will be 25% smaller in 1990 than it is today, and the percentage of this labor pool likely to enlist in the military services is also expected to decrease. The reduced officer requirements of the Hornet and A-7E, relative to the F-4J, reflects the single-pilot designs.

Fig. 29 Navy Squadron Manning
Based on Squadron Manning Documents



Projected O&S cost savings from introduction of the Hornet are depicted in Figure 30. For this comparison, F-4J and A-7E operating costs based on the Navy Resources Model (NARM) are used to construct a fictional flying hour program equal to an average 607 F/A-18 force operating for 20 years.

Fig. 30 F/A-18 O&S Cost Savings
Compared to F-4J and A-7E Force



As compared to a force of F-4J and A-7E aircraft, fuel contributes most to O&S cost reductions. This is due to the F-4J's relatively large fuel consumption; the A-7E consumes slightly less fuel than the F/A-18. Squadron personnel is the next largest contributor. Depot rework, repair material, and replenishment spares contribute a somewhat lesser amount; the much lower frequency of material replacement is somewhat counterbalanced by the higher costs of F/A-18 material and spares.

These O&S cost comparisons illustrate that introduction of the Hornet will reduce the Navy's operating cost budget when F-4Js and A-7Es are replaced. It should be noted that the NARM report uses Hornet inputs that are somewhat more conservative than the requirements imposed on the contractor.

X. LESSONS LEARNED

The "New Look" emphasis on improved R and M is the key to achieving the improved readiness and lower LCC objectives of the Hornet program. The F/A-18 designers utilized the state-of-the-art in design technology and management initiatives to accomplish this key program objective. Only the highlights of the Hornet's R&M design features and program management initiatives are presented in this paper. Designing for improved R and M involves continuous attention to all levels of detail throughout the design and test phase of the program.

The Hornet FSD flight test program is completed. An accurate answer to the question of how much this intense R and M emphasis during the design phase will impact operational readiness and support requirements probably will not be known before 1983, at the earliest. However, both the U.S. Navy and contractors involved in the Hornet program have learned many lessons about the challenges of designing for significant improvements in reliability and maintainability. Some of these "Lessons Learned" are summarized in Figure 31.

Fig. 31 Lessons Learned

- **ESTABLISH REALISTIC DESIGN-TO REQUIREMENTS**
- **ESTABLISH DESIGN-CENTERED, MULTIDISCIPLINED, CO-LOCATED TEAM**
- **TAKE TRADE STUDIES SERIOUSLY**
- **CONSIDER R&M IN MAJOR PROCUREMENT DECISIONS**
- **USE OME TO DESIGN AND TEST EQUIPMENT**
- **CONDUCT RIGOROUS MULTIDISCIPLINED DESIGN REVIEWS**
- **TRACK AND DEMONSTRATE R&M AT THE AIRCRAFT LEVEL DURING FSD TESTING**

We have learned that designing for improved R&M is not greatly different from designing to any other technical parameter. It is essential that the designer have a "design-to" allocation presented in an understandable form; in terms of key design-sensitive R and M parameters. Allocations should be challenging, but not unreasonable.

It is impossible for a "cultist" group of R and M analysts to set up shop remote from the design action and have any meaningful impact on the evolving design. An effective, multidisciplined design support team consisting of specialists in reliability, maintainability, and ILS must work hand-in-hand with the project design team. It is especially important that R and M engineers be co-located with the design teams which they support.

Trade studies have traditionally been the heart of the iterative design optimization process. In the Hornet program, the trade study process has been expanded to encompass all elements of R, M, and logistics support and to ensure that all specialists are heard before a design decision is made. In addition, documentation has been strengthened to provide traceability and auditing of the design process.

A cost-effective procurement process is essential to the success of a Design-to-LCC program. More than 50% of the Hornet's reliability and maintainability is contributed by subcontractor's hardware. Therefore, procurement policy must put teeth into source selection by emphasizing these elements in the source selection process. Equipment suppliers must be convinced that the customer, both the prime contractor and the using service, place highest priorities on improved R and M.

Designing and testing to an Operational Mission Environment is one of the key technical innovations of the F-18 program. The OME emphasis, tied to a Test, Analyze and Fix philosophy, has undoubtedly done more to improve the Hornet's basic equipment reliability than any other action taken in the program.

Thorough design reviews must be conducted by qualified program management teams to ensure that all elements of R and M are being balanced in the evolving design.

We have shown that aircraft R and M performance can be tracked and demonstrated prior to introduction into fleet use. This has the advantage of finding and correcting R and M problems during FSD test flying and greatly reducing the cost of engineering changes and retrofits.

Designing to improve Operational Readiness and reduce LCC is a way of life in today's budget-limited weapon system procurement environment. This design philosophy requires some changes in the historic design process; industry definitely cannot continue "business-as-usual". However, the technology and management disciplines to effectively accomplish these new objectives are in hand. The Hornet program is demonstrating that significant improvements in weapon system reliability and maintainability to improve OR and reduce support resources can be effectively accomplished.