New Approach to Assurance Technology on "The Hornet"

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Weapon system designers are often presented with opposing requirements, namely low total cost during peacetime and the ability to win a war. However, one design discipline that enhances both demands is "assurance technology." In assurance technology, reliability and maintainability are equal to other design disciplines. Low failure rates, rapid fault isolation, and short repair time combine to reduce requirements for maintenance personnel and spares. This lowers operating and support costs in peacetime, while simultaneously increasing the system's availability, thereby multiplying the effective force for sortie generation in wartime. The F/A-18 Hornet program has incorporated such assurance technology. Specific management and design practice includes guarantees and incentives; a test, analyze, and fix program; realistic operational environment; derating criteria; built-in test; and on-aircraft maintenance concepts.

Background

UNTIL recent years, industry traditionally used the rapid advances in technology to achieve lower weight, lower volume, higher thrust-to-weight, higher speeds, and higher equipment performance. The price paid for this higher performance, however, was low readiness and high total cost. At the present time, many of the current fleet aircraft are not avialable for operational sorties but are waiting for maintenance or spares, which is costly in peacetime and dangerous in times of crisis.

Today, mechanical and electronic technology can be used to meet the challenge of high performance and availability, and provide high sortie rate and effectiveness at lower cost. Thus, the new developments in aircraft technology can be used to provide a more effective force at less cost.

The familiar and alarming trend in total Defense Department expenditures is shown in Fig. 1. More and more dollars are being spent in operating and supporting old-technology aircraft, leaving fewer dollars for the procurement of new-technology aircraft. Unless this situation is altered, our country will have inadequate weapon systems which have less performance than desirable and high operating costs.

The current operational ready rate of fleet strike fighters is now at 50-60%[1]; that is, the aircraft are down about as often as they are able to fly, as shown in Fig. 2. This trend can be reversed by taking a new look at reliability and maintainability through design. The F/A-18 Hornet is a good example.

By featuring designed-in reliability and maintainability, more effective systems can be kept in an "up" status with fewer personnel and fewer spares. The essential elements of such a program include: established guarantees with associated specific demonstrations, incentives, a mission-based environment for design, design guidelines that include specified derating, and an integrated test schedule with closed-loop test/design fix.

The expected reliability and maintainability field performance is shown in Fig. 3. The design-to numbers are up to 6 times better than the current fleet performance. Calculations show that fleet measured operational Maintenance and Material Management data will be approximately 3 times the current fleet performance,[1,2] with an attendant 30-60% reduction in maintenance manhours per flying hours. (The design-to numbers are based on design related failures only, which is normal for a flight demonstration program. The fleet-measured Maintenance and Material Management data contains all failures, no matter what the cause.) In the F/A-18 Hornet program some very real actions have been implemented providing confidence in these data.

Reliability is more than a set of numbers; it cannot be achieved through statistical conditions. Reliability is inherent in the character of the design,and the final numbers will reflect the emphasis placed on this parameter just as surely as those related to performance. Although absolute values can be difficult to ascertain, the trend relationships and comparisons cannot be denied at this phase in the Hornet program.

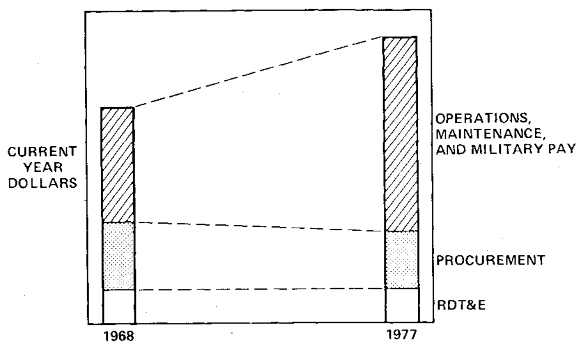

Fig. 1 Department of Defense expenditures.

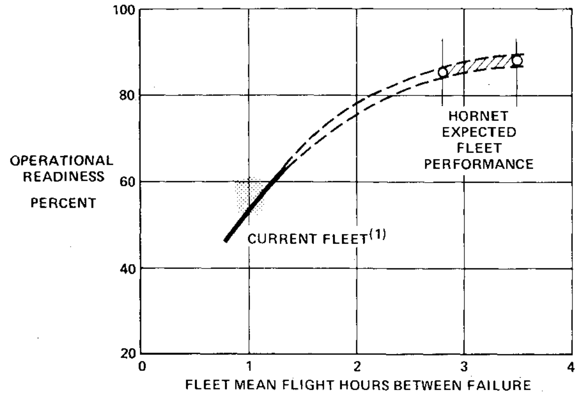

Fig. 2 Projected Hornet operational readiness.

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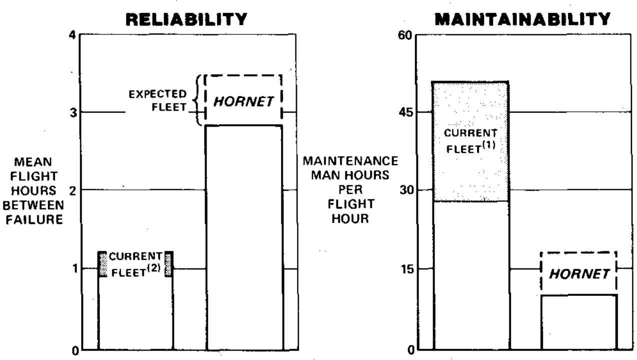

Fig. 3 Calculated F/A-18 reliability and maintainability.

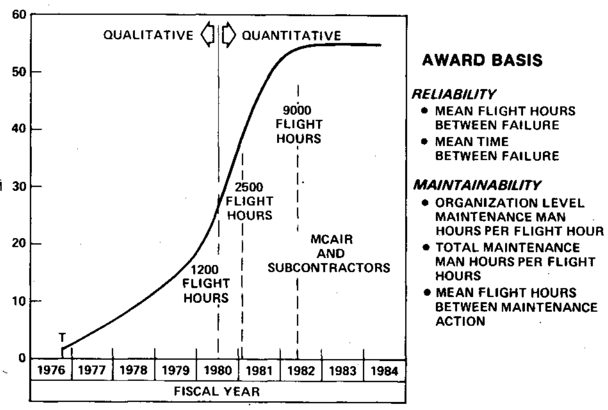

Fig. 4 Potential reliability and maintainability incentives.

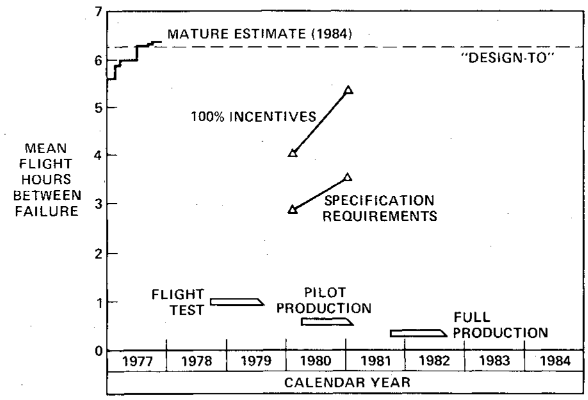

Fig. 5 Reliability requirements.

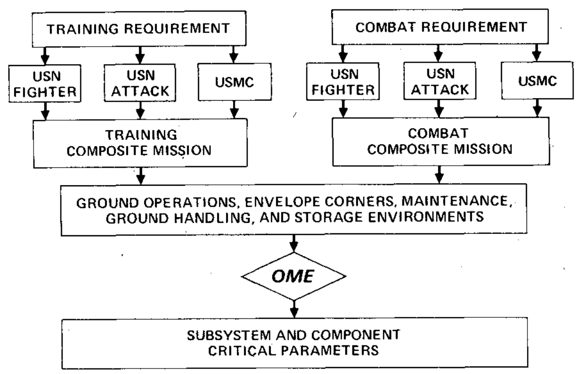

Fig. 6 Operational mission environment development.

Program Features

On the F/A-18 Hornet, the prime contract and all subcontracts have reliability and maintainability guarantees, and the prime contractor as well as major subcontractors have a specific reliability and maintainability demonstration program. Until recent years, reliability and maintainability goals have been used in military contracts, while guarantees were reserved for weight and performance. The intent of the customer became clear—performance, including weight, was important enough to have a guarantee and associated demonstration, while reliability and maintainability were usually carried as design goals that were not achieved during program execution. The worst cases were remedied, but that was usually during fleet operations. The importance of giving reliability and maintainability equal priority with performance is clearly shown by recent in-depth operations analyses. Effectiveness of the carrier complement with the Hornet compared to today's complement showed that the large improvement was equally divided—50% due to combat performance and 50% due to reliability, maintainability, and survivability.

The Hornet program has specific guarantees to be demonstrated during the flight demonstration program. These guarantees will be monitored throughout the program, with specific grading at 1200 and again at 2500 flight hours. All major subcontractors have guarantees and laboratory demonstration programs.

In addition to the guarantees, the Hornet program has gone one step further. The Navy has provided substantial financial incentives to the prime contractors, General Electric and McDonnell Douglas. In turn, McDonnell Douglas has passed these on to the major subcontractors.

The total incentive provision for reliability and maintainability in the Hornet program is $56 million, exluding the engine, as shown in Fig. 4. Prior to accumulating 1200 flight hours, most award payments will be based upon the qualitative evaluation of reliability and maintainability performance. Beyond 1200 flight hours, most incentives will be based upon quantitative evaluation during flight test. Some subcontractors have part of their incentive based upon laboratory performance, if the hardware has not reached sufficient development status early in the flight demonstration program to provide the sole basis for evaluation.

For both the subcontractors and the prime contractor, the incentives are large enough to get management attention. If all of the incentives are earned, they represent approximately a 50% increase in potential full-scale development earnings.

Figure 5 shows how reliability and maintainability specification requirements, incentive requirements, design-to values, current estimates, and the test and production schedule relate on the Hornet program. The Hornet detail specification calls for achieving 3.7 MFHBF (Mean flight hours between failure) at 2500 flight hours. To be sure of achieving these values, we have decided to "design-to" 6.18 MFHBF. Mature estimates show that the criteria used for design and test give us high probability of success in the operational environment.

Twelve million dollars of the $56 million total reliability incentive is reserved for the reliability portion of the flight demonstration which may be earned by demonstrating the reliability illustrated in Fig. 5. Early in the flight test program, 100% of the incentive cannot be earned unless the Hornet achieves a 3.7 MFHBF, or the contract specification value. Later in the flight test program the Hornet must achieve approximately 5.4 hours (including Government-furnished equipment) to achieve 100% of the reliability incentive. The demonstrations lead the delivery of full production hardware so the Navy can evaluate the Hornet in a flight environment before any substantial number of aircraft are procured.

The Hornet program thus features guarantees, incentives, design-to goals, continuously updated estimates, and a procurement schedule which allows an orderly but intensive design and development program, leading to high availability during Fleet operation.

A Realistic Operational Environment for Design and Test

In past programs, development demonstration tests that were used to design and qualify equipment usually were not based upon the operational environment. Laboratory tests classically have been based upon MIL-standards, and the suppliers have designed equipment to pass the tests. This led to good performance in the laboratory, but not necessarily in the field.

To remedy this, a very detailed Operational Mission Environment (OME) was developed which represents the environment which the Hornet should encounter. The procedure is shown in Fig. 6. First, training and combat requirements for the U.S. Navy and U.S. Marine Corps fighter and attack squadrons were developed. The most strenuous portions of each mission were put into a composite mission, containing segments which equipment will see during its operational lifetime.

Examination of these composite missions revealed that at least five important operational environments had not been considered. These were ground operation, flight envelope corners, maintenance, ground handling, and storage requirements. These portions of the operational life were then added to the composite mission and the result was the OME.

The OME was used to define design and test conditions for Hornet hardware. The environments considered included vibration, temperature, shock, acoustic, humidity, climatic, and sustained loads, among others. The environments were tailored to the type of equipment and its location in the aircraft.

The actual operating hours needed for certain equipment in order to provide the Hornet a 6000 flight hour service life are shown in Table 1. In addition to the 6000 flight hours, there are 1800 additional engine operating hours and slightly over 2000 operating hours for maintenance. By studying the additional operating hours and maintenance requirements, it is possible to determine the amount of equipment and the stress level at which the equipment will operate. It is important to note that if it had been designed to the 6000 flight hours, and other operating hours had been ignored, more than one-third of the operating life of the equipment would not have been considered during design and test.

Table 1 Mission time analysis summary

	Service life
Flight hours	6000
Additional engine operating hours	1800
Mission related	(1667)
Maintenance	(133)
Operating hours for maintenance	2014
Auxiliary power unit	(1694)
External power	(320)
Total	9814

Table 2 Hornet design mission distribution

TRAINING MISSIONS	88%
Strike escort	
Barrier cap	
Fighter cap	
Deck launched intercept (DLI)	
Air combat training/ACM	
Air intercept training	
Interdiction/close air support	
Low-level navigation/strike	
Carrier qualification	
Field carrier landing practice	
Ferry/FAM/instruments	
Surface subsurface search	
COMBAT CRITICAL MISSIONS	12%
Strike escort	
DLI against bombers	
Supersonic medium-altitude attack	
Supersonic high-altitude attack	
High subsonic low-altitude attack	
Subsonic medium-altitude attack	

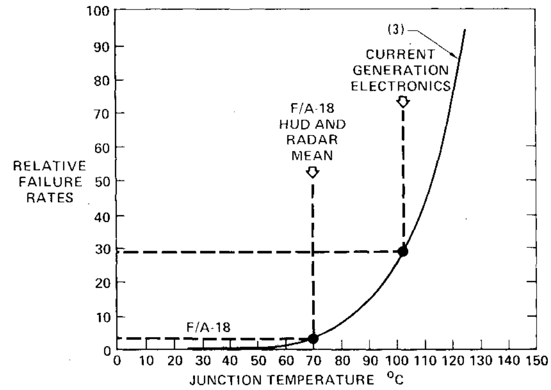

Fig. 7 Linear microcircuit sensitivity to junction temperatures.

Table 2 shows all of the training and combat critical missions considered in developing the operational mission environment. Based upon history since the beginning of World War II, 88% of all Hornet missions will be for training purposes and 12% for combat-critical missions. Training missions provide the most stringent environment because of the amount of time spent in critical flight regimes.

Each mission was evaluated, segment by segment, as flown in Navy fighter, Navy attack, and Marine Corps applications. The study required many manhours, but it was worth the expenditures because realistic technical requirements were uncovered in the process. Two of the most significant in terms of impact on the design of Hornet avionic equipment are: random plus sinudoidal vibration; and thermal shock, which is several times more severe than previously specified.

Some Unique Design Requirements

Achieving reliability and maintainability in design requires attention to details. To prevent one failure on a 34,000-lb airplane requires preventing one failure in any of millions of ounce-level parts. The battle for reliability and maintainability is won or lost at the piece-part level. Important examples are linear microcircuits and screws. Derating provides a margin of safety applicable to either type of component, electronic or mechanical.

Avionic components fail more often at high temperatures or high rates of temperature change. For example, Fig. 7 shows the sensitivity of linear microcircuits to junction temperature.[3] Mean junction temperatures for linear microcircuits of about 103°C are common on present generation strike fighter electronics. Because of derating criteria established on the Hornet program and attention to thermal design, the mean junction temperature for linear microcircuits on the F/A-18 head-up display and radar has been reduced to 70°C, reducing the relative failure rate from 30 to 4. Requirements established by the prime contractor and careful attention to derating detail and stress analysis by the subcontractors will substantially reduce failures on these types of circuits and provide a major improvement in avionic reliability.

Because of the high failure rate of avionics at elevated temperature, specification requirements on the environmental control system were reinvestigated to ascertain if delivery air temperature could be reduced. Figures 8 and 9 show the original specification schedule, requiring 62°F delivery air to 30,000 ft and a linear decrease to 0°F at 42,500 ft and above. It was discovered that the schedule could be altered without encroaching on the free water condensation zone, thereby

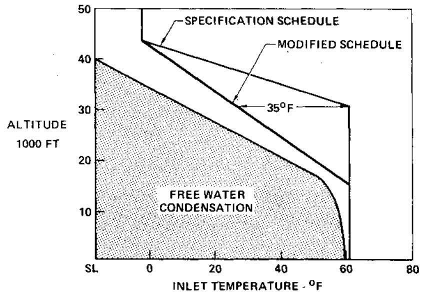

Fig. 8 Avionics delivery air temperature schedule.

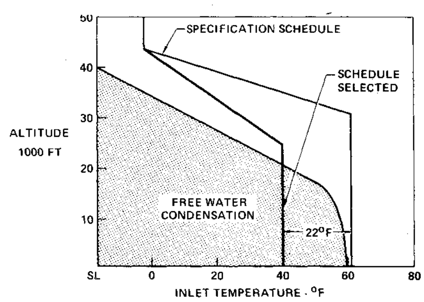

Fig. 9 Avionics delivery air temperature schedule.

reducing the avionic inlet temperature between 15,000 and 42,500 ft. This eventuated without penalty to airplane weight or aerodynamic performance. Avionics reliability was further improved by using a high-pressure water separator to dry the air, thereby allowing the air temperature to decrease by 22°F. This improved avionics reliability by an estimated 3-8% (depending upon operational circumstances.)

Fasteners account for a high number of maintenance manhours, and therefore become both a reliability as well as a maintainability consideration. As a result of previous design practices, frequent fastener failure due to overtorque caused too much maintenance time compounded by the supply problems inherent in the many different types of fasteners used on each aircraft type. The F/A-18 has only 45 different types of fasteners, with a ¼-in. minimum diameter screw size for access doors, as illustrated in Table 3. The ¼-in. minimum gives greater strength for overtorque resistance. Figure 10 illustrates the toughness of this ¼-in. screw. It has a specially designed domed head and is heat-treated to 180,000-psi tensile strength. The 3/16-in. fastener used in current Naval aircraft has the ability to withstand approximately 37 in.-lb of recess torque, whereas the F/A-18 quarter inch fastener will withstand approximately 125 in.-lb. The recommended illustration torques are shown in the shaded area. Recent Air Force field data,[4] collected and now totally distributed, indicate that in some 2000 test points the average torque applied by the maintenance personnel was 39 in.-lb and the maximum was 90 in.-lb. These data provided confidence that the ¼-in. minimum diameter screw will enhance screw reliability for the Hornet.

Test, Analyze, and Fix

An ideal test program would be organized so that development is essentially completed before laboratory and flight demonstrations. This situation is compromised many times due to schedule or cost. With proper consideration to all constraints, two important points must be achieved: 1) accomplish sufficient development testing before committing to large amounts of either demonstration testing or production testing; and 2) analyze each failure occurring during any test and incorporate a design fix to eliminate it—not simply replacing the failed component with another like it in hopes that the equipment can now pass the test. Although this latter concept is not new, it is seldom applied. It applies to both development and demonstration, but the largest payoff is during development.

Table 3 Improved F-18 fastener usage

	F-4	F-18
Fastener types	210	45
Door screw design policy	3/16-in. diam. (min.)	¼ in.-diam. (min.)

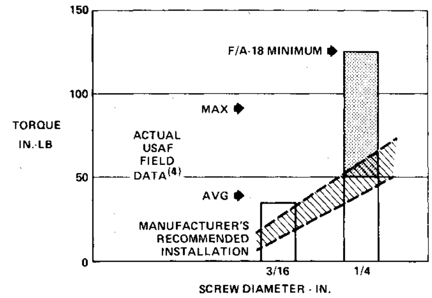

Fig. 10 Screw strength comparison—steel shear head.

In the Hornet program, money and equipment were set aside to conduct reliability development tests. Personnel are testing to the OME, analyzing every failure and incorporating the design fix. To insure that suppliers did not become engrossed with passing a reliability development test at the expense of benefiting from failure experience, no "pass or fail" criteria were imposed. They were just required to test to the specified operational environment for the specified number of hours, consider all failures as being relevant to design, and incorporate a design or quality fix to eliminate the failure.

At first consideration, this may appear to be too easy a test program because it does not have specific reliability pass or fail criteria. However, more often than not, pass and fail criteria result in major disagreements about whether a failure is relevant, and can lead to insufficient attention to fixing the reliability problems. The important principles are to test in the operational environment, and provide design or quality fixes. If these principles are followed, the fleet will have good equipment.

Summary

This paper briefly summarizes assurance technology as used on the F/A-18 Hornet program. The main point is that reliability and maintainability have been equal to all other criteria in arriving at a design decision. This philosophy has been carried out throughout the program, from the piece-part designer to the program manager. Design and test features have been incorporated which yield better reliability and maintainability consistent with necessary performance. Better reliability and maintainability will provide the Navy with a capable weapon system that will operate with reduced costs in peacetime and have the ability to generate high sortie rate in time of crisis.

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