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REPORT TO THE SENATE COMMITTEE ON APPROPRIATIONS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Operating And Support Costs Of New Weapon Systems Compared With Their Predecessors

Departments of Defense, the Air Force, and the Navy

The Department of Defense is emphasizing reliability and maintainability of new weapon systems to reduce operating and support costs. However, it is not clear to what extent reliability and maintainability can reduce operating and support costs of tactical aircraft systems because the data systems necessary for making such determinations do not exist. GAO's review of the F-14, F-15, F-16, and F-18 tactical aircraft disclosed that maintainability specifications agreed to by the military services and contractors for these weapon systems do not reflect reasonable expectations of actual results once the weapon systems are in operation.

LCD-77-429

OCTOBER 17, 1977

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-178214

The Honorable John L. McClellan
Chairman, Committee on Appropriations
United States Senate

Dear Mr. Chairman:

This report discusses operating and support costs of new weapon systems compared with their predecessors. The review was made in response to your March 30, 1976, letter, in which you asked us to see if emphasizing reliability and maintainability in new weapon systems has reduced operating and support costs and how cost savings attributable to improved reliability and maintainability are measured.

On February 25, 1977, we met with your office and provided a brief statement on the results of our work at that time. We also provided a list of suggested questions which were subsequently used in the fiscal year 1978 hearings on operation and maintenance appropriations requests before your Committee.

As your office requested, we did not obtain official written comments from the Department of Defense or the services. We obtained informal comments during discussions with officials of the services and incorporated them into this report.

This report contains recommendations to the Secretary of Defense which are set forth on page 24. As agreed with your office, we plan to release the report a week after it is sent to you so that the requirements of section 236 of the Legislative Reorganization Act of 1970 can be set in motion.

Sincerely yours,

R F Keller

Acting Comptroller General
of the United States

COMPTROLLER GENERAL'S
REPORT TO THE SENATE
COMMITTEE ON APPROPRIATIONS

OPERATING AND SUPPORT COSTS OF NEW WEAPON SYSTEMS COMPARED WITH THEIR PREDECESSORS

Departments of Defense, the Air Force, and the Navy

D I G E S T

In recent years the military services have increasingly emphasized life-cycle costs and reliability and maintainability of new weapon systems in an effort to reduce rising operating and support costs. These costs represented more than two-thirds of the national defense budget in the early 1970s. If the upward trend continues, few defense dollars will be left to modernize and replace aging systems.

GAO reviewed the Navy's F-4J, F-14, and F-18, and the Air Force's F-4E, F-15, and F-16 tactical aircraft systems. But data to measure benefits attributable to reliability and maintainability improvements for weapon systems are not kept by the services. For this reason it is not clear to what extent these improvements have resulted in fewer personnel, spares, support equipment, or other requirements.

Nevertheless, GAO tried to measure the effect of reliability and maintainability on successive tactical aircraft systems by using the services' maintenance data collection systems and cost estimates, without validating the accuracy or merits of these systems. It should be recognized that the systems were not designed for this purpose; comparisons only provide indications.

Some factors impeding comparability between new and old systems are differences in capability, complexity, and technology. Also, systems are in different stages of their life cycles. Major subsystems may not be directly comparable between aircraft because of functional variances. All of

these factors can distort reliability and maintainability comparisons. The services' data systems do not provide for assessing the effects of these variables.

CONCLUSIONS

Reliability and maintainability appear to be receiving increasing attention in attempts to control operating and support costs of new weapon systems. However, it is not clear to what extent the increased reliability and maintainability efforts have reduced operating and support costs.

GAO's review of the four tactical aircraft systems provides general indications, but it does not compare the effects of reliability and maintainability in successive weapon systems. The data systems necessary for accurately assessing the costs and benefits of reliability and maintainability efforts do not exist.

In addition, the effects of changes in weapon system complexity, capability, and technology would have to be separated from effects of reliability and maintainability. This is not presently done. The services do not maintain such intricate data and GAO is not certain that such systems would be feasible.

Emphasis on reliability and maintainability has not necessarily reduced operating and support costs of successive weapon systems. For example, the F-14s are much more costly to operate and support than the F-4s they are replacing. But the F-14 has capabilities the F-4 does not possess, making the F-14 one of the most complex fighter aircraft ever produced in the United States.

Reliability and maintainability of the F-16 and F-18 are being stressed, and contractual provisions give contractors incentives to meet these goals. The aircraft are considered to be simpler than the F-14 and F-15 and are expected to cost much less to operate and support, but they do not necessarily have the same capabilities.

It appears that emphasis on reliability and maintainability of the Air Force's F-15 may have paid off, but it is not known to what extent these reductions are attributable to other factors. The Air Force requires over 100 fewer maintenance personnel for a wing of F-15s than for an equal number of F-4s at the base level.

The contractual maintainability specifications for the F-16 and F-18 do not necessarily reflect reduced support costs when compared with fighters in operation. The F-16 and F-18 represent the low cost options of the high-low weapons mix, but maintenance personnel may not be significantly reduced when compared with the F-15, if their maintainability specifications are comparable.

The maintainability specifications in terms of direct maintenance manhours per flight hour for the F-16 and F-18 are the same for the F-15. The simpler F-16 has specifications for 12 direct maintenance manhours per flight hour compared with 11.3 for the F-15.

The Air Force stated that the difference in aircraft utilization rates used in the computation renders the specifications not directly comparable. At maturity, the F-16 is expected to require less maintenance personnel than the F-15 as reflected by their total maintenance goals of 23 and 28 maintenance manhours per flight hour, respectively. Air Force officials also stated that specification definitions and measurement requirements are not identical for the F-15 and F-16, thus distorting comparability. However, the extent of this distortion has not been identified quantitatively.

The services should continue to strive to narrow the gap between contractually specified reliability and maintainability and those factors measurable under operational conditions. The F-16 and F-18 specify overall weapon system reliability in terms of mean flight hours between failure, which is measurable in the operational environment. Formerly, only mean time between failure or mission success probabilities were specified.

As described earlier, mean time between failure is not tracked in the services' data systems. Not all measurement problems, such as failure determination, are resolved with this change, but at least more meaningful reliability monitoring can be accomplished. There would also be greater awareness to make subsystem test conditions more representative of the operational environment.

At the request of the Senate Committee on Appropriations, GAO did not obtain written agency comments; however, GAO discussed the report with Defense officials and incorporated their comments, where appropriate.

RECOMMENDATIONS

The Secretary of Defense should require the Air Force and the Navy to

--make certain that contract maintainability specifications more closely correspond to the actual results expected once the weapon systems are in operation;

--explore the possibility of developing reasonable criteria and data systems for measuring and evaluating the results of their programs for improving maintainability, reliability and life cycle costs; and

--provide congressional committes with estimates of reliability and maintainability improvements the military service expect to see in new weapon systems development.

Contents

ABBREVIATIONS

GAO General Accounting Office

NORM not operationally ready-maintenance

NORS not operationally ready-supply

MMH/FH maintenance manhours per flight hour

CHAPTER 1

INTRODUCTION

In recent years the military services have increasingly emphasized life cycle costs and reliability and maintainability of new weapon systems in an effort to reduce rising operating and support costs. These costs represented more than two-thirds of the national defense budget in the early 1970s. If the upward trend continues, few defense dollars will be left to modernize and replace aging systems.

The services recognize that operating and support costs generally constitute about half the total life cycle cost of an aircraft weapon system. They also recognize that potential savings may accrue from increased reliability and maintainability in the form of reduced maintenance personnel requirements and logistics support.

Reliability is the likelihood that an item will perform its intended function for a specified amount of time under stated conditions. Consequently, reliability can affect operating and support costs. The lower the reliability, the higher the anticipated failure rate, which in turn could require increased maintenance and spares support. The reliability for a weapon system or subsystem is usually stated in terms of mean time between failure. In the operational environment, all malfunctions requiring a maintainance action, regardless of their severity, are counted as failures. Many malfunctions do not make a weapon system inoperable, nor do they necessarily restrict a weapon system's ability to accomplish its mission.

Maintainability is the likelihood that an item will be retained in or restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources. Maintainability is the ease with which an item is maintained, whereas maintenance is a series of actions necessary to restore or retain the item in the specified condition.

Reliability and maintainability are important factors in determining operating and support costs. The higher the failure rates and the more equipment there is to fail, the higher the maintenance cost for parts and personnel. Similarly, the more difficult access is to components and parts, the greater will be the time required to remove and replace an item. New weapon systems being developed stress operating and support cost by means of new approaches toward reliability and maintainability.

Contracts for newer aircraft state reliability and maintainability as requirements rather than as goals. Various contract incentives are provided for meeting or exceeding these requirements and life cycle cost targets. More funds are being made available for testing early in the development of weapon systems to avoid or reduce costly modifications after the design is defined and in production. Reliability improvement warranties are also being included.

The military services informed the Congress that improved reliability and maintainability are paying off in terms of reduced support costs. We were asked by the Senate Committee on Appropriations to look into the following areas:

--Operating and support cost savings resulting from improved reliability and maintainability.

--Comparative reliability and maintainability of the new weapon systems and subsystems with their predecessors.

--Information systems and records maintained to track reliability and maintainability of a weapon system and the results achieved in an operational environment.

--Efforts by the services to reduce logistics and maintenance personnel.

SCOPE OF REVIEW

We reviewed reliability and maintainability and their effects on operating and support costs for the F-14, F-15, F-16, and F-18 tactical aircraft to the extent that such information was available from the services' data systems. We did not validate the accuracy of the services' data. We contacted the following organizations, discussed pertinent subjects with agency and contractor personnel, and obtained information from their records.

Headquarters, U.S. Air Force, Washington, D.C.
Tactical Air Command, Langley Air Force Base, Virginia
Headquarters, Aeronautical Systems Division,
  Air Force Systems Command, Wright-Patterson Air Force Base, Ohio

Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio
McDonnell Douglas Corporation, St. Louis, Missouri
Chief of Naval Operations, Washington, D.C.
Naval Air Systems Command, Washington, D.C.
Commander, Naval Air Forces, Atlantic, Norfolk, Virginia
Commander, Fighter Wing One, Oceana, Virginia
Aviation Intermediate Maintenance Division, Naval Air Station, Oceana, Virginia
Naval Air Rework Facility, Norfolk, Virginia
Naval Aviation Integrated Logistic Support Center, Naval Air Station, Patuxent River, Maryland
Grumman Aerospace Corporation, Bethpage, Long Island, New York

CHAPTER 2

RESPONSE TO SPECIFIC QUESTIONS

OPERATING AND SUPPORT COST SAVINGS RESULTING FROM IMPROVED RELIABILITY AND MAINTAINABILITY

As far as we could determine, the services do not maintain data systems which measure benefits of reliability and maintainability improvements in weapon systems; nor is the portion of design and development effort devoted to reliability and maintainability identified separately in the development contracts. As a result, it is not clear to what extent reliability and maintainability improvements have affected operating and support costs as compared with the effects of technological advances and changes in complexity and capability.

Operating and support cost data of weapon systems is limited and imprecise. The services are in the process of developing standardized operating and support cost systems for weapon systems, but it is not clear that they will provide data necessary for evaluating the relative costs of maintaining new weapon systems in comparison to the systems they replace. We obtained some cost comparisons indicating the trends for the weapon systems we reviewed. Both the Air Force and the Navy record cost factors per flight hour for various cost categories for aircraft systems. Similarly, both services maintain data systems to estimate the annual cost to operate and support a single aircraft or squadron of aircraft by type. We did not validate either of the cost accumulation systems.

Annual operating and support cost estimates

The services' data show that the F-14 and the F-15 are more expensive to operate and support than the F-4s they replaced. The F-16 and F-18 tactical aircraft, however, are expected to be less expensive than the F-4 aircraft.

The Navy estimates the following costs to operate and support aircraft of each type per year.

Aircraft	Estimated annual operating and support costs	Percent of increase or (decrease) compared with the F-4J
F-4J	$1.0 million	-
F-14	$1.4 million	40
F-18	$ .76 million	(24)

The Air Force provided us with the following estimated yearly costs to operate and support a squadron of each aircraft type.

Aircraft	Estimated annual operating and support costs	Percent of increase or (decrease) compared with the F-4E
F-4	$22.9 million	-
F-15	$23.8 million	4
F-16	$16.4 million	(28)

Comparative personnel requirements

Except for the Navy's F-14, the services appear to be successful in reducing the number of personnel needed to operate and support the new weapon systems we reviewed. Air Force data shows that a wing of 72 F-15s requires over 200 less people to operate and support than a similar unit of F-4s. Maintenance personnel reductions of 120 persons account for the largest decrease. The reduction in aircrew from two persons to one per plane accounts for most of the remaining reductions. The F-15 is a single-seater aircraft, whereas the F-4 is a double seater. Maintenance decreases comprise over half of the personnel savings in the maintenance category, indicating that maintainability features incorporated into the aircraft may be paying off.

The Navy's personnel data shows that a squadron of F-14s requires 28 more people, or an increase of 10 percent, than a similar squadron of F-4Js. Navy officials attribute the increase to the F-14's complexity.

The Air Force and Navy both project personnel savings for the F-16 and F-18 aircraft. The Air Force estimates that a wing of F-16s will require nearly 570 less people to operate and maintain than a similar wing of F-4s. Nearly 460 of the anticipated personnel reductions are in the maintenance category.

The Navy estimates that a squadron of F-18s will require about 77 less personnel to operate and support than a squadron of F-4s. Annual personnel costs are estimated at $208,000 for each F-18 compared with $313,000 for an F-4J and $336,000 for an F-14. Navy officials expect maintenance personnel requirements for the F-18 to be less than those of the F-4 or F-14 due to the F-18's relative simplicity and added maintainability features.

Comparative spares costs

According to available Air Force and Navy data, spares support costs per flight hour for the F-14 and F-15 aircraft more than doubled compared to the F-4s they succeeded. While spares costs per flight hour for the F-16 and F-18 are expected to be considerably less than for the F-15 and F-14, respectively, replacement spares per flight hour are expected to be markedly higher than for the F-4 aircraft.

While we did not examine the reasons for the large cost increase per flight hour, there are indications that individual replacement spares for the new weapon systems are substantially more expensive than their earlier counterparts. For example, our limited comparison of F-14 items with items on the F-4J performing a similar function showed that the F-14 items cost two or three times as much as the F-4J items. Identical items used on both aircraft cost the same.

Comparative support equipment costs

Navy and Air Force data show that support equipment costs for the F-14 and F-15 are more than double the cost for the F-4s they will replace. Automatic avionics maintenance support equipment is largely responsible for the higher support costs associated with these aircraft. However, due to the complexity of many of the new avionic systems, it appears unlikely that they could be maintained manually.

The F-16 and F-18 will also require expensive automated test equipment to support the avionics. The Air Force is developing completely new test systems for the F-16 at a cost of more than $100 million. Air Force officials stated this is more economical than to adapt the F-15 test systems based on life cycle cost analyses performed by them. The Navy plans to use, to the extent possible, existing test equipment now serving the F-14 and two other aircraft for F-18 avionics.

COMPARING RELIABILITY AND MAINTAINABILITY OF THE NEW SYSTEMS WITH THEIR PREDECESSORS

To obtain some measure of comparative reliability and maintainability for the F-14 and F-15 tactical aircraft with the predecessor F-4s, we used the services' maintenance data collection systems without validating the accuracy or merits of these data systems. The reliability and maintainability data for different aircraft systems may not be truly comparable. A number of factors can affect the reliability and maintainability of successive weapon systems and distort comparisons between the systems. One such variable is the life cycle phase of each particular aircraft system at the time of the comparison. The new weapon systems, such as the F-14 and F-15, may not have fully matured, but the predecessor system is mature or past this stage and fatigue and wear may have caused reliability problems. In addition, there are changes in weapon system complexity, capability, and technology, which detract from the comparability of the weapon system and major subsystems. The services' data systems do not allow for these variables, nor were we able to isolate the effects thereof to make more valid comparisons. While we made reliability and maintainability comparisons between the F-15, F-14, and the F-4s to respond to the request, these variables should be kept in mind.

According to the services and the respective contractors, reliability and maintainability were major considerations during the design and development of new weapon systems, such as the F-14 and F-15 fighter aircraft, although more emphasis was given to performance parameters. The services assure us that during the design and development of the F-16 and F-18, reliability and maintainability are stressed even more than they were for the F-14 and F-15. To achieve better reliability and maintainability, the contractors are given incentives through reliability improvement warranties, fees tied to logistics support cost targets, fees tied to life cycle cost factors, program milestones to be met, and reliability and maintainability parameters.

Comparative reliability

The reliability of weapon systems generally improves for several years after they are introduced into the operational environment, before stabilizing. The precise stabilization point for a specific weapon system is difficult to predict. Navy and Air Force officials said that the F-4J and F-4E are considered to be mature weapon systems, whereas both the F-14 and F-15 are still in the reliability growth stages, and reliability improvement efforts are continuing.

The services' maintenance data systems show both the F-14 and F-15 to be generally more reliable than the F-4s being replaced. For February through May 1976 the F-15 averaged .75 flight hours between failure as compared with .65 for the F-4E for November 1975 through May 1976. The F-15 attained 1.1 flight hours between failure during June through August 1976. Air Force officials are optimistic that the F-15's reliability will improve as the new weapon system matures and reliability improvement efforts are accomplished.

The Navy's data shows that from October 1975 through March 1976 the F-14 averaged .8 flight hours between failure as compared with .7 for the F-4J. January through June 1976 data shows similar performance. Navy officials, too, are optimistic that the F-14's reliability will improve as the aircraft matures and reliability improvement efforts materialize.

At the subsystem level performance varies--some are more reliable than their functional counterparts in the old aircraft, whereas others are not. For example, the F-15's engines averaged only 2 flight hours between failure as of May 1976, but the F-4E's engines had a reliability of 13 flight hours between failure. Although the differences are much smaller, the engines of the F-14 also do not appear to perform as well as those of the predecessor F-4J. From January through June 1976 the F-14 and F-4J engines averaged 18.6 and 20.7 flight hours between failure, respectively.

While the services' maintenance data systems show the F-14 and F-15 to be generally more reliable than the predecessor F-4s, both aircraft have had significant problems and as yet do not live up to expectations. For example, in our report concerning the effectiveness of the F-14A/Phoenix weapon systems issued in August 1976 (PSAD-76-149, Aug. 3, 1976), we pointed out concerns about mission capability, low operational readiness, and technical performance problems, including low reliability in a number of avionics systems. The engines had problems and were responsible for a number of crashes and groundings of the aircraft.

Similarly, the F-15 has had problems concerning operational readiness, engine reliability, and delays in incorporating the defensive avionics package. As we point out in appendix II, even though the F-15 weapon system as a whole is meeting reliability specifications, several of the major subsystems, such as avionics and propulsion, are below their "guaranteed" reliability goals.

The F-16 and F-18 are being developed and there are no operational aircraft of these types. If reliability specifications are met, both of these planes will be more reliable than the F-4s, F-14s, and F-15s. The F-16 is to achieve 1.75 average flight hours between failure at the end of development. At maturity this value is to improve to 2.9 average flight hours between failure. These values compare favorably with the .65 and 1.1 flight hours between failure achieved by the F-4E and F-15 in the operational environment. Similarly the reliability for the F-18 is 3.63 average flight hours between failure. In comparison, the F-4J and F-14 averaged .7 and .8 flight hours between failure, respectively, in the operational environment.

According to Navy officials the F-18 is expected to be spectacularly more reliable in the operational environment than the F-4J and A-7E it is scheduled to replace. The F-4J and A-7E have a reliability of only .6 and 1.2 average flight hours between failure, respectively. During authorization hearings in 1976, the Navy stated that the F-18 is expected to achieve 5.9 average flight hours between failure as measured by the maintenance data system in the operational environment. These stated expectations considerably exceed the contractual reliability specifications of 3.63 average flight hours between failure.

Comparative maintainability

The maintainability of similar aircraft can be compared on the basis of maintenance hours required per flight hour. A distortion in making comparisons is that contract specifications are in terms of direct maintenance manhours per flight hour whereas the services' maintenance data system reports only total maintenance manhours (direct plus indirect time).

At the time of our review, the services' maintenance data systems showed that the F-14 required more maintenance effort per flight hour than the F-4, whereas the F-15 required about the same as its predecessor. The operational F-14 squadron we visited incurred 58 maintenance manhours per flight hour. A squadron of F-4s with an equal number of planes required 42 maintenance manhours per flight hour. Navy officials state that the F-14 has many maintainability improvements when compared with the F-4, but that the F-14 is more complex and capable with more equipment to fail. For corrective maintenance alone for October 1975 through March 1976, Navy data showed that the F-14 required 26.5 maintenance manhours per flight hour compared with 20.7 for the F-4J. Nearly all of the F-14's functional subsystems required more corrective maintenance effort than those of the F-4J. Navy officials are optimistic that the F-14's maintenance requirements will decrease as the weapon system matures and becomes more reliable, and maintenance personnel become more experienced.

The F-15 required about 35 maintenance manhours per flight hour in mid-1976 as did the F-4E. However, most aircraft were deployed in training squadrons at that time. The Air Force expects the F-15 to stabilize at 28 maintenance manhours per flight hour at maturity, which they contend will be in the early 1980s.

The F-16 and F-18 are considered to be less complex than the F-15 and F-14, respectively. The specifications for the F-16 and F-18 show that about the same maintenance effort is required as for the F-15. Specified maintenance parameters are as follows.

	Direct maintenance manhours per flight hour
F-15	11.3
F-16	12.0
F-18	11.02

The Air Force stated that the direct maintenance manhour specifications are not directly comparable because they are based on different utilization rates. The F-15 specifications were based on planned aircraft utilization of 45 flight hours per month, whereas the F-16 specifications are based on 30 flight hours per month. To adjust for the differing utilization rates, the Air Force set goals of 28 total maintenance manhours per flight hour and 23 total maintenance manhours per flight hour for the F-15 and F-16 at maturity, respectively.

Department of Defense and Air Force officials contend that the maintainability specifications are not directly comparable between services or aircraft developed during different time frames. For example, the Navy and Air Force do not necessarily use the same components or aircraft utilization factors in deriving their respective direct maintenance manhour per flight hour parameters. The impact on the specifications has not been identified. The Air Force officials also stated that the measurement of the maintainability specifications under compliance test conditions for the F-15 and F-16 will not necessarily be the same, which detracts from comparability. However, the extent of this distortion has not been identified quantitatively.

As in the case of reliability, the Navy may have been overly optimistic in expressing its maintainability expectations during congressional hearings. Maintainability forecasts for the F-18 presented before the Senate Committee on Armed Services in March 1976 are extremely favorable in comparison with weapon systems in operation. The Navy said that the F-18 will require only slightly more than half the maintenance effort needed for the A-7E.

In their presentation, the Navy said it expects the F-18 to require only 14.6 maintenance manhours per flight hour in the operational environment as compared to 26 maintenance manhours per flight hour for the A-7E. Contractual maintainability specifications for the F-18 do not suggest such a large decrease in maintenance requirements when compared with the A-7E. The A-7E contract specified 10.2 maintenance manhours per flight hour, whereas the F-18 contract specifies 11.02. This seems to indicate that the F-18 could require more maintenance effort than the A-7E.

INFORMATION SYSTEMS AND RECORDS MAINTAINED TO TRACK RELIABILITY AND MAINTAINABILITY

The services have data systems which record maintenance actions and when they occur in relation to the number of flight hours incurred. We used these data systems to obtain reliability and maintainability indicators for the various weapon systems and subsystems in the same service. However, the data collected in the operational environment does not directly relate to contractual specifications or goals. Detailed analysis of every maintenance action, when it occurred and how it was disposed of, would be required to estimate the relationship between the data collected in the operational environment and specifications.

Comparability of specifications and information system data

Contractors generally demonstrate reliability and maintainability specifications under controlled test conditions which do not necessarily duplicate the operational environment. Nor do specification parameters for the F-14 and F-15 correspond with the parameters measured in the maintenance data system. At the time of our review, the contractors were generally able to demonstrate compliance with the F-14 and F-15 reliability and maintainability specifications.

Contractural reliability specifications for the F-14 and F-15 were expressed in terms of mission success rates and mean hours between failure. These parameters are not usually measured in the operational environment. The services' data systems record the number of maintenance actions and flight hours, but not the actual subsystem operating times. (Subsystem operating hours do not necessarily correspond to flight hours incurred.) Another complicating factor is the difference in failure definition. Under the contract terms only relevant failures are considered, whereas in the operational environment all failures and adjustments, actual or inappropriately indicated, must be dealt with.

Some of this conflict can be expected to disappear after the F-16 and F-18 tactical aircraft are introduced, because overall reliability specifications are expressed in terms of mean flight hours between failure and measured in the operational environment. However, this does not apply to the subsystem level. Goals for subsystems are still expressed in terms of mean time between failure.

A similar disparity exists with measuring compliance with maintainability specifications. Contracts for both the F-14 and F-15 specify precise maintenance manhours per flight hour. However, the parameters measure only direct maintenance time which is defined as "hands on" or "wrench time," excluding indirect activities such as travel to or from the job, unavoidable in the operational environment. For example, the F-15 contractor is to demonstrate 11.3 maintenance manhours per flight hour, whereas the Air Force anticipates 28 maintenance manhours per flight hour in the operational environment.

Contracts for the four aircraft systems we reviewed specified only overall aircraft reliability and maintainability parameters, such as mean flight hours between failure for the entire weapon system. The contractor allocates goals to the contractor-furnished subsystems to meet the overall requirement, with the services' approval. These goals are subject to subsequent negotiations and may change, but contractual requirements are met as long as compliance with the overall specifications can be demonstrated.

OTHER EFFORTS BY THE SERVICES TO REDUCE LOGISTICS AND MAINTENANCE PERSONNEL

The services have taken some steps toward reducing maintenance and support personnel, such as applying life cycle cost targets for weapon system components, encouraging improved reliability and maintainability, and changing maintenance philosophy at the depot level. Payoffs attributable to logistics and maintenance personnel reductions are difficult to measure because the necessary data systems are not maintained and specific benefits would be difficult to isolate due to variances in system complexity and similar factors.

In the design phase of components, the ownership costs for the expected life of the system are considered and reliability and maintainability are matched against capability factors. The services use incentive fees to achieve reliability and maintainability targets which in turn affect operating and support costs.

The services are also slowly changing their depot level maintenance philosophies. Overhaul intervals are being lengthened, even for old aircraft systems such as the F-4, because in the past such frequent overhauls were not necessary for continued safe and effective operations. The services are also adopting depot level maintenance methods whereby depot work is performed only when needed after inspection has disclosed a problem. This method of operation has already been adopted by the commercial airlines.

In our review concerning maintenance personnel requirements below depot levels, we are finding that the services' maintenance personnel determination systems have numerous weaknesses and alternatives to having the work done by active duty personnel are not fully considered. We did not cover similar work during this review.

Appendixes I through IV provide additional detailed information on the reliability and maintainability of F-14, F-15, F-16, and F-18 aircraft.

CHAPTER 3

OPERATING AND SUPPORT COST FACTORS

OFFSETTING RELIABILITY AND MAINTAINABILITY IMPROVEMENTS

OPERATING AND SUPPORT COSTS

In response to more demanding performance requirements, weapon systems became more complex and sophisticated and caused operating and support costs of new weapon systems to increase. For example, an October 1975 report covering the proceedings at the Joint Logistics Commanders Electronic Systems Reliability Workshop states that the complexity of electronic systems has steadily increased because of the growing demands of modern warfare. These higher complexity levels, reflected by an increased number of parts, have resulted in lower field reliability even though individual part reliability has improved. As a result, poor field reliability has led to degraded performance and increased support costs.

Factors other than aircraft complexity and capability are also responsible for the escalation of operating and support costs. Operating and support costs of old weapon systems have increased along with those of the new systems. Price escalation and personnel cost increases appear to be significant factors in the growth of weapon system ownership, operating, and support costs.

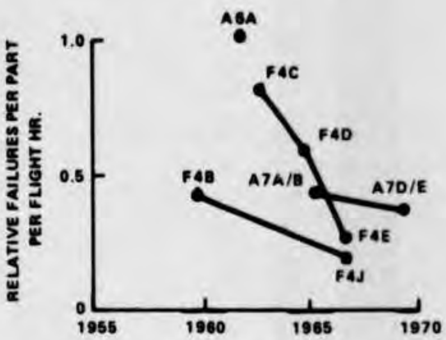
PROBLEMS OF ATTAINING RELIABILITY IN COMPLEX WEAPON SYSTEMS

In its March 1974 study entitled "Criteria for Evaluating Weapon System Reliability, Availability and Costs," the Logistics Management Institute observed that modern defense tactics require military weapon systems and equipment of a highly complex nature. Performance requirements and environmental operating conditions are increasingly demanding. Many weapon systems today require a large number of subsystems and equipment to function in an integrated manner. The Institute also observed that development schedules are tight and funds are often limited. The result is that the design characteristics of modern military hardware are highly complex and continually stretching the state-of-the-art. Time and other constraints often prevent adequate testing, analysis, and correction of the equipment to achieve high reliability. According to the Institute, this situation leads to deployed military systems and equipment which frequently fail or malfunction and require extensive resources to maintain and support.

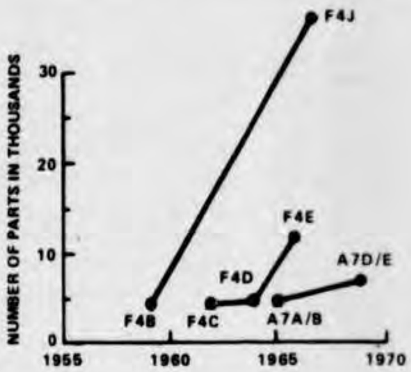
The Institute noted that the Department of Defense and contractors have recognized the reliability problem and have expended much effort over the past two decades to improve the situation. This effort is continuing at the Government and industry level. Despite military standards, reliability tests, and other efforts, the operational reliability of many military systems and equipment is still unacceptable, resulting in low operational readiness, high risk of unsuccessful mission performance, and costly maintenance and support programs. The Logistics Management Institute stated that the underlying cause of low operational reliability may be due to design immaturity and complexity.

Despite reliability improvements over the years, many subsystems have become more complex due to increased performance requirements. For example, the Department of Defense illustrates this point with radar components. While radar components have become more reliable, demands for better performance have increased radar complexity. As a result, expected reliability improvements of radar did not materialize. The following charts illustrate this relationship.

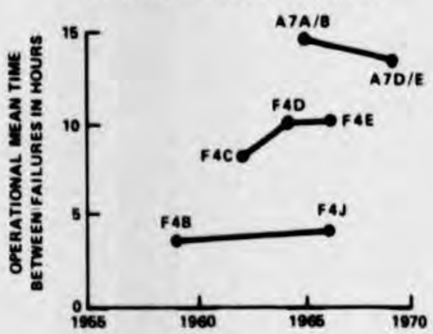
RADAR PARTS FAIL LESS



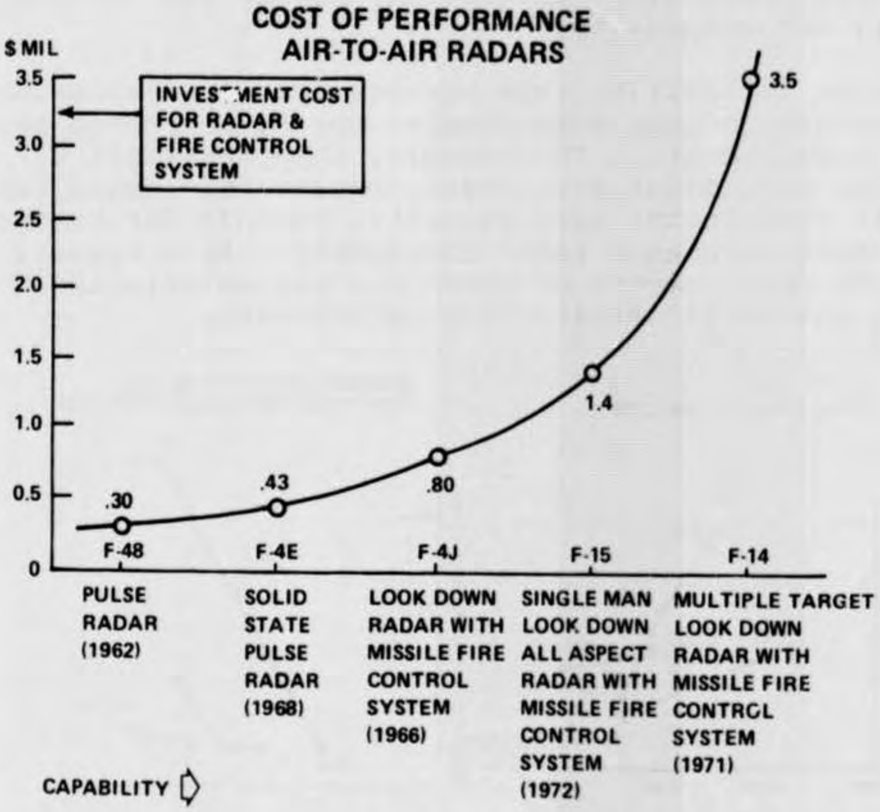
DEMANDS FOR PERFORMANCE
HAVE INCREASED RADAR COMPLEXITY



BUT OVERALL RADAR RELIABILITY
HAS NOT IMPROVED MARKEDLY



Radar capability and complexity have increased over the years, and acquisition costs have increased accordingly, as illustrated below.

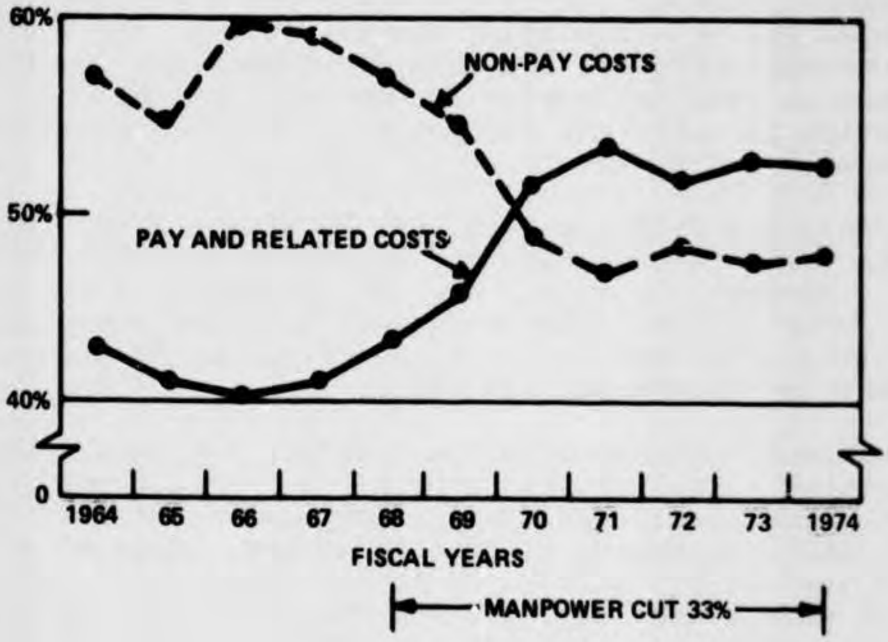


It is generally agreed that equipment reliability can be improved through more realistic tests, analyses, and appropriate corrective action. New weapon systems now being developed, such as the F-16 and F-18, incorporate some of the reliability growth concepts through improved testing. The services claim that more emphasis is being placed on reliability during the design and prototype development of the new weapon systems.

INCREASES IN PERSONNEL COSTS

The Department of Defense's personnel costs have increased disproportionately compared to other costs in the last decade. Although personnel was reduced by about one-third from 1968 through 1974, personnel costs during this period rose sharply (illustrated by the following chart).

PAY AND RELATED COSTS AND NON-PAY COSTS AS A PERCENT OF TOTAL DEFENSE BUDGET (BUDGET AUTHORITY)



EMPHASIS ON RELIABILITY AND MAINTAINABILITY IN NEW WEAPON SYSTEMS

To insure improved reliability and maintainability in new weapon systems, the services said that they are placing more emphasis on the design and development stages. The F-16 and F-18 programs are placing more emphasis on reliability growth and connected monitoring and testing. There are reliability improvement warranties and incentives to contractors for achieving specific reliability/maintainability goals. Most of the methods used now have been used in the past. For example, the early F-14 contracts contained penalties if certain reliability/maintainability objectives were not met, but subsequent contract modifications deleted these provisions.

Other specific provisions, such as tests, analyses, and other reliability growth techniques were performed in the past, but they were applied at the discretion of the contractors. The services are taking a more active part in these development stages by monitoring the contractors' efforts more closely. However, as in the past, the overriding factor is the total system reliability specification. The contractors provide reliability goals for subsystems furnished by them, and as long as compliance with the overall reliability specification is achieved, subsystem reliability goals are not necessarily enforced.

The F-16 and F-18 aircraft systems have a potential for being more reliable than the more expensive F-15 and F-14 aircraft. However, in total, the new systems will not have the same capabilities. They are considered less complex and less sophisticated than the F-15 and F-14, and therefore their development is considered less risky.

Development contracts do not identify the amount of effort devoted to reliability growth. For this reason we could not ascertain if additional emphasis was in fact placed on design and development efforts to achieve improved reliability and maintainability. Service officials assured us that reliability, maintainability, and support costs are important factors in comparative analyses made for the new weapon systems. However, these factors also entered into comparative analyses made for the F-14 and F-15.

DISCREPANCIES BETWEEN SPECIFIED CONDITIONS AND THE OPERATIONAL ENVIRONMENT

Reliability parameters

One of the persistent problems with weapon systems has been the discrepancy between contractually specified reliability goals and those encountered in an operational environment. Much controversy appears to rest on this discrepancy. Even though contractors generally meet the specified reliability requirements, the experience of operational units differs.

Specified reliability parameters, usually stated in terms of mean time between failure, often are much stricter than actual performance measured by field activities. The wide gap between specified reliability and field reliability is ascribed to

--differences in failure definitions and

--poor definition or simulation of the operational environment.

Failure definitions

For laboratory purposes, only relevant failures are counted; whereas in the operational environment all failures must be dealt with. For example, in the laboratory test environment only failures causing loss of equipment functions are considered. In the operational environment, if a built-in test shows a component to have failed, the indicated component must be tested. Often subsequent tests show the item to be in operating condition. Thus, as far as the field activities are concerned, a failure occurred because they had to remove, replace, and test the component, even though they were unable to reproduce the failure. Such failures are not considered relevant failures for contractual purposes. The services are trying to close the gap between laboratory test conditions and the operational environment by making test conditions more realistic. But the gap will probably never be bridged completely, because contractors cannot be expected to assume responsibility for conditions outside their control.

Testing parameters

Regarding poor definition or simulation of the operational environment, in the past laboratory testing has been oriented toward temperature environments, with some consideration given to vibration and voltage cycling. In the operational environment humidity, random vibration and shock are important, but reliability testing has rarely included these environmental conditions.

The services recognize these shortcomings and try to make the test environment more realistic. For example, in the test plans for the F-16 and F-18 they are considering more realistic humidity and vibration environments. However, it is doubtful that exact operational conditions can be recreated economically in the laboratory, and some of the disparity can be expected to continue.

Maintenance parameters

The same kind of disparity is evident in defining maintenance parameters. Contracts generally specify maintenance manhours per flight hour for aircraft systems. Upon closer examination, however, it is evident that the terms specified in the contracts do not correspond to the operational environment. Contracts address direct maintenance time and actual "hands on" or "wrench time," but supervision, travel from task to task, and other use of time in the real world situation are excluded. The contractors were able to demonstrate compliance with the contractual specifications for the aircraft systems we examined, even though Air Force and Navy maintenance data systems reported higher than specified manhours per flight hour.

While it would be desirable to make reliability and maintenance specifications correspond as closely as possible to the operational environment, contractors cannot be expected to do this. In the case of measuring maintenance time, the contractor cannot be expected to assume responsibility for the services' inefficiencies in personnel assignment and utilization, nor can the contractor assume responsibility for the services' quality of maintenance personnel and training. Therefore, it is not reasonable to expect these contract specifications to correspond to the operational environment, but efforts should be made to have them match as closely as possible.

PROGRESS IN RELIABILITY AND MAINTAINABILITY

There has been progress in specifying test conditions closer to the operational environment, and reliability and maintainability improvements are being encouraged. Reliability and maintainability are being emphasized during the design and development phase of new weapon systems. In the new contracts we reviewed, reliability growth was formalized, whereas before it had been left to the contractor.

Reliability and maintainability incentives of as much as $24 million may be earned by the F-18 contractor. The incentives are based on demonstrated reliability and maintainability goals at particular phases of the aircraft development.

Another method to improve reliability is the use of reliability improvement warranties. Such warranties are now in effect for the F-16 and are under consideration for the F-18. The warranties provide that the contractor will perform the maintenance on the components he developed for a specific time period at a fixed price. Provisions may also be added for the contractor to provide the necessary spare components for an additional fixed fee. The respective prices for reliability improvement warranties are negotiated before the component development is complete. The theory is that the contractor will be motivated to design and develop components which are reliable or he will share at least a portion of the penalties by being responsible for their repair in the early life of the components. While there is risk for the contractor, it would appear that the reliability improvement warranty fee for the specific components covered reflects such risk to the extent it can be anticipated.

The emphasis on field reliability is leading to noticeable changes in the portrayal of reliability requirements in weapon systems program contracts. The following table contrasts reliability requirements for weapon systems initiated in 1970 and 1976, demonstrating the trend toward field reliability terminology in specifications.

Typical 1970 weapon system requirements	1976 weapon system requirements
Mission Success Probability	Mission Reliability
Mean Time Between Failure	Mean Flight Hours Between Failure
	THRESHOLD - Specified Mean Flight Hour Between Failures to be demonstrated at key decision points throughout full scale development. Demonstration to 90 percent confidence level.
	All reliability values will be calculated using the ground rules and procedures of the services' data collection system.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Reliability and maintainability appear to be receiving increasing attention in an effort to control operating and support costs of new weapon systems. However, it is not clear to what extent these efforts have reduced operating and support costs. Our review of four tactical aircraft systems provides indications of trends, but we cannot precisely compare the effects of reliability and maintainability in successive weapon systems. The necessary data systems for accurately assessing the costs and benefits of reliability and maintainability efforts do not exist. In addition, the effects of changes in weapon system complexity, capability, and technology would have to be separated from effects of reliability and maintainability, which is not presently done. The services do not maintain such intricate data systems, and we are not certain if such systems would be feasible.

Emphasis on reliability and maintainability has not necessarily reduced operating and support costs of successive weapon systems. For example, the F-14s are much more costly to operate and support than the F-4s they replaced. But the F-14 has capabilities the F-4 does not possess, making the F-14 one of the most complex fighter aircraft ever produced in the United States.

Reliability and maintainability of the F-16 and F-18 are being stressed, and contractual provisions provide incentives to contractors to meet certain goals. These aircraft are considered to be simpler than the F-14s and F-15s, and they are expected to cost considerably less to operate and support. Of course, these simpler aircraft do not necessarily have the same capabilities.

It appears that emphasizing reliability and maintainability of the Air Force's F-15 may have paid off, but we do not know to what extent these reductions are attributable to other factors such as improved manufacturing, maintenance, and technology, and procedures. The Air Force requires over 100 fewer maintenance personnel for a wing of F-15s than for an equal number of F-4s at the base level.

We believe that the contractual maintainability specifications for the F-16 and F-18 may not necessarily reflect reasonable expectations when compared with fighters in operation. The maintainability specifications for direct maintenance man hours per flight hour for the F-16 and F-18 are the same as for the F-15.

We believe that the services should continue to strive to narrow the gap between contractually specified reliability and maintainability and those factors measurable under operational conditions. The F-16 and F-18 specify overall weapon system reliability in terms of mean flight hours between failure, which is measurable in the operational environment. Formerly, only mean time between failure or mission success probabilities were specified. As described earlier, mean time between failure is not tracked in the services data systems. Not all measurement problems, such as relevant failure determination, are resolved with this change, but at least more meaningful reliability monitoring can be effected. There also appears to be greater awareness to make subsystem test conditions more representative of the operational environment.

RECOMMENDATIONS

We recommend that the Secretary of Defense require the Air Force and the Navy to

- --make certain that contract maintainability specifications more closely correspond to the actual results expected once the weapon systems are in operation;
- --explore the possibility of developing reasonable criteria and data systems for measuring and evaluating the results of their programs for improving maintainability, reliability, and life cycle costs; and
- --provide congressional committees with estimates of reliability and maintainability improvements the military services expect to see in new weapon systems development.

Contents

RELIABILITY AND MAINTAINABILITY OF THE F-14 AND THE EFFECT ON OPERATING AND SUPPORT COSTS

RELIABILITY AND MAINTAINABILITY OF THE F-14 AND THE EFFECT ON OPERATING AND SUPPORT COSTS

The Navy's maintenance data collection system shows that the F-14 aircraft are somewhat more reliable than the F-4s they replaced. In addition, Navy officials are optimistic that the reliability of the F-14 will improve as the new weapon system matures and continuing reliability improvement efforts are accomplished.

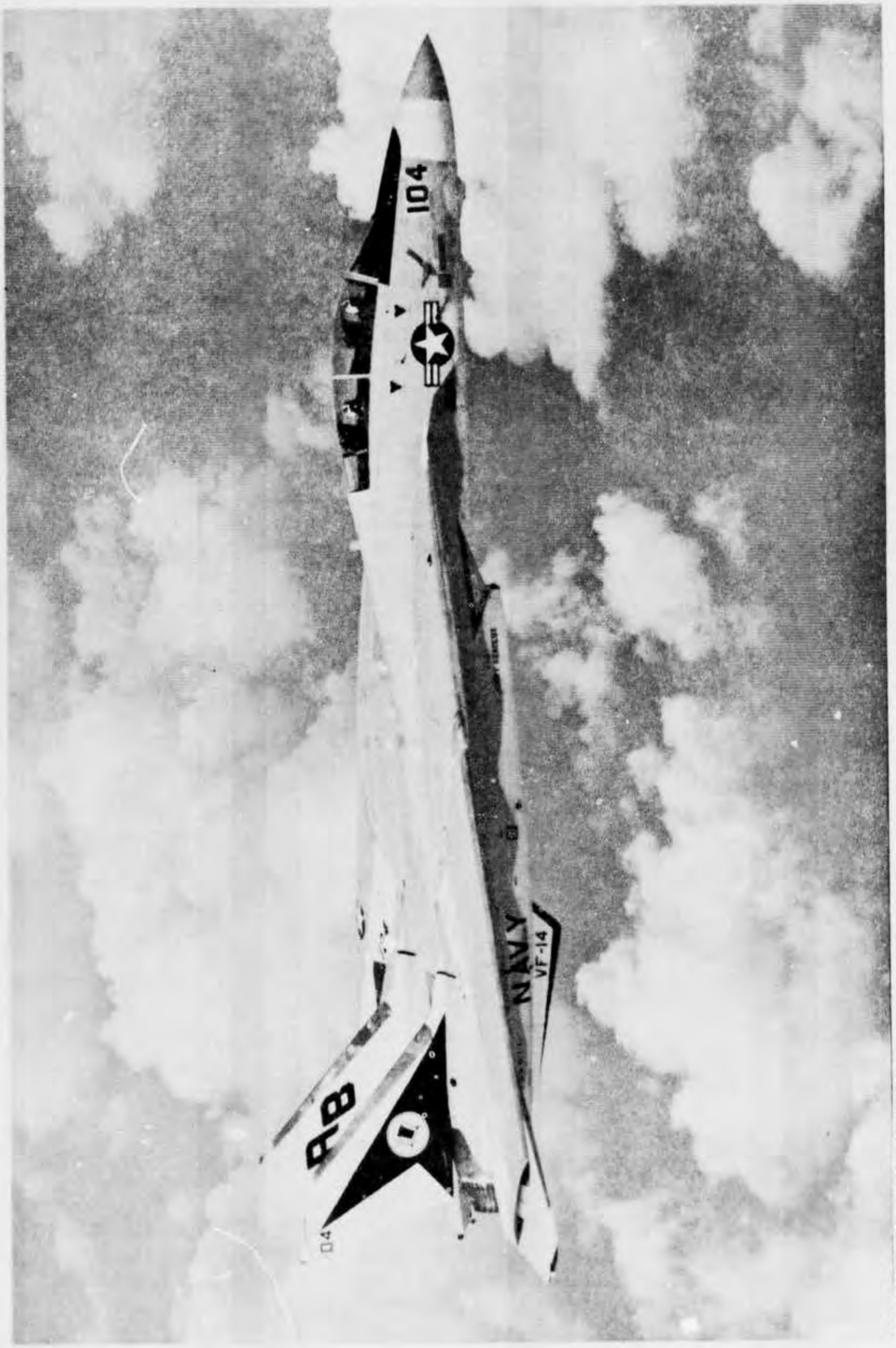
As of February 1977, the Navy estimates that the F-14 is about 40 percent more expensive to operate and support than the F-4J. The Navy's F-14 requires more maintenance personnel than the F-4. Data available at one naval base showed that the F-14 and F-4J required about 58 and 42 maintenance manhours per flight hour, respectively. The Navy's maintenance staff reflects the increased effort required for the F-14 in that squadron maintenance personnel standards require 28, or 10 percent, more personnel than the F-4.

Spares costs for the F-14 are more than double those for the F-4s. Subsystem complexity may be one of the causes for this increase.

Support equipment requirements, particularly for automated test equipment for avionics, have increased substantially for the new aircraft as compared to the predecessor. But we found no evidence that automated test equipment has brought about savings in personnel. On the other hand, it is doubtful that some of the complex digital avionic subsystems could be maintained without the sophisticated test equipment. It is difficult, if not impossible, to reconstruct what the personnel and test equipment needs would have been without the development of the expensive automated test equipment.

THE WEAPON SYSTEM

The F-14A/Phoenix is an all-weather, carrier-based weapon system consisting of a fighter aircraft and an airborne missile designed to meet a broad array of enemy weapons including (1) air-to-surface missiles launched from masses of enemy bombers and (2) enemy fighters in escort and fighter projection roles. This multimission performance is accomplished using various combinations of ordnance for (1) interdiction, (2) fighter escort, and (3) combat air patrol missions.



(COURTESY OF THE U.S. NAVY)

THE NAVY'S F-14 FIGHTER AIRCRAFT

The aircraft, the F-14A is a twin-engine, two-seater, variable-sweep-wing supersonic fighter capable of engaging targets at altitudes from sea level to over 80,000 feet.

The Phoenix is a long-range air-to-air missile capable of being used on single or multiple targets in an all-weather and electronic countermeasures environment. The Phoenix is the system's primary defense weapon against air-to-surface missiles but it is secondary to the Sparrow and Sidewinder missiles and the M-61 gun in missions against enemy fighters.

The system is controlled by the AWG-9 weapon control system, which includes a radar designed to detect and track up to 24 targets and attack 6 individual targets simultaneously with Phoenix missiles while continuing to scan the airspace. The AWG-9 also provides computations for radar launchings of Sparrow and Sidewinder missiles, M-61 gun firings, and air-to-air and air-to-ground weapon deliveries.

The principal contractors of the aircraft and related system components are:

--Grumman Aerospace Corporation, Bethpage, Long Island, New York (F-14A aircraft).

--Hughes Aircraft Company, Culver City, California (AWG-9 weapon control system; Phoenix missile).

--Pratt and Whitney, Division of United Technologies Corporation, East Hartford, Connecticut (TF30 engine).

PROGRAM STATUS

There were eight operational F-14 squadrons (12 aircraft each) and four squadrons converting to F-14s as of September 1976, according to a Navy official. By fiscal year 1980 the Navy will have 18 F-14 squadrons and it plans to purchase 13 aircraft per year thereafter for attrition.

COMPARATIVE RELIABILITY AND MAINTAINABILITY BETWEEN THE F-14 AND THE F-4J

In general terms, the F-14 was somewhat more reliable than the F-4J at the time of our review, but it required more maintenance hours per flying hour as measured by the Navy's maintenance data collection system.

Maintainability and reliability goals

Maintainability and reliability were key considerations from the very beginning of the F-14 program. Various features to enhance maintainability were incorporated into the aircraft during its design. In that phase of the program reliability/maintainability was measured in relation to other system parameters like weight, cost, and performance.

Maintenance engineering techniques, continuous evaluations of actual fleet usage, and formal review of proposed changes are performed to track and evaluate reliability/maintainability performance.

Reliability/maintainability improvements are being incorporated into the F-14; still other improvements are being considered. The effects of these are expected to affect the future maintainability of the aircraft.

Navy officials advised us that while maintainability and reliability were considered during the F-14 development, performance parameters were the driving force. The F-14 contract includes maintainability and reliability specifications covering the weapon system as a whole. Maintenance effort is not to exceed 19.8 direct maintenance manhours per flight hour. The weapon system is to achieve a mission reliability, expressed as the probability that the airplane weapon system can perform all the mission functions successfully, equal to or exceeding 75 percent based on a 3-hour mission duration. In addition, the weapon system is to have a "refly" reliability, expressed as the probability that the weapon system can be returned to full operational capability without corrective maintenance between missions, equal to or greater than 25 percent.

The Navy gave the contractor maintainability and reliability data relating to the sizeable amount of Government-furnished equipment. The contractor in turn assigned maintainability and reliability goals for each of the contractor-furnished subsystems, to achieve the overall specified values. The goals for these subsystems, however, are flexible in that they may be changed with Navy approval as long as the overall values are met.

Maintainability and reliability features of the F-14

Maintainability and reliability factors were considered during the design of the F-14. The contractor made studies to analyze design impacts on maintainability, reliability, cost, weight, performance, and other areas. As a result, the F-14 has many maintainability and reliability features. Some of the more prominent features are highlighted below.

Maintainability features built into the F-14

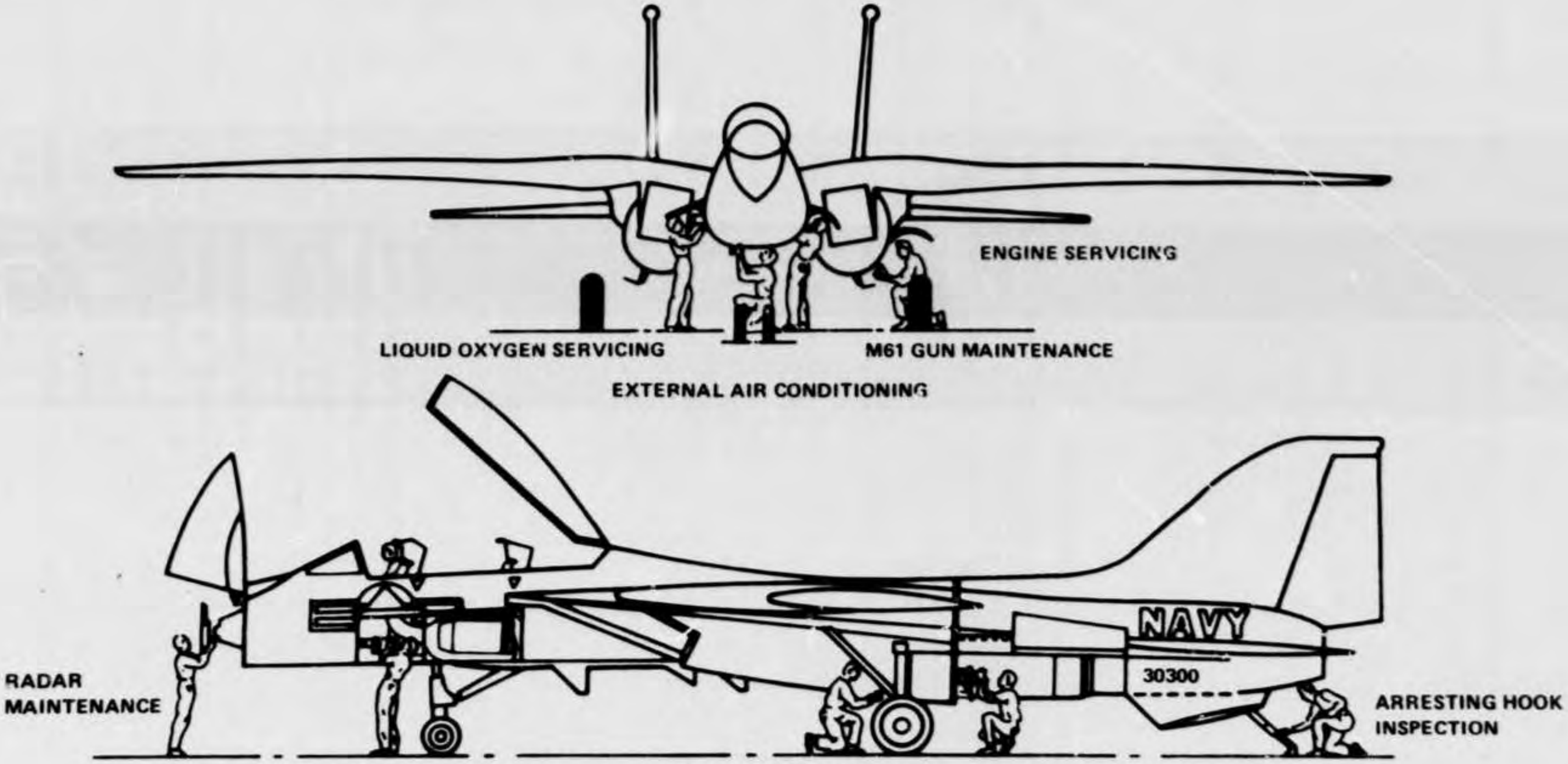
Many features were included to enhance F-14 maintainability. Accessibility to airframe, avionics, and engines is facilitated, for instance, by using quick-open doors and quick-release mounts. Interchangeable left and right engines were provided. The aircraft has onboard checkout and built-in test capability to permit quick identification of malfunctioning equipment. The overall effect of maintainability features on operating and support costs has not been measured.

During the early design phase Grumman Aerospace Corporation performed analyses to provide maximum access to equipment. Trade-off studies were made involving various areas such as conventional vs. pallet weapons installation, digital central air data computers, compatibility of the Navy's standardized Versatile Avionics Shop Test system with the F-14 design at the intermediate maintenance level, and integrated drive generating system. In conducting design trade-offs, maintainability was given consideration equal to other design parameters, such as reliability, weight, and cost. There is evidence that personnel cost savings resulting from faster maintenance and increased reliability were factors evaluated during these trade-offs. However, according to Grumman, many of the reliability/maintainability design features studies involved penalties to the total weapon system in terms of space, weight, power, performance, acquisition cost, and/or development risk. These trade-off studies, which involved weighted engineering judgment factors, can be used to evaluate design decisions, and they had a pronounced effect on Grumman's F-14 design.

Grumman officials told us that the reliability/maintainability impact is formally reviewed as engineering changes are processed. Additionally, they pointed to two specific improvement programs involved in upgrading F-14 reliability and maintainability in 1974 and 1975. So far, according to Grumman, the Navy has incorporated some of the changes recommended by the contractor while others are still being considered.

Even in those cases where an improvement has been decided on, the effects may not yet be evident. For example,

COMPONENT ACCESSIBILITY FROM GROUND LEVEL ENHANCES MAINTENANCE



- 80% OF ALL AVIONIC MAINTENANCE ACCESSIBLE FROM GROUND LEVEL
- 100% OF ALL SERVICING, ARMING, AND TURNAROUND REQUIREMENTS ACCOMPLISHED FROM GROUND LEVEL
- ALL PREFLIGHT, POSTFLIGHT, AND DAILY INSPECTION REQUIREMENTS CAN BE ACCOMPLISHED WITHOUT NEED FOR MAINTENANCE PLATFORMS

APPENDIX I

two changes were processed to improve the mean time between failure in the following F-14 equipment.

System	Engineering change proposal number	Estimated increase in mean time between failure
Central air data computer	753 (block change)	10 times
UHF radio set ARC-159	743	2 times

In both cases, the improvements were introduced starting with aircraft number 184 which was to be delivered in December 1975. Thus, the effect of these improvements will only begin to show up in the fleet as aircraft with these improvements are delivered and become operational.

Reliability features built into the F-14

The use of developed avionics is a prime reliability enhancer. In addition, hardware advances contributed to lighter weight and more capable systems. These advances allowed for more redundancy and backup modes to provide a margin of mission reliability. Mission reliability was also improved by the use of solid state digital computers with the attendant reduction in number of parts and the elimination of separate general-purpose navigation computers.

Comparative reliability

Based on Navy data we reviewed, the F-14 weapon system as a whole is somewhat more reliable than the F-4s it is replacing. On a subsystem to subsystem comparison the picture is mixed. A number of the subsystems of the F-14 are more reliable than their counterparts performing the same function on the F-4, but many of them are less reliable. The F-14's engines were the primary reliability problem in mid-1976.

The Navy's maintenance material management system reports data recorded by maintenance and supply personnel. We were informed by Navy officials that the data reported for reliability and maintainability represents in-fleet or operational experience and is not directly comparable to the contract specifications or the results achieved during the controlled acceptance tests. Grumman's maintainability measure of direct maintenance manhours per flight hour is basically "hands-on" or "wrench-time," while the maintenance data collection system includes some administrative support and other indirect time. The reliability measure of mean time between failure used by contractors also cannot be directly compared to system data since the system does not include ground operating time for testing and maintenance.

Navy officials stated data from the maintenance data collection system is not used for comparing reliability and maintainability specifications but is used as a management tool in identifying problem components and comparing similar systems between aircraft. The following table shows comparative reliability of the F-14 and F-4J systems for the period October 1975 through March 1976. More recent data covering January through June 1976 does not significantly change in overall terms.

Mean Flight Hours Between Failure
Comparison of the F-14 and F-4J Aircraft

System	System code	F-14	F-4J	Change
Airframe	11	9.6	15.3	- 5.7
Cockpit/fuselage	12	21.4	33.0	- 11.6
Landing Gear	13	10.5	9.6	+ .9
Flight Controls	14	15.4	13.2	+ 2.2
Engines	23	17.3	15.7	+ 1.6
Power Plant Installation	29	14.5	43.7	- 29.2
Environmental Control	41	23.0	30.1	- 7.1
Electrical Systems	42	20.7	21.8	- 1.1
Lighting System	44	9.6	11.7	- 2.1
Hydraulic/Pneumatic Power	45	25.3	23.7	+ 1.6
Fuel System	46	31.0	28.9	+ 2.1
Miscellaneous Utilities	49	53.1	159.8	-106.7
Instruments	51	17.8	16.2	+ 1.6
Flight Reference	56	15.5	16.2	- .7
Integrated Guidance and Flight Control	59	53.1	33.8	+ 19.3
VHF Communications	63	23.2	69.5	- 46.3
Interphone	64	160.5	125.6	+ 34.9
Identification friend or foe	65	33.2	52.5	- 19.3
Communication Navigation Identification	67	31.1	9.0	+ 22.1
Radio Navigation	71	98.5	108.8	- 10.3
Bombing Navigation	73	46.4	37.5	+ 8.9
Weapons Control	74	5.4	2.9	+ 2.5
Weapons Delivery	75	45.5	49.8	- 4.3
Electronic Counter-Measures	76	31.2	45.9	- 14.7
Total air vehicle (hours)		.8	.7	

The engine is the F-14's single most readiness-degrading item. As of September 30, 1976, the engines accounted for more than 20 percent of the not-fully-operationally-ready rate. The second most readiness-degrading item accounted for only 6 percent. In reliability terms, however, the F-14 engines are comparable in performance to the F-4J's. From January through June 1976, the F-14 and F-4J engines averaged 18.6 and 20.7 flight hours between failure, respectively. For October 1975 through March 1976, the F-14's engines incurred 17.3 as compared with the F-4J's 15.7 mean flight hours between failure.

The F-4J's engines also were a high readiness-degrading item. They ranked fourth as of September 30, 1976, accounting for about 7 percent of the not-fully-operationally-ready rate.

The reliability of the F-14 may improve in the future if the reliability improvement program is successful. The comparison of subsystems indicates, however, that the F-14 does not represent across the board improvements when compared with the F-4J. Many of the subsystems fail more frequently. We could not locate analyses contrasting the effect of increased capability and complexity on the reliability of the F-14 compared with the F-4.

Operational readiness

The operational readiness rates of the F-14 have been improving, whereas those of the F-4J have deteriorated from March through August 1976. During August 1976 the F-14 showed a slightly higher readiness than the F-4J, as shown in the tabulated percentage differences between the F-4J and the F-14.

Percentage Differences in Operational Readiness in 1976 between the F-4J and the F-14

	Difference
March	-10.2
April	- 9.[illegible]
May	- 9.8
June	- 4.0
July	- 4.7
August	+ 1.6

An analysis of not-operationally-ready rates due to supply and maintenance demonstrates that the difference in readiness rates is caused by supply problems. Supply support problems have plagued the F-14 aircraft since its introduction into the fleet as shown in another GAO report (PSAD-76-149, Aug. 3, 1976).

<u>Percentage Differences Non-operational Readiness in 1976 between the F-4J and F-14</u>

	Difference due to supply	Difference due to maintenance	Net Difference
March	+13.4	-3.2	+10.2
April	+12.3	-2.9	+ 9.4
May	+15.2	-5.4	+ 9.8
June	+10.6	-6.6	+ 4.0
July	+12.7	-8.0	+ 4.7
August	+ 4.7	-6.3	- 1.6

The Navy data indicates that maintenance for the F-14 is carried out in a more timely manner than for the F-4J, whereas the F-4J has better parts availability. However, the gap appears to be closing in that the F-14 operational readiness status is improving and that of the F-4J is deteriorating.

The F-14 is experiencing severe spare parts shortages, as evidenced by high cannibalization rates when compared with the F-4. Most of the cannibalization is attributable to avionics in both aircraft. Cannibalization is the act of replacing a failed item in an aircraft with a functioning item removed from another aircraft because functioning spares are not available in supply. The following table shows the comparative extent of failed items replaced by cannibalization for the two weapon systems during 6 months in 1976

Comparative Cannibalization Rates (Percent) in 1976

Month	F-4J	F-14
March	10.3	35.2
April	13.0	39.4
May	12.5	45.2
June	11.6	39.3
July	10.5	43.8
August	13.2	41.2

Comparative maintainability

Despite its maintainability features, the F-14 maintenance manhour per flight hour requirements remained higher than the F-4J requirements during the six-month period ending March 1976. Navy officials maintain that although the F-14 is more maintainable than predecessor aircraft, it is also more complex and components are more thoroughly tested because of the use of automatic test equipment. As the following table shows, the F-14 engine has been a major contributor to the increased maintenance manhours per flight hour.

**Maintenance Manhours Per Flight Hour
Comparison of the F-14 and F-4J Aircraft
for Unscheduled (Corrective) Maintenance**

System	System code	F-14	F-4J	Change
Airframe	11	2.20	1.75	+ .45
Cockpit/Fuselage	12	.37	.57	- .20
Landing Gear	13	1.82	1.63	+ .19
Flight Controls	14	2.32	1.63	+ .69
Engines	23	3.96	1.75	+ 2.21
Power Plant Installation	29	N/A	.27	-
Environmental Control	41	N/A	.53	-
Electrical Systems	42	.94	.78	+ .16
Lighting System	44	.37	.28	+ .09
Hydraulic/Pneumatic Power	45	.73	.64	+ .09
Fuel System	46	.65	.86	+ .21
Miscellaneous Utilities	49	.28	.06	+ .22
Instruments	51	.85	.51	+ .34
Flight Reference	56	1.35	.93	+ .42
Integrated Guidance & Flight Control	59	.61	.43	+ .18
VHF Communications	63	.36	.16	+ .20
Interphone	64	.05	.06	- .01
Identification Friend or Foe	65	.19	.23	- .40
Communication Navigation Identification	67	.09	1.15	- 1.06
Radio Navigation	71	1.33	.09	+ 1.24
Bombing Navigation	73	.93	.42	+ .51
Weapons Control	74	3.93	4.67	- .74
Weapons Delivery	75	N/A	.43	-
Electronic Counter-Measures	76	.62	.44	+ .18
Total air vehicle (hours)		26.5	20.7	+ 5.8

The total average maintenance manhours per flight hour for the F-4J and F-14 operational squadrons visited during our review were 41.9 and 57.7, respectively, for all maintenance actions associated with these aircraft, including scheduled and unscheduled maintenance, at the base level.

The total maintenance manhours per flight hour for the F-14 and most of its systems are higher than for the F-4J. However, we observed that neither aircraft appears to be consistently more maintainable at the organizational level, although the F-4J items which consumed more hours for maintenance were significantly improved on the F-14 as shown in the following table.

	Estimated removal and replacement times (workhours)	
	F-14	F-4J
Engines	20.0	41.5
Stabilator	6.0	34.0
Ejection seat	11.0	8.3
Main landing gear	32.0	16.0
Central air data computer	2.0	1.75
VHF communications	1.0	1.0
Tactical air navigation	2.0	0.4
Identification friend or foe	2.0	0.4
Automatic power compensator	1.0	3.0

We did not attempt to compare intermediate maintenance requirements and turnaround times for the F-4J and F-14 squadrons visited because some personnel, such as avionics mechanics, could not be identified by type of aircraft. The type of work performed at the intermediate level for the F-4J and F-14 also differs. Complete engine repairs are done at the intermediate level for the F-4J and at the naval air rework facility for the F-14.

Intermediate avionics maintenance personnel said that the complexity makes the F-14's avionics less maintainable than the F-4J's. In addition to being more difficult to repair, the avionics are more thoroughly tested because of the use of automatic test equipment.

The depot level maintenance for the F-14 was more time consuming and costly than for the F-4J as shown in the following table for scheduled work at the time of our review.

	Average overhaul time in days		Average overhaul cost
	Calendar	Work	
F-4J	141	101	$261,525
F-14	194	139	374,138

In mid 1976, F-14 scheduled depot level maintenance time decreased to 110 workdays and attempts are being made to reduce the time to 100 workdays or less.

The Navy's initial estimate for scheduled depot level maintenance for the F-14 was 92 workdays. Navy officials attributed the additional time to the F-14 contractor's claim that certain work requirements could be performed at greater intervals or not at all. Moving surfaces were to require no rework, but in practice they are reworked during every scheduled depot overhaul. Landing gear expected to be reworked during every other scheduled depot maintenance action requires rework each time.

Engine maintainability

The F-14A uses the TF 30-P-412 engine, which is an outgrowth of the engine developed under the Navy's F-111B program, and it was to be used for the first 67 aircraft. The Navy had originally planned to use an advanced-technology engine beginning with the 68th aircraft. Development of the advanced-technology engine was suspended in December 1973 due to development problems and the lack of additional funding. As a result the Navy has continued using the TF 30-P-412A engine. This engine requires more maintenance manhours per flight hour than the F-4J's engine and has been cited in the Navy's readiness reports as the system having the most degrading effect on the operational readiness of the total weapon system.

As of May 4, 1976, 14 F-14As had crashed or had been damaged beyond repair. Seven of these losses involved the engine. Problems with the TF-30-P-412A engine resulted in groundings of the F-14 aircraft in 1975. Crashes of additional F-14s in 1976 also resulted in the suspension of normal flight operations. Contractor and Navy personnel claim that higher than usual maintenance manhours per flight hour occur as the result of groundings or suspension of flight operations, because some maintenance is still required although recorded flight hours are reduced.

Intermediate maintenance officials stated that numerous modifications have been made to the F-14's engine during the past 2 years to improve reliability.

IMPACT ON PERSONNEL AND LOGISTICS

Overall, the F-14 is expected to be much more costly to operate than the F-4J it replaces. For example, Navy operating and support cost estimates per aircraft per year as of February 1977 show the following.

Cost category	F-4J	F-14	Percent change
	(in thousands)		
Personnel	$ 313	$ 336	+ 7
Operating consumables	218	374	+ 72
Replenishment spares	62	139	+124
Depot rework	332	414	+ 25
Indirect support	104	159	+ 53
Total per aircraft	$1,029	$1,422	+ 38

The Navy's estimated data shows that except for fuel, lubricants, and related consumption, the F-14 will be more expensive to operate in all categories as is evident from the following table.

Aircraft Estimated Cost per Flight Hour

Cost item	F-4J	F-14	Percent Change
Fuel, lubricants, etc.	$ 578	$ 484	- 16
Organizational and intermediate maintenance	267	477	+ 79
Replenishment spares	159	358	+125
Engine overhaul	53	209	+294
Component rework	270	607	+125
Total	$1,327	$2,135	+ 61

Personnel authorizations

Maintainability and reliability improvements on the F-14 as compared with the F-4J have not resulted in lower squadron staffing for the F-14. Overall squadron staffing has increased by a total of 28 personnel or 10 percent for the F-14. Increased complexity of the F-14 weapon system appears to have more than offset any personnel savings attributable to improved maintainability and reliability. Following is a comparison of personnel requirements for squadrons of 12 aircraft each.

	F-14	F-4J	Change
Officers	40	38	+ 2
Enlisted personnel			
Squadron operations and administration	25	16	+ 9
Squadron level maintenance	135	131	+ 4
Other squadron functions	32	34	- 2
Squadron personnel assigned to intermediate maintenance	39	27	+ 12
Integrated services	34	31	+ 3
Subtotal	265	239	+ 26
Total	305	277	+ 28

The largest increase in personnel requirements for the F-14 is in the intermediate maintenance area.

There are indications that the F-14 is not as maintainable as originally anticipated. This is reflected in the contractor's estimates of the number of squadron maintenance personnel, as shown in the following schedule.

Contractor's Maintenance Personnel Determinations for a Squadron of F-14s

Maintenance level	Number of personnel Initial	Final	Percentage increase
Organizational	139	169	22
Intermediate	38	44	16
Total	177	213	20

Spares support

The Navy has not recorded any reductions in spare components and part costs attributable to maintainability and reliability improvements for the F-14 as compared with the F-4J. However, general information we obtained indicates that spares and material costs for the F-14 are significantly higher than for the F-4J.

The Navy's operating and support cost estimates and cost factors per flight hour show that spares requirements have more than doubled for the F-14 as shown on page 41. In addition, our limited comparison of items on the F-14 with items on the F-4J performing a similar function also discloses spiraling costs.

Unit Cost Comparison of Items Performing Similar Functions on the F-14 and the F-4J

Item	Unit price, F-14 item	Unit price, F-4J item	Percent change
Radar antenna	$110,887	$32,990	+236
Central air data computer	68,136	18,288	+273
Receiver/transmitter	10,854	3,739	+190

The unit price comparison does not reflect price changes attributable to increased complexity and capability for the F-14 items. However, we found no suitable measure to make such a comparison.

The Navy is experiencing spares support problems with the F-14, as reported in our report "Review of the Effectiveness of the F-14A/Phoenix Weapon System," (PSAD-76-149, Aug. 3, 1976). The high cannibalization rates further attest to this problem. Navy officials attribute their difficulties to initial provisioning problems, insufficient failure experience, funding constraints, and general unavailability of spares caused by requirements for new aircraft at assembly lines.

Support equipment cost

Support equipment costs at the base level are more than twice as much for the F-14 as for the F-4J. Comparative authorization lists for the organizational and intermediate maintenance levels of one squadron of F-14 and F-4J aircraft disclosed the following.

Support Equipment Authorization for One Squadron of Aircraft

	F-14	F-4J
Organizational level	$ 2.5 million	$ 1.9 million
Intermediate level	12.4 million	4.5 million
Total	$14.9 million	$ 6.4 million

If more than one squadron of the same aircraft are stationed together, the intermediate level requirements are not necessarily multiples of the number of squadrons. However, if only one squadron of 12 aircraft of each type is supported, then the above level of support equipment is needed.

In addition to the above requirements, the F-14 avionics requires the Versatile Avionics Shop Test. We estimate that this automated tester and the necessary interface will amount to about $2.1 million per F-14 squadron.

As shown on page 42 the increase in support equipment costs is not necessarily reflected in reduced personnel requirements. At the organizational level the number of maintenance personnel has remained about the same for the F-14 as it was for the F-4J. At the intermediate level, however, the number of personnel for the F-14 has increased to 39 enlisted people as compared with only 27 for the F-4J, an increase of more than 40 percent.

The automated test equipment has not reduced the number of avionics repairmen at either the organizational or the intermediate maintenance levels. The number of electronic components and fire control equipment repairmen increased from 17 for the F-4J to 24 for the F-14. While the number of maintenance personnel has increased rather than decreased in absolute terms, adjustments for increases in weapon system complexity and improved capability have not been made, and such data was unavailable. The F-14 is supposedly more complex and capable than the F-4J, and some of the digital components could probably not be maintained if automated test equipment did not exist. This interrelationship has not been measured by the Navy.

Training requirements

Sketchy information on the F-14's impact on training requirements shows mixed results. While some training requirements have been reduced, most have increased.

The F-14's organizational level training appears to last longer than that of the F-4J. Beyond the basic schooling which all personnel receive, the training times are:

Length of Training (in hours)

Aircraft system	F-4J	F-14	Change
Power Plant & Related Systems	304	440	+136
Weapons Control Systems	652	747	+ 95
Armament Systems	348	440	+ 92
Airframe & Hydraulic Systems	336	440	+104
Environmental/Escape Systems	319	480	+161
Electronic Systems	434	544	+110
Electrical Systems	492	640	+148
NM Designated Personnel	163	160	- 3
Plane Captain	278	360	+ 82

The intermediate maintenance training is difficult to compare. Forty-seven F-14 avionic components are tested on the Versatile Avionics Shop Test system. The system operator's courses are as follows.

Course title	Total training time
Basic system operator	15 weeks
Advanced operator	19 weeks

A comparison of the F-4J and F-14 avionics training times by common rate designators did not show a significant change. The training time for intermediate maintenance engine personnel is 12 weeks for the F-4J and 18 weeks for the F-14.

MAINTAINABILITY GOALS AND ACHIEVEMENTS

Maintainability objectives were included in the initial F-14 contract. In addition, the initial contract provided for incentive profits to be earned if the contractor achieved the contract objective of 19.8 direct maintenance manhours per flight hour. These incentives were deleted by subsequent contract modifications.

Pre-production testing, which included the maintainability objectives for the F-14, was successfully completed in October 1972. Although the maintainability objectives of pre-production and production aircraft are identical, acceptance test requirements are more stringent for the production aircraft to allow for learning experience.

Production testing of aircraft is preformed under controlled conditions at the contractor's facility to satisfy production acceptance test criteria. Navy and contractor officials stated that the results of the tests under these controlled conditions could not be expected under fleet conditions.

Contractor test results for the latest 40 production aircraft flights as of June 1976 showed that the F-14 contractor was not meeting two of the four maintainability acceptance criteria, as shown in the following table.

Production Maintainability Parameters

	Requirement	Actual	Meets or exceeds requirement
	(hours)		
Corrective maintenance manhours per flight hour at organizational level:			
Contractor-furnished equipment	5.92	2.9	yes
Total	8.10	4.2	yes
Weapon system corrective down time:			
Median	2.1	3.67	no
80th percentile	4.4	5.68	no

The F-14 contractor has initiated corrective action on items not meeting the test criteria, and the local Naval Plant Representative Office withheld funds against F-14s delivered during the period October 1975 through September 1976 for non-compliance with specification requirements.

The direct maintenance manhours are defined in the contract specification as the amount of direct labor expended on the weapon system or related support equipment. Indirect maintenance activities such as supervision, administration, training, and activities with delay times are excluded from the contractually specified direct maintenance manhours. Both Navy and F-14 contractor officials told us there is no direct comparability between the contract specification values and the maintenance time reported by the Navy's Maintenance Material Management system which includes some indirect activities as part of the normal fleet operational environment.

RELIABILITY GOALS AND ACHIEVEMENTS

Reliability objectives were also included in the initial F-14 contract. Pre-production testing to the reliability specifications was successfully completed in October 1972 during 20 flights of the pre-production aircraft.

Testing of production aircraft is being performed under controlled test conditions at the contractor's facility. Contractor test results for the latest 40 production aircraft flights as of June 1976 showed that the contractor was achieving one of the two reliability requirements for the F-14.

Navy and contractor officials stated that corrective action is being taken on items degrading the weapon system's reliability. The Naval Plant Representative is withholding funds against the delivery of F-14As from October 1975 through September 1976 for failing to comply with specification requirements.

Engineering changes have been processed to increase the reliability and maintainability of the F-14A and others are under consideration by the Navy. Examples of these changes for the F-14A equipment are shown in the following table.

System	Estimated increase in mean time between failure
Central air data computer	10 times
UHF radio set ARC-159	2 times

Other examples where the field failure rate has been converted to mean time between failure for comparison to reliability objectives also show that some avionics subsystems are well below their objectives. The GAO report entitled "Review of the Effectiveness of the F-14A/Phoenix Weapon System" (PSAD-76-149, Aug. 3, 1976), showed the following comparison.

	Mean time between failure objective	Mean time between failure actual	Percent of objective achieved
	(hours)		
AWG-15 Fire Control System	1,600	94	5.9
Central Air Data Computer	2,070	15.6	.8

In addition to the overall weapon system reliability objectives, the F-14 contract requires that reliability and maintainability requirements be allocated to each element of the weapon system. Navy and contractor officials stated that the allocated reliability requirements could not be compared to results achieved in the fleet since contractor testing is performed under controlled test conditions. This lack of comparability between contract and fleet experience is demonstrated by the following comparison made in January 1976.

Equipment	Specified mean time between failure	Actual mean flight time between failure
	(hours)	
Multiple Display Indicator Group	400	85.8
Vertical Display Indicator Group	202	31.7
Central Air Data Computer	2,070	723.8
Automatic Flight Control System	600	50.2
Approach Power Control	3,000	11,581.0
Fire Control Set	1,600	48.4
Digital Data Indicator	2,000	723.8
Interference Blanker	2,000	7,720.7
Air Inlet Control	3,000	216.5
Ice Detector	6,000	626.0
Steering Damper	1,500	723.8

Navy officials said there is no specific comparability between the mean time between failure specified in the contract and fleet experience because reported fleet experience does not include ground operating hours and other environmental factors. For example, the computer signal data converter for the F-14 demonstrated its specified 420 mean hours between failure at the contractor's facility and only 60 mean flight hours between failure in field performance.

Navy officials contend that the computer signal data converter operates 2 hours on the ground for each flight hour and therefore is exhibiting a field mean time between failure of 180 hours.

This field time of 180 hours falls short of the specified mean time between failure by 57 percent. Additional changes to improve the reliability of the computer signal data converter were under study at the time of our review.

Navy officials stated that most weapon systems exhibit reliability degradation in field use because of

--environments which exceed designed or specified limits such as inadequate cooling air during ground operation;

--differences in skill levels between personnel resulting in faulty removals and replacements in the field;

--maintenance-induced failures in the field which are counted as failures but are not counted during reliability demonstration testing;

--counting adjustments to the equipment as failures in the field which are usually omitted during reliability testing;

--piloting errors, such as exceeding specified flight envelopes;

--spare parts reliability being unequal to original equipment reliability; and

--a Navy data collection system which includes all apparent failures returned to the depot even though subsequent tests at the depot may show that some equipment is good.

As a result of the differences between field environment and the contractor's test environment, Navy officials stated that converting field mean flight hours between failure to the contactor's specified mean time between failure requires a conversion factor which may be several times the specified value.

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COMPARATIVE RELIABILITY AND MAINTAINABILITY BETWEEN THE F-15 AND ITS PREDECESSOR WEAPON SYSTEM AND THE EFFECT ON OPERATING AND SUPPORT COSTS

The Air Force's maintenance data collection systems show that the F-15 aircraft system is somewhat more reliable in overall terms than the F-4s it replaces. In addition, Air Force officials are optimistic that the reliability of the F-15 will improve as the new weapon system matures fully and reliability improvement efforts are accomplished.

At this time, the Air Force's F-15 requires about the same amount of maintenance effort at the base level as the F-4 it is replacing. While the F-4 requires about 35 maintenance manhours per flying hour, it is anticipated that the F-15 will stabilize at about 28 maintenance manhours per flying hour, a reduction of about 20 percent. The Air Force's maintenance personnel allocations reflect the anticipated reduction. Overall maintenance personnel allowances are about 10 percent less for the F-15 than for the F-4.

Spares costs for the F-15 are more than double those for the F-4. Subsystem complexity may be one of the causes for the increased spares costs.

Support equipment requirements, particularly those for automated test equipment for avionics, have increased substantially for the new aircraft as compared to its predecessor. It is doubtful that some of the complex digital avionics subsystems could be maintained without the sophisticated test equipment. It is difficult, if not impossible, to reconstruct what the personnel and test equipment needs would have been without the development of the expensive automated test equipment.

COMPARATIVE RELIABILITY AND MAINTAINABILITY BETWEEN THE F-15 AND THE F-4E

The F-15 is a twin engine, single pilot aircraft designed to achieve and maintain superiority in air-to-air combat. It has a high thrust-to-weight ratio and low wing loading for maximum turnability, acceleration, and agility. It will eventually replace F-4 Air Force aircraft. The current program unit cost is approximately $16.3 million in escalated dollars.

APPENDIX II

(COURTESY OF THE U.S. AIR FORCE)

THE AIR FORCE'S F-15 FIGHTER AIRCRAFT

Deliveries to the first tactical wing began in January 1976. Through July 1976, the F-15 required less maintenance manhours per flight hour than the F-4E and experienced about the same system mean-time-between-failure rate as the F-4E.

The McDonnell Douglas Corporation is the airframe contractor, and Pratt & Whitney Division, United Aircraft Corporation, is the engine contractor.

Designed as an air superiority aircraft, F-15 tactical missions are fighter sweep, escort, and combat air patrol. To perform these missions, the F-15 will carry AIM-9 short range, heat-seeking missiles; AIM-7 medium range, radar-guided missiles; an internally mounted, rapid firing cannon; and a defensive avionics package. The Air Force plans to buy 749 F-15 aircraft (20 development and 729 production). Luke Air Force Base, Arizona, which houses the F-15 training wing, received its first production aircraft in November 1974. Deliveries to the initial tactical wing at Langley Air Force Base, Virginia, began in January 1976. Through August 1976, Luke had 42 unit-equipped aircraft and Langley had 48.

Maintainability and reliability goals

Officials of the System Program Office for the F-15 claim that the F-15 program was the first Air Force aircraft to specifically consider maintainability and reliability from the start. Due to the difficulty in obtaining data on the F-4E, we did not establish how or when the F-4E program dealt with maintainability and reliability. Our review, however, did substantiate that both the Air Force and the contractor considered F-15 maintainability and reliability from the beginning.

Maintainability and reliability goals were included in the program specifications. These goals cover the total air vehicle, its subsystems, various components, and test equipment. However, the goals are not contractual requirements and they are not enforceable.

Under the contract, maintainability and reliability are to be demonstrated at several points in the program.

During the Air Force's development test and evaluation, 1/ an overall maintainability goal of 20 relevant maintenance manhours per flight hour and a reliability goal of 3.5 mean hours between failure were to be demonstrated. The 20-hour goal excluded support equipment which was not available during test and evaluation. Also, an overall maintainability goal of 11.3 maintenance manhours per flight hour was to be demonstrated in March 1977, which was 18 months after delivery of the 24th production aircraft. We were told that this demonstration has not yet been completed as of July 1977. According to Air Force officials, the contract does not have a penalty clause pertaining to failure to meet the maintainability and reliability goals.

Maintainability and reliability features of the F-15

Maintainability and reliability factors were considered during the design of the F-15. Contractor staff performed trade-off studies to analyze design impacts on maintainability, reliability, cost, weight, performance, and other areas.

The F-15 has many maintainability and reliability features resulting from efforts by the Air Force and the contractor. Some of the more prominent features are highlighted below.

Maintainability

--Access to work area. Over 80 percent of the F-15's 570 square feet of doors and panels are accessible without work stands. Of the 570 square feet, 283 square feet are accessible by quick access doors compared to 55 square feet on the F-4E.

--Separated work areas. The F-15 has separated work areas to permit simultaneous maintenance activity without interference between equipment or congestion of work areas.

1/The development test and evaluation maintainability and reliability demonstration was conducted between April 1974 and June 1975. According to the final report a 3.8 hour mean time between failure was achieved and 20.5 maintenance manhours per flight hour was measured. The final report concluded that reliability was generally good when compared to other aircraft in the inventory and that maintainability was generally good.

--Fault isolation systems. For faster trouble shooting the F-15 has built-in tests for avionics, the environmental control system, and other systems. The built-in test fault isolates to a line replaceable unit.

--Quick avionics line replaceable units. Avionics line replaceable units are mounted to the aircraft structure by the unit mounting feet and swing bolts, eliminating safety wire requirements.

--Engine installation. The F100 engine aft removal concept, plus only 10 engine disconnects, permit quick engine replacement.

--Modular engine. The F100 has five modules: (1) inlet/fan, (2) core engine, (3) fan drive turbine, (4) augmentor duct and nozzle, and (5) gearbox. Maintenance can be accomplished at lower maintenance levels because major functional assemblies are replaced, rather than the customary tear-down and replacement of various separate detail parts.

Reliability

--Solid state sensors. F-15 pressure sensors provide direct electrical output signals whereas F-4 sensors required additional moving parts for an electrical signal output.

--Solid state switching. The F-15 radar has 16 electromechanical relays compared to 260 relays in the F-4E radar.

--Digital circuits. F-15 avionics contains much digital circuitry which does not require the electrical isolation generally required by analog circuitry.

--Simplicity. To obtain high reliability, the airframe and its subsystems design are not so complex. For example, the F-15 has 106 electrical black boxes compared to 294 on the F-4E, and the F-15 has 202 lube points compared to 510 on the F-4E.

--Redundancy. The F-15 has redundancy in several subsystems. For example, it has three separate hydraulic systems (only one is required for safe aircraft operation). Also, the F-15 has dual electrical generators and dual main fuel boost pumps with emergency backup systems.

Comparative reliability

Based on current Air Force data, the F-15 is somewhat more reliable as a weapon system than the F-4. Certain subsystems on the F-15 are not as reliable as those performing equivalent functions on the F-4, but the majority appears to be performing more reliably. The F-15's engines were the primary reliability problem in mid-1976.

The maintenance data collection system tracks maintenance actions on the F-15 and other Air Force aircraft. It does not summarize these actions in terms consistent with the contractor's goal. As stated earlier, the contractor's reliability measurement is a ratio of failures to operating hours. The maintenance data collection system, however, measures reliability by mean time between maintenance action although the Air Force calls it mean time between failure. This factor includes not only failures of the item, but maintenance actions such as replacing worn out or damaged items, minor adjustments, replacement of items which failed because an adjacent item failed, and maintenance on items reported as failures that re-test without failure.

Maintenance data does, however, permit easy comparisons of the failure rates of Air Force aircraft by system. The following table shows such a comparison for the period November 1975 to May 1976, for the weapon system as a whole as well as the various major subsystems for the F-4E, F-15, F-111F, and A-7D. The F-15 averaged .75 flight hours between failure as compared with .65 flight hours between failure for the F-4E.

Mean Time Between Failure
Comparison of Air Force Maintenance
Data (hours)

System No.	System Name	Nov. 75 - Apr. 76 F-111F	Feb-May 76 F-15	Nov. 75-Apr. 76 F-4E	Nov. 75-Apr. 76 A-7D
	Airframe				
11	Airframe	9	10.3	8	9
12	Cockpit/fuselage	-	21.7	18	45
13	Landing gear	11	7.3	7	9
14	Flight controls	13	29.7	8	12
41	ECS/Air cond	18	65.0	32	36
42	Electrical	71	61.2	35	51
44	Lighting	14	31.9	23	27
45	Hydraulic	31	31.5	20	14
46	Fuel	27	26.9	26	29
47	Oxygen	59	135.7	51	64
49	Misc utilities	62	173.4	107	157
91	Emerg equip	-	3,121.0	544	143
97	Explosive devices	155	1,040.3	549	10,799
	Propulsion				
23	Engine	12	1.9	13	13
24	SPS/APU	-	60.0	-	-
	Avionics				
51	Instruments	17	45.2	17	31
11	Auto pilot	14	84.4	41	17
55	Malfunction analysis	304	66.4	-	-
57	Integ guidance	-	141.9	-	-
63	UHF comm	38	24.4	-	20
65	Indentification friend or foe	50	52.0	-	106
71	Radio nav	101	21.5	5	19
74	Fire control	71	6.6	3	29
75	Weapon deliv	26	53.8	20	51
76	Electronic counter-measures	11	148.6	27	49
	Systems not separately identified on the F-15				
16	Escape capsule	20	-	-	-
61	HF comm	31	-	-	-
62	VHF comm	-	-	-	93
64	Interphone	57	-	-	132
69	Misc/integ comm	67	-	-	118
72	Radar nav	-	-	56	75
73	Bomb nav	3	-	19	4
77	Recon syst/camera	397	-	111	-
92	Tow Target	-	-	2,000	-
93	Drag chute	-	-	184	-
96	Personnel equip	9,125	-	1,556	6,017
	Total air vehicle (hours)	0.672	0.75	0.65	1.01

The Air Force said that errors in the reporting system for the February through May 1976 F-15 data understate the aircraft's reliability. The F-15 actually had a reliability factor of .83 hours between failure rather than the reported .75 hours. More current data for June through August 1976 shows that the F-15 attained 1.1 hours between failure. The Air Force is optimistic that the F-15's reliability will improve further.

If the above is an indicator, the reliability of the F-15 may improve in the future. Numerous changes are being made to various subsystems to improve reliability. However, the defensive avionics package, one of the major avionics subsystems, has not yet been installed in the aircraft, which can be expected to reduce reliability to some extent.

As could be expected with an overall weapon system reliability greater than the predecessor, almost all the F-15's subsystems are more reliable than their functional counterparts on the F-4E. The engine is the only major deviant. While the F-4E engines have a reliability of 13 hours between failure, the F-15 engine failed in less than 2 hours on the average as of May 1976. According to the F-15 System Effectiveness Report, as of March 1976, the F-15 engine ranked first in contributing to both the system non-operationally-ready-maintenance hours and to force degradation (the percentage of unavailable force directly identifiable to a specific work unit code).

Although there are numerous engineering changes proposed for engine reliability improvements, the mean time between failure is not expected to exceed 28 hours.

While subsystem reliability has generally improved for the F-15 when compared with the predecessor F-4E as shown on page 57, the same relationship does not necessarily follow for aircraft systems in general. For example, comparing subsystems of the F-111F model with their functional counterparts on the F-15, a number of F-111 subsystems have better reliability records, while some are markedly worse. However, many of the subsystems are not comparable on a line for line basis due to functional differences.

Operational readiness rates

The F-15 was introduced to operational units in January 1976 at Langley Air Force Base in Virginia, after training aircraft were delivered to Luke Air Force Base in Arizona.

The number of aircraft in operational units at the time of our review was probably not sufficient to allow a meaningful projection of future operational readiness rates. However, during the introductory phase from January through September 1976, the F-15 had a lower readiness rate than the F-4E stationed at another Air Force base, as shown below.

	Average readiness rate	
	F-15	F-4E
January-September 1976	44.6%	-
January-July 1976	-	55.8%

To date, spares support for the F-15 is problematic as evidenced by the following not-operationally-ready-caused-by-supply (NORS) rates and the number of cannibalization actions.

Month	Langley AFB NORS	Langley AFB Cannibalization (parts)	Luke AFB NORS	Luke AFB Cannibalization (parts)
January	29.1%	10	24.7%	179
February	18.2%	25	21.1%	227
March	21.3%	33	26.0%	279
April	24.9%	182	24.7%	434
May	20.1%	116	27.8%	370
June	21.5%	203	21.8%	371
July	25.2%	225	17.1%	230

For comparison, the F-4E NORS rates and cannibalization actions at MacDill AFB for the same period were:

Month	NORS	Cannibalization (parts)
January	10.8%	58
February	10.6%	49
March	9.7%	55
April	5.1%	52
May	6.8%	29
June	4.1%	27
July	4.9%	35

Operational readiness rates for the F-15 may improve over time. Air Force officials state that as experience is gained concerning the rate of failures for items, the supply system will make the necessary adjustments based on demand and funding constraints. This position appears to be reasonable in view of the present stage of the system's life cycle. It is too early to draw meaningful conclusions concerning the F-15's long-term readiness posture.

Comparative maintainability

Despite its recent introduction, the F-15 is already equalling or surpassing the maintenance experience with the F-4E. The Air Force's maintenance data collection system shows that the F-15 maintenance experience for the first half of 1976 compares favorably with the F-4E maintenance experience at another base, as shown in the following table. However, the F-15 has been in the system only a relatively short time involving a relatively small number of aircraft.

Maintenance-manhours Per Flight Hour

Month	F-15 at Luke AFB(note a)	F-4E at MacDill AFB(note b)
January	32.8	42.1
February	28.2	41.3
March	34.3	35.7
April	30.1	41.7
May	35.1	37.2
June	34.3	32.1
July	37.0	36.8

a/The average number of planes stationed at Luke AFB ranged from 32 to 41.

b/The average number of planes stationed at MacDill ranged from 80 to 85.

The F-15 required 33.8 maintenance manhours per flight hour during July 1976 at Langley AFB. An average of 35 aircraft were stationed there during the month. The experience during the other 6 months was considerably higher, but the aircraft inventory grew steadily from an average of only two aircraft in January to the 35 in July.

Presently it appears that the F-15 may require less maintenance manhours per flight hour than the F-4E. The lower maintenance requirements may be a payoff of the maintainability and reliability features. But, according to a December 1973 Air Force Flight Dynamics Laboratory report, low maintenance manhours per flight hour are typical for new aircraft. The report, which addressed maintainability and reliabiliy impact on system support costs, reviewed data on several aircraft including the F-4, F-111, B-58A, B-52D, and C-141.

The report pointed out that field experience of the aircraft indicated that maintenance effort per flight hour starts low, builds to a high point, and then gradually lowers to a point which remains relatively stable until the aircraft approaches wearout. The initial low is attributed to low service time on brakes, tires, engines, airframe, and the lack of major inspections. The buildup is attributed to inexperienced personnel, training flights, and the beginning of major inspections. The tapering off represents the maintenance personnel learning curve.

We obviously cannot predict if the F-15 will follow the cycle, and we were not able to determine whether the current maintenance requirements will ever be reduced to the Air Force's goal of 28 maintenance manhours per flight hour. We are aware, however, of several other factors which may influence the maintenance level. These factors are the built-in test, the Avionics Intermediate Shop, and the addition of avionics.

The built-in test is experiencing technical problems such as (1) indicating component failure when in fact the component is functioning properly, and (2) indicating properly functioning components when they have actually failed. False indications result in wasted effort to check out a nonexistent problem and may even terminate a mission.

Several built-in test engineering changes have been made in an attempt to correct the problems. Also, the Air Force and the contractor have jointly conducted a special study of the built-in test. According to an Air Force official, a report was to be issued in November 1976.

The Avionics Intermediate Shop may also influence levels of maintenance effort. Because the shop is not yet completely operational, the Air Force is sending avionics components to contractors for repair. As of August 1976, a total of 20 components are being returned because of limited or no test capability. Eventually, these components are to be repaired in the Avionics Intermediate Shop. Thus, additional maintenance effort will be incurred when the shop is fully operational and the Air Force units assume the repair responsibility. The items being returned to the contractors for repair tend to be the more complex avionic components, requiring substantial maintenance effort in terms of testing times and associated repair.

Also, the defensive avionics package, one of the major avionics subsystems, has not yet been installed in the aircraft. Maintenance manhours per flight hour can be expected to increase to some extent once this subsystem is installed.

Air Force officials pointed out that these potential maintenance increases may be offset as overall aircraft reliability improves and newer aircraft are equipped with improved reliability systems.

Engine maintainability

The contractor's goal for the F-15 engine was 4 maintenance manhours per flight hour by December 1975. For the period December 1975-February 1976, the engine required 4.8 maintenance hours. In comparison, the F-4E (J-79) engine required 1.7 maintenance manhours per flight hour for the period August 1975-January 1976.

Air Force officials support the contractor's claims that the F-15 engine (F100) was designed for easy maintenance. Some significant features include

--faster engine change,

--modular maintenance design,

--a minimum number of disconnects, and

--inspections performed on installed engines thereby avoiding engine removals.

The engine consists of five modules. Modular maintenance allows for the replacement of the major functional engine assemblies or modules rather than the customary tear-down and replacement of many separate detail parts.

The decrease in the shop repair time of the F100 compared to the J-79 engine is significant. The shop repair time standard for the F100 is 6 days; the J-79 is 13 days. In actual practice, documentation from Langley AFB and Luke AFB reflect in-shop repair times averaging 4.26 to 6.5 days, respectively, for the F-15 engine. An F-15 engine maintenance official estimated that the average time for repairing the F-4E engine is 15 days.

The contractors stated that module replacement can and should be accomplished at the organizational level. This practice has not been followed by the Air Force. Module replacements are performed at the intermediate level to

--avoid conditions where exposed engine parts may be subjected to the elements (dust, rain, etc.),

--prevent transporting special tools and other engine-handling equipment to the organizational level, and

--increase aircraft availability.

Langley AFB is currently experiencing about 3 hours per engine change according to the superintendent of the engine shop. We were told that this faster engine change feature has led to a significant increase in shop work at the intermediate level as compared to an F-4E shop. Efforts to troubleshoot, fault isolate, and/or repair F-4E engines are generally made at the organizational level to avoid the time-consuming maintenance required for engine removals. On the other hand, the faster engine change feature of the F-15 has influenced managerial decisions to change engines to avoid extensive troubleshooting time. In addition, lack of experience and inadequate training of maintenance personnel has led to premature (unnecessary) removals.

The contractor advertised that the F-15 engine design supports the on-condition-maintenance concept. The accepted Air Force definition of on-condition-maintenance is: "Application of inspection and testing procedures and techniques without removal and disassembly that allows the condition of the equipment to dictate the need for maintenance or the extent of repair/overhaul required to restore serviceability." Documentation supports the position that the key to on-condition-maintenance is evaluating engine condition by periodically assessing component integrity and system performance through the use of on-hand and portable ground diagnostic equipment. Currently, the limitations imposed by existing equipment design deficiencies threaten to erode the major benefit of on-condition-maintenance. To remedy this condition, the Air Force is monitoring the development and testing of an on-board engine diagnostic system.

The F-100 engine diagnostic system is currently in a 30-month, $10 million flight demonstration program to end in April 1979. The flight demonstration program is funded by the F-16 program (the F-16 will also use the F-100 engine).

This system is designed to monitor various critical engine parameters. The advantages to be gained include

--fault isolation to the engine module,

--necessary inputs for failure predictions which will aid in timely maintenance scheduling,

--continuous updating of trending data,

--reduction in engine ground run time with subsequent reductions in maintenance manhours,

--replacement of certain existing external diagnostic aerospace ground support equipment, and

--a major contributing factor to the on-condition-maintenance concept.

While the system could improve troubleshooting, Air Force officials said that the system may not be added due to weight and cost constraints. A similar system was part of the initial design but was deleted in the early 1970s during a campaign to reduce aircraft weight and cost.

IMPACT ON PERSONNEL AND LOGISTICS

Since joining the operational inventory in January 1976, the F-15 has required about the same maintenance time per flying hour as the F-4E and has experienced a somewhat better failure rate than the F-4E. Furthermore, Air Force officials predict the F-15 maintenance requirements and failure rates will improve as the system matures. We analyzed the effect of the maintainability and reliability levels on maintenance personnel and logistics costs.

The Air Force expects the F-15 to be somewhat more expensive to operate and support than the F-4E. The extent of the cost increase is not clear, however, because different data sources show differing magnitudes.

The Air Force has developed operating and support cost estimates for standard squadrons of 24 aircraft. In March 1977 the Air Force estimated that a squadron of F-15s costs only 4 percent more a year to operate and support at a 300 flight hour level than a squadron of F-4s.

	Estimated cost to operate and support a squadron of 24 aircraft
F-4	$22.9 million
F-15	23.8 million

Cost-per-flight-hour factors used by the Air Force do not include flight crews, base support, or other indirect factors. The cost-estimating factors show comparative relationships for the items covered. As shown below, fuel costs for the F-15 are expected to decrease, whereas maintenance and spares costs are expected to increase substantially.

Estimated Aircraft Flight Hour Cost Factors per Flight Hour (note a)
(dollars)

Cost Item	F-4E	F-15 (note b)	Percent change
Fuel	$ 558	$ 410	- 27
Depot maintenance	175	252	+ 44
Total material	120	245	+ 104
Base maintenance			
Labor	416	504	+ 21
Spares	118	263	+ 123
Total per aircraft	$1,387	$1,674	+ 21

a/For fiscal year 1976.

b/Factors are estimates because no historical data is available.

Personnel authorizations

The aircrew for the F-15 is half that for the F-4 because the F-15 is a single seater aircraft as compared to the double seater F-4. Air Force personnel authorizations show that the F-15 requires about 120, or 10 percent, fewer maintenance personnel per 72-aircraft wing than the F-4E. Initial information given to us by the operating command shows the maintenance personnel requirements for a 72-aircraft wing to be almost equal; 1,141 maintenance personnel for the F-15 compared with 1,144 for the F-4E. Subsequent information obtained in March 1977, however, reflects the approximate difference in personnel authorizations claimed by the Air Force.

An Air Force personnel official stated that the personnel requirements for the F-15 are based on a logistics composite model study using such factors as

--the maintenance per flight hour determined to be representative of the effort required to encompass all situations, and

--Air Force standard personnel requirements for munitions, maintenance, and other functions.

Contractor personnel estimates are not identifiable in the model. However, they were considered as inputs into the Aerospace Systems Division's personnel estimates, some of which are used in the model. These estimates were for the F-15 in its developmental stages.

The Air Force gave us the following personnel requirements for typical wings of 72 aircraft of the F-15 and the F-4E.

Type of personnel	F-4E	F-15	Change
Aircrew	180	90	- 90
Maintenance	1,293	1,173	- 120
Munitions	426	414	- 12
Overhead	135	138	+ 3
Weapon systems security	27	27	-
Total	2,061	1,842	- 219

The operating command provided us with the following breakdown of maintenance personnel requirements for a 72-aircraft wing of each of two planes.

Function	Number of people authorized F-4E	F-15	Change
Administration	53	59	+ 6
Quality control	48	32	- 16
Maintenance control	102	92	- 10
Subtotal-Chief of Maintenance	203	183	- 20
Administration	10	10	-
Flight line maintenance	279	225	- 54
Inspection	38	30	- 8
Support equipment	14	15	+ 1
Subtotal-Organizational maintenance	348	280	- 68
Administration	12	9	- 3
Fabrication shops	77	59	- 18
Propulsion shops	101	150	+ 49
Aerospace systems shops	176	148	- 28
Aerospace ground equipment shops	77	82	+ 5
Avionics maintenance	308	284	- 24
Subtotal-Intermediate maintenance	751	732	- 19
Total	1,302	1,195	-107

Contractor literature described reductions in F-15 maintenance personnel and savings in logistics and support equipment. For example, a brochure states that the F-15 requires 15 percent fewer maintenance personnel compared with the F-4E. It also states that maintenance training will require 28 percent fewer classroom hours than the F-4E. The Air Force's personnel authorizations partially reflect such reductions. The Air Force's goal of 28 maintenance manhours per flight hour for the F-15 represents a 20-percent reduction when compared with the maintenance effort of 34 maintenance manhours per flight hour. Air Force officials said they do not plan to use the maintenance manhour goal in their maintenance personnel determination models until fiscal year 1982 and beyond.

Air Force officials agree with the contractor's claims that the F-15 is a more maintainable weapon system than the F-4E, because of the maintainability features incorporated into the aircraft. The improved maintainability is most noticeable at the organizational maintenance level.

Although maintainability features enhance turnaround times of the aircraft at the squadron level, more time may be required at the intermediate maintenance level. For example, avionic components are more accessible and more easily removed and replaced on the F-15, but more maintenance effort is required at the base level to test and repair the components. Air Force officials provided the following example:

	F-4E	F-15
	(hours)	
Organizational level troubleshooting	4	2
Intermediate level test and repair	2	4
Total	6	6

Air Force officials claim that the F-15's avionics testing philosophy is the primary cause for the increase in test time. It differs from the F-4E philosophy in that F-15 components are completely tested while F-4E components are repaired only as required. The result is a more thorough yet time-consuming testing of F-15 avionics.

We were told that the maintenance concepts differed in that the avionics maintenance personnel on the F-4E were rotated between organizational and intermediate maintenance levels. On the other hand, staffing for the F-15 avionics is distinct and dedicated to a particular level.

According to maintenance officials, the additional 49 authorizations in the propulsion shops were required to carry out the maintenance responsibilities that are not associated with the F-4E. These responsibilities include

--3 noise suppressors,

--airframe mounted accessory drive,

--jet fuel starter and test stand,

--central gear box, and

--24 small ground support equipment gas turbine engines.

Spares support

The Air Force has not recorded any reductions in spare components and parts costs attributable to maintainability and reliability improvements of the F-15 as compared with the F-4E. However, general information we obtained shows that spares and material costs for the F-15 will be significantly higher than for the F-4E. As demonstrated on page 66, material and spares costs per flying hour for the F-15 are expected to more than double when compared with the F-4E.

At the time of our review, the Air Force was experiencing spares support problems for the F-15 and cannibalization rates were higher than for the F-4E. Maintenance officials attributed this condition to initial provisioning problems, insufficient failure experience, funding constraints, and general unavailability of spares.

Support equipment costs

At the base level, support equipment costs for the F-15 far exceed similar costs for the F-4E. While flight line equipment requirements for the F-15 are less costly as advertised by the contractor, avionics maintenance test equipment is inordinately higher in comparison. The following table shows comparative support equipment costs for a wing of each of the aircraft.

Support Equipment Costs For
The F-4E and F-15 Aircraft

Type	F-4E	F-15
Organizational	$10,742,457	$ 3,264,027
Intermediate	9,101,634	4,608,382
Avionics	-	30,170,291
Munitions maintenance	-	1,925,573
Total	$19,844,091	$39,968,273

As illustrated, avionics maintenance support equipment accounts for approximately 75.5 percent of total F-15 support equipment costs. The majority of this cost is attributable to the Avionics Intermediate Shop Testers, consisting of a number of manual, semi-automatic, and automatic testers.

The increase in support equipment costs may have reduced personnel requirements. For example, as was shown on page 68, avionics maintenance for a wing of F-15s requires 24 fewer people than a wing of F-4Es.

Engine shop support equipment authorizations per wing, containing 72 aircraft each, reflect a similar situation at the base level. The F-15 requires more than four times the number of equipment units at more than four times the cost, as shown below.

	F-4E	F-15
Units	549	2,317
Value	$910,110	$3,837,826

Training requirements

During our review we obtained some information on comparative training requirements, and results are mixed. While training requirements for certain specialties have been reduced, in others they have increased.

Air Force training requirements for some personnel have been reduced since the introduction of modularized avionic components and resultant changes in maintenance procedures. For example, a list comparing training requirements for an F-4E and F-15 apprentice weapon control mechanic showed total training time to be 40 and 22.4 weeks, respectively. The approximate 18-week decrease is in the required technical school.

Prototype courses developed by the Air Force and studies by the Rand Corporation indicate that the F-15's training requirements can be reduced further. The proposal would result in 16 weeks of training for first-term enlisted personnel and 18 weeks for career personnel.

Air Force officials said that all engine mechanics attend a 10- to 12-week basic course on the J-57 engine. After reassignment to the field, they are given specialized training on the applicable engine. This training is conducted by Field Training Detachments. The information we reviewed shows that this training totals 260 hours for F-4E engines and 426 hours for F-15 training requirements. This is an increase of 166 hours or 60 percent for F-15 engine training.

We were also told that the present field training program is inadequate. The problem has resulted in the long ground run times of the engine during check-outs and the number of premature engine removals. As a result, there are plans to have the engine contractor--Pratt & Whitney Corporation--conduct seven classes at Langley AFB and four at Luke AFB for both Field Training Detachment instructors and engine maintenance personnel. The first class was scheduled to begin in late September 1976.

ACHIEVEMENT OF MAINTAINABILITY AND RELIABILITY GOALS

The F-15 contract contained overall maintainability and reliability goals. Subsequent verification during Air Force development test and evaluation substantiated that the broad overall goals had been met. Operational experience, however, has shown that maintainability and reliability in the field are not directly reconcilable with the specifications and test results.

Maintainability goals and achievements

Air Force development test and evaluation was completed in June 1975, and it was concluded that F-15 maintainability was generally good and met goals guaranteed by the contract. Test results follow.

Guaranteed Versus Demonstrated Maintainability

Type of maintenance	Guaranteed MMH/FH (note a)	Demonstrated MMH/FH (note a) Chargeable	Demonstrated MMH/FH (note a) Operational
Scheduled (preventive)	3.7	4.9	11.2
Unscheduled (corrective)	16.3	15.6	22.7
Total	20.0	20.5	33.9

a/MMH/FH = Maintenance manhours per flight hour.

The Air Force currently has a goal of 28 maintenance manhours per flight hour at the operational level. An overall relevant maintainability goal of 11.3 maintenance manhours per flight hour was to be demonstrated by the contractor in March 1977. Operational experience as of mid-1976 was about 35 maintenance manhours per flight hour.

It is clear that contract maintainability goals do not relate to the operational environment. While the contractor is to demonstrate 11.3 maintenance manhours per flight hour, the Air Force has an operational goal of 28. In essence, maintainability specifications count "hands on" or "wrench time" maintenance only, excluding supervision and other indirect activities charged against maintenance time in the operational environment. Examples of such indirect actions are maintenance performed for reasons other than directly attributable to the airframe or its component parts, delays, work order preparation, time spent traveling to or from the work site, etc.

To account for the "not relevant" items, the Air Force uses a factor of 16.1 maintenance manhours per flight hour. Thus, the total maintenance manhours per flight hours for the mature F-15 are expected to be no less than 27.4, consisting of the 11.3 maintenance manhours per flight hours and the factor of 16.1 hours for indirect maintenance actions.

Reliability goals and achievements

During the reliability and maintainability evaluation of the F-15 by the Air Force, reliability goals exceeding those of the contract were achieved. Specific goals and measurements follow.

Guaranteed Versus Measured Reliability

Subsystem	Mean time between failure (hours) Guaranteed (note a)	Measured
Airframe	14.0 (15.0)	23.0
Propulsion	47.0 (34.0)	25.4
Fuel	155.0 (100.0)	287.[illegible]
Flight Control	91.0 (92.0)	107.9
Avionics	11.4 (10.2)	8.9
Armament Weapons Delivery	23.0 (44.0)	No failure
Environmental Control	158.0 (151.0)	100.6
Secondary Power	403.0 (158.0)	55.7
Electrical	75.0 (100.0)	143.9
Hydraulic	110.0 (110.0)	143.9
Crew Station	89.0 (89.0)	95.5
Total Air Vehicle	3.5 (3.5)	3.8

a/The figures in parenthesis represent the adjusted goals as of June 1976. As is readily apparent, the goals for the various subsystems are not fixed even though they are termed "guaranteed." As long as the overall goal for the air vehicle is met, subsystem goals are adjustable.

Although several of the subsystems fell below the guaranteed values, the overall reliability specification of 3.5 mean time between failure was exceeded. Several of the avionic subsystems were not always tested, and the Air Force estimated that the avionics reliability measured would have fallen to 7.8 hours mean time between failure if they were fully considered. However, the Air Force stated that measured reliability for the overall aircraft system would have been 3.6 hours mean time between failure, which still exceeds the guaranteed value of 3.5

Again, the test conditions are not fully representative of the operational environment as was the case in maintainability. Only "relevant" failures are counted. For example, one-time intermittant failures whose cause could not be determined were not counted. Malfunctions reported by the pilot that could not be verified by subsequent investigation, flight, or ground checks were not counted. Failure caused by accidental damage, operator error, etc., were not considered, among many other items. In the field, however, these items create significant workloads, particularly in the avionics area.

The major difference between reliability contract goals and reliability experienced in the field is the basis of measurement. Contract goals are stated in terms of mean time between failure as the ratio of equipment operating hours to the number of failures. The Air Force uses mean time between failure as a measure of flight hours to the number of failures. Flight hours do not necessarily correspond to equipment operating hours because test and warm-up times, etc., are not counted in flight hours. Nor is it practical to try to track operating time because different subsystems function at different times, each requiring time counters to do so. Recognizing the disparity, the Air Force operating command for the F-15 expects the mean time between failure contract goal of 3.5 hours to amount to 1.13 flight hours in the operational environment. While this is a significant reduction, the 1.13 flight hours compare favorably with the F-4E's failure rate of .65 hours, if it can be achieved on a continuing basis.

The magnitude of the nonrelevant contract failures is readily apparent from the following tabulation of March 1976.

Mean Time Between Failure in Hours

Subsystem	Contractor goal	Raw maintenance data	Purified maintenance data (note a)
Airframe	8.2	2.0	13.8
Propulsion	55.2	2.6	23.5
Avionics/ Instrumental Weapons Delivery	6.9	1.8	6.7

a/The purified statistics reflect system failures in the contractor's terms.

Contents

RELIABILITY AND MAINTAINABILITY IMPLICATIONS FOR THE F-16

RELIABILITY AND MAINTAINABILITY IMPLICATIONS

FOR THE F-16

The F-16 development was motivated by the need to investigate the feasibility of low cost, high performance, fighter aircraft. The F-16 is considered to be less complex and sophisticated than the F-15. One of the primary differences between the two aircraft is that the F-16 is designed for the visual fighter air combat environment, whereas the F-15 has all-weather capability. This has a significant effect on the avionics required on the F-16. Less avionics capabilty is needed, which fosters less complexity.

PROGRAM DESCRIPTION

The F-16 is a fighter aircraft which will be used by the Air Force for air-to-air and air-to-surface combat. Full-scale development contracts were awarded in January 1975. The General Dynamics Corporation is the prime contractor for the airframe, and Pratt & Whitney Aircraft is the prime contractor for the engine.

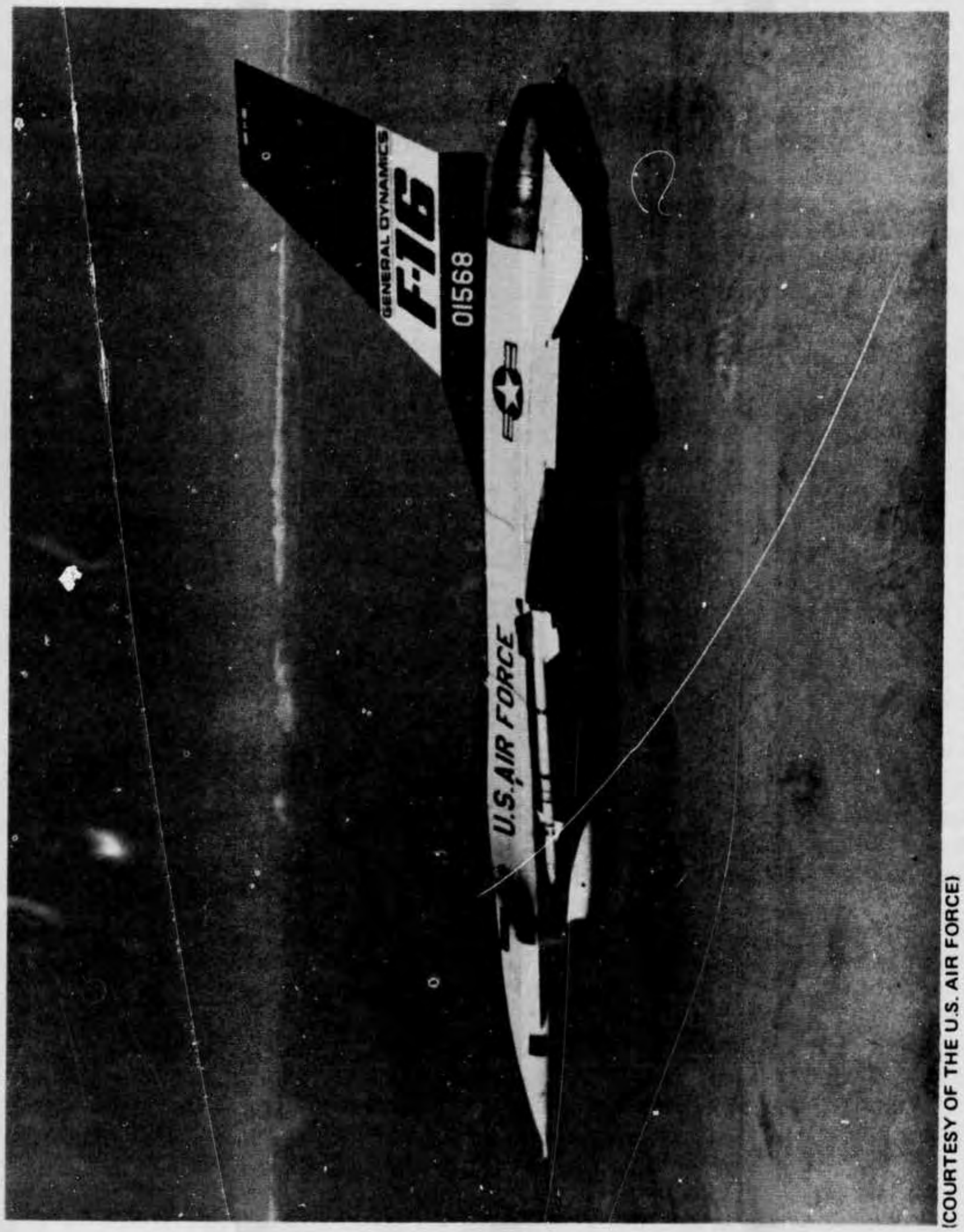
The first production aircraft is not scheduled for delivery until 1978. We obtained information of program maintainability and reliability features, goals, and tracking systems. This information, along with a brief program description, follows.

The F-16 program is a follow-on to the lightweight fighter prototype program conducted by the Air Force from 1972-1975. The purpose of the lightweight fighter program was to demonstrate improved aircraft combat flight capabilities in such areas as acceleration, maneuverability, and handling.

The F-16 is a single-seat fighter aircraft to be used by the Tactical Air Command. It is being designed to be highly maneuverable in the Mach 0.6 to Mach 1.6 speed range.

The F-16 is powered by a single Pratt & Whitney F100 engine. The F100 is fully qualified for production and will cost about $2 million each. This is the same engine used on the F-15 aircraft, and it is being bought through the Joint Engine Project Office in the F-15 System Program Office. Avionics will include a pulse-doppler radar capable of detecting moving targets below the F-16 while rejecting ground clutter. In November 1975, General Dynamics announced the selection of Westinghouse as contractor for the F-16 radar.

APPENDIX III



(COURTESY OF THE U.S. AIR FORCE)

THE AIR FORCE'S F-16 FIGHTER AIRCRAFT

A two-seat model, the F-16B, is also being developed. It is intended primarily as a training aircraft and will be capable of performing the F-16 missions with a reduced range capability.

Full-scale development contracts were awarded in January 1975. In addition to the Air Force's planned purchase of 1,388 aircraft, the countries of Belgium, the Netherlands, Denmark, and Norway plan to buy up to 348 F-16s.

STEPS TAKEN TO ACHIEVE LOWER OPERATING AND SUPPORT COSTS

The overall program risk associated with the F-16 development is termed moderate by the Department of Defense. The contractor, on the other hand, considers the program risk to be low due to the following factors:

--Demonstrated technology and aircraft performance.

--Demonstrated prototype program performance.

--No major changes to the F-16 from the prototype.

--Qualified engine in production.

--Solid base for cost and schedules.

The F-16 contractor claims that the F-16 will have, along with a high sortie rate, lower operating and support costs than any other fighter in the Air Force inventory. The contractor maintains that the following steps will achieve this goal:

--Use of life cycle cost analyses to control operating and support costs.

--Design innovations, such as self-test in the flight control system and engine accessibility features in the propulsion system.

--Correction of support related problems found during the prototype program.

--Design solutions to chronic fighter aircraft high cost support problems, such as fuel containment, water intrusion into electronic equipment, corrosion, and electrical connectors.

The primary design features that inherently lead to low cost support and operation according to the contractor are:

--Small airframes with component interchangeability.

--Mature single engines with modular replacement and on-aircraft boroscope inspection.

--Subsystems which use qualified second or third application hardware.

--Essential avionics with fault isolation and self-test.

--Fewer maintenance points and systems connections.

The F-16 contract includes target logistics support cost and reliabilty improvement warranty options. Recently the Air Force exercised these options for the 12 most critical avionic components of the F-16.

All contractor-furnished avionic components contributing 80 percent of the expected failures and 80 percent of the expected repair costs were identified and placed under the target logistics support cost program. For all of these items the expected lifetime logistics support cost was computed using an Air Force model. The items contributing at least 50 percent of the total logistics support cost were designated as control components, the remainder being non-control components along with all Government-furnished components.

The contractor estimated the various parameters of the logistics support model that he felt would be achieved in an operational environment, and established the target logistics support cost for the non-control components. If the measured logistics support cost during a 3,500 flying hour test is less than the target logistics support cost 6 months after the first full squadron activation, the contractor is eligible for an award fee of up to $6.4 million. If the measured logistics support cost is greater than the target, no penalties are imposed for the non-control components.

The contractor can earn an award of up to $2 million if the Government accepts the target logistics support feature for the 12 control components and the measured logistics support cost is below target. If the measured cost is between the target and 25 percent above target, no fee is earned, nor is a penalty imposed. If the measured cost is above 125 percent of the target, the contrator must correct the deficiency. The contractor is paid an amount agreed upon for each control component covered by the target logistics support option to compensate for the increased risk.

The control components are also eligible to be covered under reliability improvement warranties. However, none of the components are covered by both the target logistics support cost option and the reliability improvement warranty. Under the reliability improvement warranty, the contracor guarantees that the component shall be free from defects in design, material, and workmanship, and that any component that fails will be returned to the contractor's repair facility (at Government expense) to be repaired or replaced at the contractor's expense. The warranty lasts 4 years from the delivery of the first production aircraft or 300,000 flying hours, whichever occurs first. The contractor is paid a predetermined amount for each of the items covered in this manner.

A third option is the reliability improvement warranty with guaranteed component mean time between failure. In addition to repairing the components, the contractor must also (1) determine the cause of non-conformance, (2) make the necessary engineering design changes, (3) modify the components at contractor expense, and (4) provide additional spares in accordance with predetermined formulas, if the components do not meet the guaranteed mean time between failure during the specified test cycle. To cover increased contractor risk, the predetermined contract fees for each item covered are correspondingly higher than those under the reliability improvement warranty.

Comparative contract fees for control components under each of the three options are:

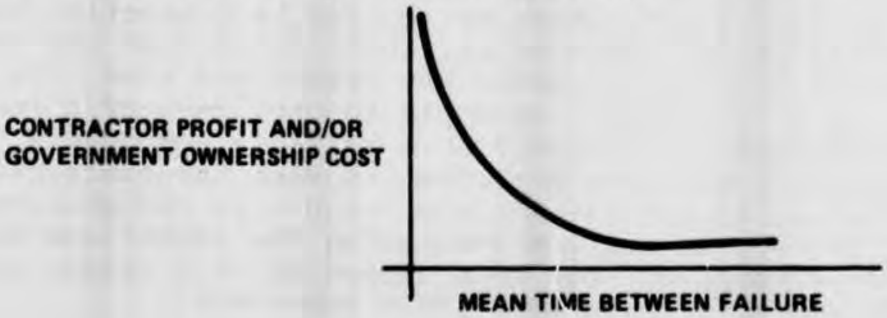
Option Price in Fiscal Year 1975

Component	Target logistics support cost	Reliability improvement warranty	Reliability improvement warranty with guaranteed performance times
	(millions)		
Radar antenna		a/$ .865 X	$ 1,264
Radar low power radio frequency		3.490 X	5.445
Radar transmitter		2.284	3.070 X
Radar digital signal processor		2.029 X	4.001
Radar computer		.905 X	3.001
Radar/electro-optical display	$ .774 X	1.453	2.500
Radar/electro-optical symbol generator/electronics	.133 X	2.433	3.428
Heads-up display (display)	.778	1.521 X	2.616
Heads-up display (electronics)	.459	1.227	1.876 X
Fire control computer	.991 X	1.937	3.332
Inertial navigation unit	.963	1.882 X	3.237
Flight control computer	1.620	3.160 X	5.440
Total		$23.186	$39.210

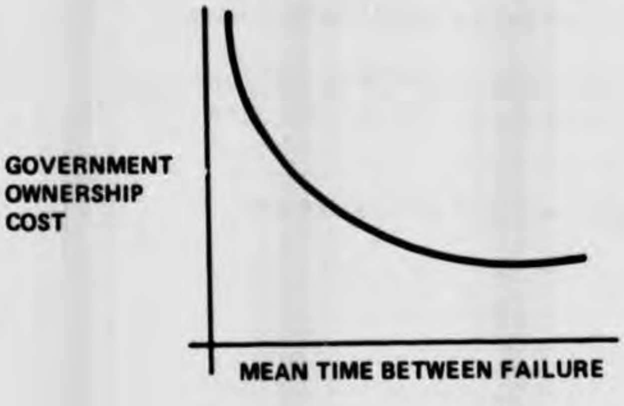
a/X indicates the option exercised, but not necessarily at the price shown.

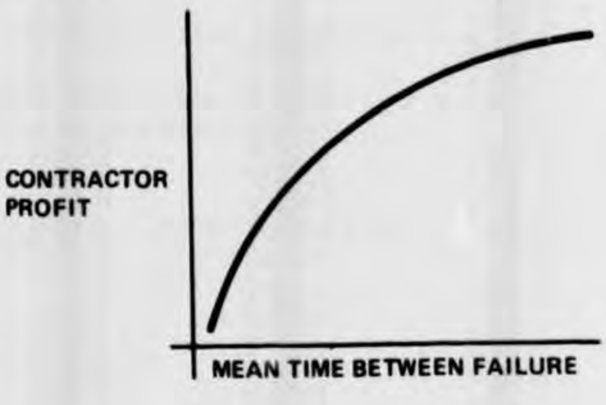
Air Force officials advised us that the options exercised will include Air Force as well as European aircraft at a cost of $30.4 million in fiscal year 1975. The amount attached to each of the components is not yet definite. Exercising the options is expected to cost $44 million in then-year dollars through 1982. The contract provides for additional payments in case of abnormal escalation.

The philosophy behind the target logistics support cost and reliability improvement warranty concepts is to give the contractor an incentive to develop reliable components. To maximize profits, the contractor may provide a component with minimum acceptable reliability if the price is fixed. The lower the reliability, however, the higher the lifetime Government ownership cost will be, because more maintenance labor and spares are required. In essence, the objectives of the contractor (maximize profit) and the Government (least lifetime ownership cost) are contradictory, as illustrated in the following simplified chart.



By means of the target logistics support cost incentives and/or the reliability improvement warranty, the contractor has a stake in the subsequent component support costs. The contractor has made commitments to the logistics supportability of the components in the operational environment in the future and will be rewarded or penalized accordingly. In the case of target logistics support costs, the contractor may earn specified premiums, earn nothing beyond the fixed contract price, or have to take action to correct deficiencies, depending on the performance of the specific items in question. In the case of reliability improvement warranties, the contractor will repair the specific components for a predetermined, fixed charge for a specified time period and/or take corrective action depending on the agreement for the specific item. The purpose of the concept is to reward the contractor for reducing the component ownership cost to the Government. This relationship is illustrated in the following chart.





Of course, contractors are entitled to fees to enter into these types of guaranty arrangements because they are taking more of a risk. In determining the propriety of the fees demanded, the Government must evaluate the resultant reliability improvements or other derived benefits and see if they are at least equal in value to the additional fees paid.

The fees demanded by the contractor for any of the warranty items can be expected to be at least high enough to cover the most likely outcome plus a safety margin. When viewed in this light, there may be little connection between the incentives and improved reliability, because the fees may be sufficiently high to cover any reasonable risk. In any event, the F-16 contract attempts to provide profit incentives to the contractor to deliver more reliable components, in contrast to traditional arrangements when the contractor's incentive was to provide minimum acceptable reliability at a fixed price. We are not evaluating the incentives used in the F-16 contract, but they appear to be a viable approach to encourage more reliable avionic components.

MAINTAINABILITY AND RELIABILITY FEATURES

The primary maintainability features of the F-16 include

--quick access doors and removable covers to avionics, engine, and mechanical equipment compartments;

--built-in test capability to identify failing components, and

--other features, such as modular engines, modular airframe construction, and right/left part interchangeability.

Some of the more prominent reliability features of the F-16 include

--extensive use of existing hardware and technology;

--system redundancy to assure that a critical function can be accomplished even though a component has failed; and

--other features, such as system simplification.

MAINTAINABILITY AND RELIABILITY GOALS

The programmed full-scale development requirement for maintainability is 20 direct maintenance manhours per flight hour. At maturity the F-16 has a goal of only 12 direct maintenance manhours per flight hour.

In terms of reliability, the F-16 is required to achieve 1.75 mean flight hours between failure at the end of full-scale development. At maturity this value is to improve to 2.9 mean flight hours between failure.

POTENTIAL EFFECT OF RELIABILITY AND MAINTAINABILITY IMPROVEMENTS ON OPERATING AND SUPPORT COSTS

The Air Force forecasts that the F-16 will be one-fourth less expensive to operate and support than the F-4 it replaces. Comparative operating and support costs as of March 1977 (in fiscal year 1976 dollars) for a 24-aircraft squadron of the two aircraft follows. The estimates include direct costs, such as personnel, spares, fuel, as well as indirect costs, such as base support and training.

	Estimated cost to operate and support a squadron of 24 aircraft	Percent
F-4	$22.9 million	100
F-16	16.4 million	72

The F-16 is expected to be a more reliable and maintainable aircraft than the F-15, with resultant lower operating and support costs. The F-16 is considered to be a less complex and capable aircraft than the F-15, and for this reason alone it should be more supportable. Maintainability and reliability improvements may contribute to lower operating and support costs for the F-16, but the credit for lowering operating and support costs is probably attributable to reductions in complexity and capability. The Air Force has not recorded benefits derived from maintainability and reliability improvements associated with the F-16 in comparison with other aircraft, and cannot do so with certainty. To protect the potential operating and support cost advantage, the Air Force should guard against adding capabilities purposely excluded during the F-16's development to make the aircraft more austere.

Comparison between aircraft systems has been complicated by applying different measures of reliability. For example, the F-15 used mean time between failure as the standard reliability measure. The standard reliability measure for the F-16 is mean flight time between failure. No standard conversion from one measure to the other has been developed. The change toward the new standard has a major advantage in that it corresponds more closely to the field environment than the former standard.

The Air Force expects the F-16 to be less expensive to operate per flight hour than the F-4E and the F-15 as reflected in their operating cost estimates per flight hour shown below.

Aircraft Cost Per Flight Hour

Factors for Cost Estimating Purposes in Fiscal Year 1976

Cost item	F-16 (millions)	F-4E	Percent change	F-15 (millions)	Percent change
Fuel	$ 252	$ 558	-55	$ 410	-39
Depot maintenance	171	175	- 2	252	-32
Total material	152	120	+27	245	-38
Base maintenance					
Labor	386	416	- 7	504	-23
Spares	166	118	+41	263	-37
Total	$1,127	$1,387	-19	$1,674	-33

Reduced fuel consumption accounts for most of the cost savings for the F-16 when compared with the F-4E. Considering that the F-16 is a single engine plane whereas the F-4E and F-15 have two engines each, projected fuel cost savings seem reasonable, particularly since the F-16 uses the F-15 engine. Spares and material costs are expected to increase markedly in comparison with the F-4. Compared with the F-15, the Air Force expects large cost savings in all cost categories.

Potential impact on maintenance personnel

The Air Force expects to reduce personnel requirements for the F-16 by about one-fourth compared with the F-4E. Most of the reduction is to be in maintenance functions. The aircrew requirements for the F-16 are one-half those of the F-4E because the F-16 is a single-seater, whereas the F-4E is a two-seater. Following are the Air Force's comparative personnel requirement estimates for a wing of 72 aircraft as of March 1977.

	F-4E	F-16	Change
Aircrews	180	90	-90
Maintenance	1,293	837	-456
Munitions	426	396	-30
Overhead	135	144	+9
Weapon systems security	27	27	-
Total	2,061	1,494	-567

While the Air Force forecasts significant maintenance personnel reductions for the F-16 compared to the F-4E and the F-15, on the surface contract maintainability goals do not reflect these expectations. The maintainability goal for the F-16 is a requirement of 12 direct maintenance man-hours per flight hour. The F-15 has a goal of 11.3 direct maintenance manhours per flight hour. On the surface this indicates that the F-16 will require at least as many, if not slightly more, direct maintenance personnel than the F-15.

However, the Air Force stated that the direct maintenance man-hour specifications are not directly comparable because they are based on different utilization rates. The F-15 specifications were based on planned aircraft utilization rates of 45 flight hours per month, whereas the F-16 specifications are based on 30 flight hours per month. According to the Air Force, adjusting for the differing utilization rates would result in less maintenance requirements for the F-16. At weapon system maturity, the Air Force has total maintenance manhour per flight hour goals of 28 for the F-15 and 23 for the F-16.

The Air Force also stated that specification definition and measurement requirements are not identical for the F-15 and F-16, thus distorting comparability. However, the extent of this distortion has not been identified quantitatively.

Personnel requirements for the F-16 appear to be tenuous at this stage. For example, contract requirements do not agree with contractor claims. The contractor estimates that the total maintenance effort for the F-16 should require 15 maintenance manhours per flight hour, which compares extremely favorably with the 33 maintenance manhours per flight hour for the F-4E.

Potential impact on spares

Air Force officials are confident that the emphasis on reliability and maintainability on the F-16 will result in reduced spares requirements. However, any connected savings have not been determined, and the Air Force does not intend to do so because this cannot be done with reasonable certainty. Other factors, such as time required to repair failed items, spares management philosophy, and availability of support equipment, also affect the reductions.

Based on the Air Force's cost estimates per flight hour shown on page 86, spares and material costs will be higher than costs for the F-4E.

Support equipment

The F-16 requires very expensive automated test equipment to support the avionics as does the F-15. Simplicity, less complexity and capability, and emphasis on maintainability and reliability seem to have had little effect in this area. For example, peculiar support equipment, which includes avionics test equipment, is expected to amount to $435 million for 650 F-16s through fiscal year 1982. This category is expected to amount to $476 million for 729 F-15s through fiscal year 1981.

CAN OPERATING AND SUPPORT COSTS BE ALTERED DRASTICALLY BY IMPROVING AIRCRAFT RELIABILITY?

The Aeronautical Systems Division of the Air Force Systems Command addressed the question of what would be the costs and benefits of increasing F-16 reliability by 30 percent. Using an F-16 cost model, a rough analysis was made without determining if such an increase would be possible. The analysis concluded that total fleet acquisition costs would increase nearly $700 million, and an increase of $40 million in the reliability program would be needed if F-16 reliability for five control avionics, armament/weapons delivery systems, and primary flight control systems could be increased by 30 percent. Tangible savings of only $17.3 million in avionics maintenance personnel and support personnel over a 15-year aircraft lifetime were identified. Spares costs could also be expected to increase because their acquisition cost would increase. Of course, mission effectiveness would increase, but it is not quantifiable.

While this analysis is very tenuous, it does point out that a frontal attack on aircraft reliability improvement will not necessarily be cost effective. Operating and support cost savings are possible because of improved reliability, but overall costs associated with reliability improvement may by far exceed expected benefits. The analysis indicates that cost implications for the entire life cycle of a weapon system must be evaluated before deciding to reduce only one aspect of cost, such as operating and support costs. It appears that the simplest weapon system possible which can accomplish a mission should be procured to insure the lowest acquisition cost along with the lowest operating and support costs.

Contents

OPERATING AND SUPPORT COSTS, RELIABILITY AND MAINTAINABILITY OF THE F-18

OPERATING AND SUPPORT COSTS, RELIABILITY AND MAINTAINABILITY OF THE F-18

THE F-18 WEAPON SYSTEM

The F-18 weapons system is a twin-engine, all-weather, multimission tactical aircraft. A fighter and an attack version of the F-18 are planned. The primary mission of the fighter is escort with fleet air defense as a secondary mission, and the attack mission is interdiction and close air support. Both versions have common engines and can accomplish the fighter or attack missions with minor changes in components and software.

The F-18 is expected to be superior to the F-14 in air combat maneuvering and in scenarios involving mixed force air combat at shorter range. The F-14 weapon system with Phoenix missiles will dominate in long-range intercept situations. The F-18 with its single-seat, less powerful radar, fewer missiles, lower weight, smaller size, and simpler avionics is expected to cost less than the F-14, and its role in the fleet will complement and support the F-14.

Navy officials believe the F-18 is superior to the F-4 and A-7 it will replace. The F-18 will be superior to the F-4 due to increased air combat maneuvering performance, better radars, more reliability, and smaller deck space requirements. It will be superior to the A-7 by providing the necessary range-payload and accuracy requirements with greatly increased agility, which enhances its survivability and capacity to act in a self-escort role.

Navy officials supporting the F-18 cite its superiority over the A-7 and F-4 as well as the need to begin replacing the aging F-4 aircraft in the early 1980s and the A-7 aircraft in the mid-1980s. The F-18 and F-14 aircraft are expected to have mutually complementary and supportive roles. In justifying the F-18, Navy officials have stated that the F-14 is large, complex, and expensive to acquire and maintain. They have contended that an overall mix of F-14 fighter-inceptors and F-18 fighter-attack aircraft will provide the best combination toward reducing the problems of space, logistics, and support while improving mission flexibility and effectiveness.

The F-18 was in full-scale development at the time of our review and the production contract had not been awarded.

THE NAVY'S F-18 FIGHTER AIRCRAFT

(COURTESY OF THE U.S. NAVY)

The Navy schedule, however, calls for the delivery of 11 full-scale development F-18 aircraft beginning in August 1978 and ending in December 1979. The first pilot production aircraft are expected to be produced in February 1980 with high-rate production beginning in October 1981.

F-18 MAINTAINABILITY GOALS AND FEATURES

Navy officials expect the F-18 to be more maintainable than the aircraft it will replace and other predecessor aircraft such as the F-14. The specified maintenance requirements for the F-18 are lower than for the F-14 as shown below. The comparison is not accurate on the differences in mission duration, aircraft utilization, and other factors, but it is adequate to show the contrast between the two aircraft.

	F-18	F-14
Direct maintenance manhours per flight hour	11.02	19.8
Weapon system turnaround time (minutes)	15	36

The maintainability of the overall F-18 weapon system is expected to be better than the aircraft it is replacing, as shown in the following chart.

Aircraft	Maintenance manhours per flight hour
F-18	14.6
A-7E	26.5
F-4J	38.0

During authorization hearings in 1976, the Navy testified that it expects to incur only 14.6 maintenance manhours per flight hour as measured by their maintenance data collection system for the F-18 (as shown above). This may be overly optimistic in relation to experience with other aircraft systems. For example, the maintainability goal for the F-14 was 19.8 direct maintenance manhours per flight hour. Operational experience measured by the Navy's maintenance data collection system for the F-14 as of January 1977 was about 53.7 maintenance manhours per flight hour. The experience at the operational level measured by the maintenance data collection system is more than double the contract goal of 19.8 maintenance manhours per flight hour. The Air Force had similar experiences with the F-15, as shown on page 72.

Consequently, the 14.6 maintenance manhours per flight hour expectation appears unrealistic in comparison to the contract's specification of 11.02 direct maintenance manhours per flight hour.

The major subsystems for the F-18 are also expected to achieve higher maintainability than the weapon systems it will replace.

	Direct maintenance manhours per flight hour		
	F-18	A-7E	F-4J
Air frame	2.56	4.21	6.11
Propulsion	1.30	1.79	2.42
Avionics	2.60	5.55	8.04
Miscellaneous	.70	.90	1.74
Support action form	7.44	14.02	20.00
Total air vehicle	14.6	26.47	38.31

Another maintainability comparison shows some of the features expected to contribute to the increased F-18 maintainbility.

	F-18	A-7E	F-4J
Fault isolation--radar (hours)	.28	.61	.69
Accessibility	excellent	good	poor
Remove/replace engine (hours)	.35	18.1	10.1
Repair time--radar (hours)	1.7	2.6	4.0
Scheduled maintenance (manhours per flight hour)	1.9	3.8	6.2

Maintainability features

The F-18 has maintainability design features not previously included in Navy fighter aircraft, such as:

--A maintenance monitor panel to monitor consumables and pre-selected weapon replaceable assemblies to speed up aircraft turnaround and reduce the need for a troubleshooting crew between flights.

--An engine condition monitor to assist ground crews in fault isolation and maintenance of the engine.

--Fast engine replacement assisted by a power-operated engine installation adapter.

--Fewer types of fasteners; 41 different fasteners compared to 68 for the F-15 and 210 for the F-4.

--No ground support equipment needed for organizational maintenance on contractor-furnished avionics.

--Self test techniques to minimize false alarms.

F-18 RELIABILITY GOALS AND FEATURES

Reliability of the F-18 is expected and specified to be higher than that of the F-14 weapon system as shown below.

	F-18	F-14
Mean flight hours between failure	3.63	a/ 2.16
Mission reliability	b/ .80	b/ .75

a/An approximate value provided by Navy officials based on a reliability probability of .25.

b/Mission reliability expressed as the probability of performing all mission functions successfully.

Spectacular reliability improvements for the F-18 are expected by the Navy. During authorization hearings in 1976, the Navy stated that the F-18 is expected to have a reliability of 5.9 average flight hours between failure as measured by the maintenance data collection system in the operational environment. The F-4J and the A-7E, the aircraft which the F-18 will replace, have a reliability of only .6 and 1.2 average flight hours between failure, respectively.

Reliability features

The Navy claims that the reliability of the F-18 will be superior to other aircraft in the fleet because of its design. Features contributing to greater reliability compared to the F-14 and F-4J are shown in the following table.

	F-18	F-14	F-4J
Simplified engine inlets (moving surfaces)	2	a/ NA	6
Radar (parts)	12,000	a/ NA	20,000
Engine (parts)	14,000	a/ NA	23,000
Low voltage lighting	yes	yes	no
Equipment environmental burn-in	yes	yes	no
High reliability parts program	yes	yes	no
Formal development test requirements	yes	no	no

a/Not available

In addition to the overall reliability requirement specifications, the F-18 contractor allocated reliability requirements to each element of the weapon system. A comparison of the allocated mean time between failure for functionally similar F-18 and F-14 equipment provided by Navy officials is shown in the following table.

Equipment	F-18 mean time between failure	F-14 mean time between failure
	(hours)	
Gun control unit		20,000
M61A hydraulic unit system	2,469	
Power generator system		2,000
Variable speed constant frequency generator	2,000	
Interference blanker		2,000
Interference blanker	1,500	
Engine instrument group	700	750
Control surface position set		2,000
Flight control position indicator	6,000	

Aircraft skid control		3,545
Main landing gear skid control system	4,080	
Steering damper		1,500
Nose wheel actuator	2,250	
Sparrow missile launcher		3,000
AIM 7F ejectable missile launcher	10,000	
Shock strut		10,000
Main landing gear strut assembly	4,240	
Radar alt APN-194		1,400
Radar alt	1,543	
Ejection seat		5,000
Ejection seat SEV	1,075	
TACAN ARN-84 receiver/ transmitter		700
AN/AN/84 receiver/ transmitter	700	

As shown above, the mean time between failure for these F-18 items is not consistently higher for items considered to be functionally similar to those of the F-14.

EFFORTS TO IMPROVE RELIABILITY AND MAINTAINABILITY THROUGH CONTRACT PROVISIONS

The F-18 program contract specifies many reliability and maintainability test requirements either not required on earlier weapon systems or strengthened on the F-18.

Test, analysis, and fix procedures, for example, are required in the F-18 program. According to Navy officials, the F-18 program is the first Navy program to have these as formal requirements. Test, analyze, and fix is described as a reliability growth process in which several pre-production systems are tested in a prescribed, mission-representative environment to determine weak areas and take corrective action to improve reliability to the required level before the production "go-ahead" is given. Under the test, analyze, and fix procedures, all failures are reported and analyzed and all failure modes are eliminated through design, material, or process changes. The Navy has published a series of requirements outlining the test, analyze, and fix process.

Navy officials believe the early identification of problems during the design/development stages using the test, analyze, and fix approach will eliminate many of the reliability problems much earlier than under previous programs, and reduce the possibility of costly corrective action as development matures.

Stress analysis and derating criteria for the F-18 are not completely different from previous programs such as the F-14 program, but Navy officials stressed that the National Aerounautics and Space Administration study "Long Life Assurance Study for Manned Spacecraft Long Life Hardware" which was used as a guideline for F-18 equipment design provides much more stringent design standards and practices than used on earlier aircraft. Stress analysis is a procedure by which the maximum stresses such as thermal, electrical, and mechanical factors induced on a part in its applications are identified. Derating criteria is a standard that establishes the ratio of maximum allowable stress to rated stress for a part application.

The stress being placed on reliability and maintainability in the F-18 program compared to the F-14 is shown by a comparison of the following contract material acquistion features.

	Specified for the F-18	Specified for the F-14
Mission profile definition	yes	yes
Stress analysis	yes	yes
Derating criteria	yes	yes
Worst case analysis	a/ no	no
Sneak circuit analysis	a/ no	no
Prediction/allocation	yes	yes
Failure modes and effect analysis	yes	yes
Test, analyze and fix with closed loop reporting	yes	no
Design reviews	yes	yes
Mission profile qualification test	yes	yes

a/Not specified but the Navy has been successful in obtaining contractor cooperation.

Navy officials stated that the F-18 reliability and maintainability contract specification requirements were similar to those in the F-14 contract or performed to some degree by the F-14 contractor. The major difference in the F-18 program approach is the more formalized, comprehensive, and stringent F-18 requirements and a greater use of incentives during the early stages of design/development to achieve reliability and maintainability goals.

Efforts to improve reliability and maintainability through incentives

The initial F-14 contract and the current F-18 contract contain profits to be earned if the contractor achieves specified maintainability goals. Maintainability was, however, combined with four other performance incentive goals for the F-14 and the total incentive profit dollars were based on the total performance achieved.

In addition to maintainability, the F-18 contract also provides incentives for achieving reliability goals as well as program milestone performance and life cycle cost goals. The reliability, maintainability, and performance milestone goals are also individually identified in the F-18 contract and are earned as development progresses as shown below.

--Ten payments at 6-month intervals for a total potential award of $15 million for the life cycle cost program and program milestone performance.

--Two payments, one at 1,200 flight hours and one at about 2,500 flight hours, providing up to $12 million for improving reliability.

--Three payments, one at 1,200, one at 2,500, and one at 9,000 flight hours totaling a potential $12 million for improvement of maintainability.

By achieving the reliability, maintainability, and milestone goals, the F-18 contractor can increase his earnings by $39 million or 44 percent during full-scale development. Navy officials said that the incentives for reliability and maintainability were put "up-front" in the F-18 contract to minimize the problems and expense of corrective action often required after the introduction of a new weapon system into the fleet.

The contractor can earn up to $15 million for the attainment of program milestones and other life cycle cost factors. The contractor will be notified of his progress through quarterly report cards. The milestones and life cycle cost factors vary from period to period and the Navy provides a list of these factors in advance of each period.

Factors which are or will be incentives include

--the contractor's ability to identify reliability improvement warranties to be decided at the time of the production contract award;

--design-to-cost/life-cycle cost trade-offs;

--control of life cycle cost resulting from subcontractor and supplier efforts; and

--reduction of personnel skill levels required to maintain equipment.

Navy officials informed us that many of the major F-18 subsystems involve current state-of-the-art technology or areas of low technical risk as shown in the following table.

Subsystem	Degree of risk involved in development	New or current state-of-the-art technology used
Inertial navigation set	low risk	current
Flight control electronics set	low risk	new
Stores management set	low risk	new
Head-up display	low risk	current
Multipurpose display	low risk	current
Radar	low risk	current
Engine	moderate	current
Ejection seat	low risk	current
Auxiliary power unit	none	current

EFFORTS TO REDUCE OWNERSHIP COSTS THROUGH LIFE CYCLE ESTIMATES

The F-18 is expected to be less expensive to operate and support than the F-4s and A-7s it is to replace. The

Navy expects the F-18 to cost only half as much to operate and support than the F-14. Comparative operating and support costs for one aircraft of each type in fiscal year 1975 dollars follow.

Estimated Annual Operating and Support Costs per Aircraft as of February 1977

Cost category	F-4J	A-7E	F-14	F-18
		(thousands)		
Personnel	$ 313	$284	$ 336	$208
Depot rework	332	249	414	182
Replenishment spares	62	78	139	94
Operating consumables	218	146	374	183
Support	104	104	159	92
	$1,029	$861	$1,422	$759

Personnel costs for the F-18 are expected to be lower than for the predecessor aircraft because less maintenance will be required. As we pointed out on p. 93, the Navy may be overly optimistic in this regard when comparisons are made with other aircraft systems. However, the F-18 is expected to be less expensive to operate and support than either the F-4J or the A-7. It is encouraging that the Navy is trying to control operating and support cost growth of tactical aircraft systems. The F-18, like the A-7E, has a one-person crew, whereas the F-4J and F-14 have two-person crews. This accounts for some of the differences in personnel costs between the different aircraft.

Navy officials said that extensive use of non-corrosive composite materials and fewer fastener types reduces the depot level airframe rework requirement for the F-18. In addition, engine rework is expected to be substantially less expensive for the F-18 than for the other aircraft due to fewer parts and lighter weight. For example, the F-18's engines have about 7,700 fewer parts and weigh half as much as the F-4Js.

Spares costs per aircraft per year are expected to be somewhat higher for the F-18 than for the F-4J and the A-7E, but costs are expected to be lower than for the F-14. Navy officials attributed lower spares costs for the F-18 as compared with the F-14 to reliability and maintainability efforts. However, we suspect that less system complexity accounts for much of the difference.

We were told by Navy officials that no overall life-cycle-cost analysis was performed for the F-14 weapon system. Capability to meet the perceived threat of new foreign aircraft such as the Russian Foxbat, not cost, was the primary concern with the F-14. Navy officials, however, informed us that operating and support costs have been analyzed and considered by the Navy for the F-18 program from its development. In the past, acquisition decisions considered only the cost of prime mission equipment (e.g., flyaway cost). This resulted in the acquisition of systems not economically supportable, resulting in diminishing readiness, according to the Navy.

Limitations on the defense budget combined with the increasing costs of weapon systems has forced the Navy to recognize that the cheapest hardware was sometimes the most costly considering total ownership of life cycle costs. As a result, operating and support costs, which tend to comprise one-half or more of weapon system ownership costs, were considered early in the F-18 program. Most of the logistics life cycle cost is for operations and support comprised of

--military pay and allowance,

--petroleum, oil, and lubricants,

--replenishment spares,

--other operating consumables, and

--depot rework costs.

The most recent life cycle cost estimate for the procurement of 800 F-18s as of October 1976 in fiscal year 1975 dollars follows. The estimate illustrates the importance of operating and support costs in relation to development and production costs for the weapon system.

	Millions	Percent
Operating and support	$ 5,809.3	42.2
Production	6,524.1	47.4
Full-scale development	1,429.3	10.4
Total	$ 13,762.7	100.0

The F-18, like the F-16, has been made more austere than the F-14 and F-15 largely due to cost pressures. To protect the potential operating and support cost advantage, the Navy should guard against adding capabilities purposely excluded during the F-18's development to make the aircraft simpler and more austere.

United States Senate
COMMITTEE ON APPROPRIATIONS
WASHINGTON, D.C. 20510

March 30, 1976

The Honorable Elmer Staats
Comptroller General of the United States
Washington, D. C.

Dear Mr. Staats:

In recent years, there has been increased emphasis on the life cycle costs of new military weapon systems being developed and procured. To a significant extent, savings in operating costs of new weapons accrue from reduced maintenance and logistics support, including reductions in manpower requirements made possible by greater automation, increased reliability or lower maintenance. In this regard, the military services are indicating that improved reliability and maintainability of new weapon systems is resulting in reduced support costs. The Committee would like the General Accounting Office to determine if there is any way to measure improved performance of these systems as it affects support costs and manpower requirements.

The Committee recognizes that it will probably be difficult to determine whether improved performance in terms of reduced logistics support can be measured for an entire weapon system. Two or three weapons systems may need to be examined in various stages of development -- for example, the F-15 or F-14 and the F-16 or F-18 -- to see if information systems and records are maintained that make it feasible to track the reliability and maintainability of a weapon system (and its effect on logistics support requirements) from the specifications or goals agreed to by the Service and contractor to the actual results achieved once the system is in operation.

Although dealing with this subject at the weapon system level would be most valuable, it may be quite difficult. Therefore, it might be necessary, as an alternative, to select major components, particularly engines or electronics components, that traditionally require extensive maintenance and logistics support, and examine them. GAO should determine if similar type equipment in new weapons systems is more reliable and more easily maintained than earlier models. Also, it would be necessary to establish whether there has been an appreciable reduction in the requirements for logistics and maintenance support, including support personnel, as a direct result of the new system.

Finally, GAO should investigate what the services are doing to reduce logistics and maintenance personnel strengths. Have they made studies to assess potential trade-offs to manpower requirements such as providing additional spare components to reduce the component repair workload, assigning maintenance responsibilities at the appropriate organizational level, or taken other approaches to provide more effective utilization of support personnel?

The Defense Subcommittee staff has discussed this request with members of the GAO's Procurement and Systems Acquisition, Logistics and Communications and Federal Personnel and Compensation Divisions. Please contact the Committee staff to establish a timetable for the review or to obtain any further information needed from the Committee on its preparation.

With kind regards, I am

Sincerely,

John L. McClellan
Chairman

JLM:ljm

PRINCIPAL OFFICIALS

RESPONSIBLE FOR ADMINISTERING

ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of office	
	From	To
DEPARTMENT OF DEFENSE		
SECRETARY OF DEFENSE:		
Dr. Harold Brown	Jan. 1977	Present
Donald H. Rumsfeld	Nov. 1975	Jan. 1977
James R. Schlesinger	July 1973	Nov. 1975
William P. Clements, Jr. (acting)	Apr. 1973	July 1973
DEPUTY SECRETARY OF DEFENSE		
Charles W. Duncan, Jr.	Jan. 1977	Present
William P. Clements, Jr.	Jan. 1973	Jan. 1977
ASSISTANT SECRETARY OF DEFENSE (MANPOWER, RESERVE AFFAIRS AND LOGISTICS):		
Dr. John P. White	May 1977	Present
Carl W. Clewlow (acting)	Apr. 1977	May 1977
ASSISTANT SECRETARY OF DEFENSE (INSTALLATIONS AND LOGISTICS):		
Dale R. Babione (acting)	Jan. 1977	Apr. 1977
Frank A. Shrontz	Feb. 1976	Jan. 1977
John J. Bennett (acting)	Mar. 1975	Feb. 1976
Arthur I. Mendolia	June 1973	Mar. 1975
ASSISTANT SECRETARY OF DEFENSE (COMPTROLLER)		
Fred P. Wacker	Sept. 1976	Present
Terence E. McClary	June 1973	Aug. 1976
DEPARTMENT OF THE NAVY		
SECRETARY OF THE NAVY:		
W. Graham Claytor, Jr.	Feb. 1977	Present
Gary D. Penisten (acting)	Feb. 1977	Feb. 1977
Joseph T. McCullum	Feb. 1977	Feb. 1977
David R. MacDonald	Jan. 1977	Feb. 1977
J. William Middendorf	June 1974	Jan. 1977

DEPARTMENT OF THE NAVY (continued)

	Tenure of office From		Tenure of office To	
J. William Middendorf (acting)	Apr.	1974	June	1974
John R. Warner (acting)	May	1972	Apr.	1974
UNDER SECRETARY OF THE NAVY:				
R. James Woolsey	Mar.	1977	Present	
Vacant	Feb.	1977	Mar.	1977
David R. MacDonald	Sept.	1976	Feb.	1977
John Bowers (acting)	July	1976	Aug.	1976
Vacant	Mar.	1976	June	1976
David S. Potter	Aug.	1974	Mar.	1976
Vacant	June	1974	Aug.	1974
J. William Middendorf	June	1973	June	1974
ASSISTANT SECRETARY OF THE NAVY (FINANCIAL MANAGEMENT):				
Gary D. Penisten	Oct.	1974	Present	
Vacant	May	1974	Oct.	1974
Robert D. Nesen	May	1972	May	1974

DEPARTMENT OF THE AIR FORCE

SECRETARY OF THE AIR FORCE:				
John C. Stetson	Apr.	1977	Present	
John C. Stetson (acting)	Jan.	1977	Apr.	1977
Thomas C. Reed	Jan.	1977	Jan.	1977
James W. Plummer (acting)	Nov.	1975	Jan.	1976
Dr. John L. McLucas	July	1973	Nov.	1975
ASSISTANT SECRETARY OF THE AIR FORCE (INSTALLATIONS AND LOGISTICS):				
Richard J. Keegan (acting)	Feb.	1977	Present	
Hon. J. Gordon Kapp	Mar.	1976	Jan.	1977
Frank A. Shrontz	Oct.	1973	Feb.	1976
Richard J. Keegan (acting)	Aug.	1973	Oct.	1973
Lewis E. Turner	Jan.	1973	Aug.	1973
ASSISTANT SECRETARY OF THE AIR FORCE (FINANCIAL MANAGEMENT):				
Everett T. Keech	Sept.	1976	Present	
Francis Hughes	Mar.	1976	Sept.	1976
Arnold G. Bueter (acting)	Aug.	1975	Mar.	1976
William W. Woodruff	Apr.	1973	July	1975