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MAINTAINABILITY/RELIABILITY IMPACT ON SYSTEM SUPPORT COSTS

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AIR FORCE FLIGHT DYNAMICS LABORATORY
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PREFACE

This report was prepared by the Boeing Aerospace Company, Research and Engineering Division, Seattle, Washington, under USAF Contract F33615-73-C-3148. The contract was initiated under Project 1207, Identification of Aircraft System and Program Improvements Leading to Support Cost Reduction. The work was administered under direction of the Air Force Systems Command (AFFDL/PTC) with Nathan L. Sternberger as Project Engineer.

Boeing Aerospace program technical leader was R. E. Reel. Principal analyst was W. L. Johnson. The contractor's report number is D180-17822-1.

This document includes work performed from 29 June 1973 through 31 December 1973. This technical report has been reviewed and is approved.

G. E. Danforth Colonel, USAF
Chief, Prototype Division
Air Force Flight Dynamics Laboratory

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SECTION I

INTRODUCTION

More than two thirds of the national defense budget for the past six years has been required to support the existing military inventory of equipment. Cost of manpower and spares, which are the two main drivers in this multi-billion dollar outlay, is increasing each year. If this trend is allowed to continue, support costs could equal, or exceed the amount of dollars presently allocated for national defense. Currently, technology research and acquisition of new systems have taken the brunt of the impact, another trend that cannot be continued. Recognizing these facts, DOD is placing more emphasis on "design to cost" for new systems and reduction of total life cycle cost on both new and existing systems. With this direction, increased emphasis is being placed on cost analysis during the entire design process including preconceptual and conceptual studies.

Data derived from specific equipment/system programs show that design efforts to increase reliability and reduce maintenance requirements per failure can significantly reduce equipment/system life cycle costs. Therefore, they offer a major opportunity for support cost savings, especially on equipment that is mission essential. Consequently, improved engineering design analysis techniques, insight, and cost consciousness are needed.

This report provides a methodology for estimating life cycle cost, primarily during the operational phase and addresses quantifiable savings that can be determined during early design. Areas affecting support cost elements are discussed in Section III. Rationale, and analytical techniques used to develop design guidance and determine estimated support cost savings are discussed in Section IV. Operational field experience from the F-4, F-111 and A-7D fighter aircraft and cost planning factors from AFM 173-10 are used as the basis for most of the analysis performed (1). Although the cost reductions arrived at are based on available technology and considered reasonable for a new system they are not necessarily indicative of cost reductions for systems in the field. This report is an extension of ASD/XR72-49, Weapon System Support Cost Reduction Study, performed for the Aeronautical Systems Division in June 1972. The contents of this report does not include a computer model, but selected data could be used effectively in establishing some of the inputs needed for life cycle costs and effectiveness modeling.

SECTION II

SUMMARY

This technical report pertains to life cycle cost analyses and shows how trends in logistics support technology, primarily reliability and maintenance, influence life cycle costs during the operational phase of a program. The purpose of the report is to provide cost consideration guidelines to the design and integrated logistics support engineers. This is accomplished in the form of the curves, charts, and calculations shown in Sections III and IV. The objective is to provide a baseline, using documented field experience, for developing methods of determining cost savings through Cost Estimating Relationships (CER's) by identifying areas having the greatest impact on system support costs. Field experience information plus cost planning factors from AFM 173-10 are applied to the F-111, F-4 and A-7D aircraft.

Figure 1 shows the percentage of total ownership costs committed during conceptual planning, design, development, acquisition and operations for past major programs. In the past, decisions made during the concept and planning phases committed 70 percent of the total life cycle cost funds of a program and design, development, acquisition and operations accounted for only 30 percent of that total cost. Application of life cycle cost analysis through the planning and RDT&E phases of a program and the "design-to-cost" concept on new programs is expected to change this distribution considerably by affecting a larger portion of that early 70 percent commitment.

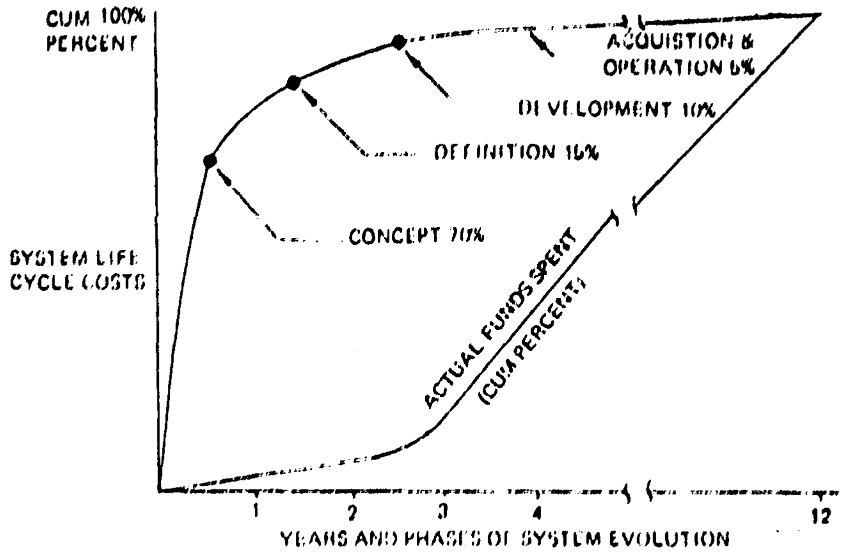


Figure 1: SYSTEMS FUNDS COMMITTED BY INITIAL PLANNING DECISIONS

Using the experience data, factors and trends discussed in the report, example cost analyses were performed on the three aircraft. The rationale and step-by-step analysis for the Integrated Logistics Support elements are shown in Section IV. The following summarizes the current field experience in each of the improvement categories discussed in Section IV, the improvement objective and how the improvements can be achieved:

IMPROVEMENT CATEGORY		FIELD EXPERIENCE	IMPROVEMENT OBJECTIVE	ACHIEVED BY
Avionics Systems	-	1 failure 12 MMH/flight	300 hr MTBF minimum	Medium/Hi Rel parts, Temperature cycling of black boxes
Mechanical Systems	-	Fasteners 71% of airframe failures, Leaks, adjustment, corrosion 40% of mechanical failures	60% for fasteners 20% other mechanical items 300 hr MTBF	Improved, minimized standardized fasteners, Improved seals, welded joints, permalube bearings, etc.
Repair-ability	-	Gaining access 2 MMH/FH on F-111, F-4	50% reduction	Component stacking by frequency of removal, Improved access location, Quick disconnect features, Modular assemblies, etc.
Test and Checkout	-	2-3 MMH/FH troubleshooting and bench check	40% reduction F-111, A-7D 50% F-4	Central Integrated Test System, Real time fault isolation, Eliminate bench check OK
Inspection Techniques	-	Major inspection - 7-9 MMH/FH IRAN inspection 6-24 MMH/FH	50% reduction	Inspection based on failures and frequencies, Improved NDI techniques, Structural sampling
Safety (Attrition)	-	1.8-3.7 material failure accidents per 100,000 FH	50% reduction	Fault Tree analysis, Hazard analysis

Highlights of the estimated overall support cost reductions are as follows:

Area of Reduction	F-111	F-4	A-7D
	Percent Reduction		
Failures per flight hour	28.0	29.3	33.6
Direct MM/FH	29.7	29.8	28.0
Direct MMH/IRAN	50.0	50.0	0
Spares replenishment	28.0	29.3	33.6
Manning requirements	12.6	14.3	13.5
Aircraft attrition	20.5	15.0	16.5

Applying AFM 173-10 Cost Planning Factors to the improvement objectives results in the following reductions of squadron annual operating costs.

	ANNUAL REDUCTION PER SQUADRON (THOUSANDS OF DOLLARS)		
	F-111	F-4	A-7D
Direct Maintenance Personnel	875	824	630
Spares Replenishment	1,220	270	295
Depot (Labor and Material			
Iran	560	138	- -
Component Repair	313	81	140
Support Elements	678	585	537
Total	3,646	1,898	1,602

SECTION III

WEAPON SYSTEM COSTS

Present concern for natural resources, the environment, and increasing cost for labor and material has resulted in cost consciousness that never before existed. Requirements being imposed on new programs are increasingly severe. To satisfy these requirements, much emphasis is being placed on reducing cost throughout all phases of new programs. It is difficult to motivate the customer and contractor program managers to spend more hard-to-get money during RDT&E phase of a program with the intent of reducing costs further downstream. Budget restrictions early in a program frequently result in substandard products from a life cycle cost standpoint. Therefore the evidence and magnitude of cost savings achievable further downstream must be reliable and overwhelming, and the initial effort to make this determination relatively quick and low cost.

In this section life cycle cost is defined, trends are developed and discussed to show generic areas of impact, and where the greatest payoffs in cost reduction exist. Trends such as these are helpful to engineers in establishing cost estimating relationships (CER) and to stimulate cost trades during initial design.

1. LIFE CYCLE COST

"Life Cycle Cost" of a weapon system is defined as the total program cost during a defined time span, normally 10 years, and is described in three primary phases. These phases are RDT&E (Research, Development, Test, and Evaluation), Acquisition, and Operations. A simplified flow diagram is provided to show the relationship of these phases and to identify major elements within each phase. Planning is also included on this diagram because of the impact it has on funds committed during the life cycle of a program even though it is not normally considered part of the total program cost.

PROGRAM LIFE CYCLE COST PHASES

PLANNING	RDT&E	ACQUISITION	OPERATIONS
o Threat	o Research	o Unit Equipment	o Replenishment Spares
o Policy	o Design	o Command Support	o Petroleum-Oil-Lubrication (POL)
o Budget	o Development	o Attrition	o Personnel Pay
o Technology	o Test	o Initial Spares	o Vehicle Maintenance
o Mission	o Evaluation	o AGE	o Vehicle Modification
		o Facilities	o AGE Maintenance
		o Training	o Facility Maintenance
		o War Reserves	o Depot Maintenance
		o Technical Manuals	

Program costs pertaining to each of these life cycle phases for the F-111A/D/E/F are reflected in Figure 2. The magnitude of each phase depends on system complexity, program redirection, pressure to reduce development time, starting large scale production before RDT&E is complete, size of production run, production rate, training and operational requirements. Figure 2 shows how these factors affect the life cycle phases of the F-111 program.

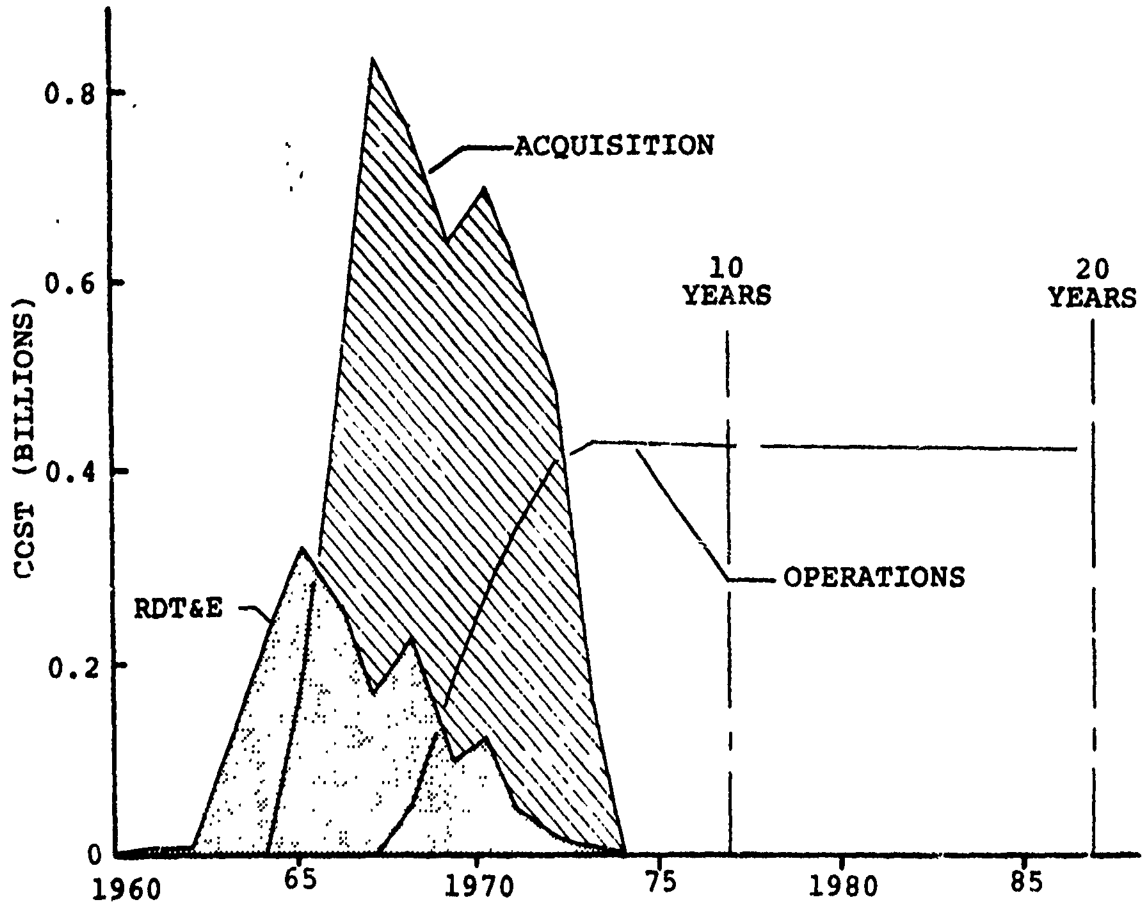


Figure 2: F-111 LIFE CYCLE COST

SOURCES: RDT&E - Senate Hearings 1973
Procurement - Senate Hearings 1973
Operations - AFM 173-10

Cumulative LCC After 10 Years of Operations

	Billions	Percent
RDT&E	$1.642	17
Procurement	4.790	49
Operations	3.406	34
	$9.838	100

Cumulative LCC After 20 Years of Operations

	Billions	Percent
RDT&E	$1.642	12
Procurement	4.790	34
Operations	7.726	54
	$14.158	100

For example, after 10 years of operation, the proportion of total program costs will be 17 percent for RDT&E, 49 percent for procurement and 34 percent for operations. The impact of operational costs become more predominant with each ensuing year. After 20 years of operation, the distribution of program costs will be 12 percent for RDT&E, 34 percent for procurement and 54 percent for operations. Operational costs are most sensitive to aircraft utilization. Present planning factors (AFM 173-10) allow for a minimum of flying time; any increase in utilization will have a direct impact on O&M costs (spares, POL, consumables, base and depot maintenance).

RDT&E (Research, Development, Test and Evaluation) includes all the expenditures necessary to commit a system into production. This includes proving grounds, test vehicles, related ground support equipment, facilities, and all the activites associated with test and evaluation. It is noted the F-111 RDT&E overlaps the acquisition phase, which does not allow for the time to incorporate and confirm all pertinent aspects resulting from RDT&E before proceeding into a high production rate. It appears that production cost overruns could have been reduced if more time had been available to assimilate RDT&E and confirm operational requirements (2).

Acquisition includes all expenditures required to introduce a new capability into the operational force, including initial procurement of major equipment and components of the system required to make it combat ready -- i.e., basic facilities, ground environment equipment, initial stocks, and initial training of personnel.

Operations include expenditure for maintaining and operating a system that has been introduced into the active force. This includes personnel pay, allowances, training of personnel replacements, maintenance (including depot maintenance), POL, equipment replacement, replenishment of spares and a share of base operations support.

Figure 3 portrays the USAF life cycle costs on the A-7D. RDT&E is proportionally lower than the F-111 program because the majority was funded through the Navy program. The greatest portion of Air Force RDT&E funds were for the TF-41 engine development. The overlap of RDT&E into the acquisition phase did not create the impact as on the F-111 program, and represents only two percent of the total program cost after ten years of operation compared with 17 percent on the F-111. Operations costs on the A-7D comprise over one-half of total life cycle costs after 10 years of operation, while they require twenty years of F-111 operation to reach a similar figure. With exception of the RDT&E costs, this graph is probably more typical of a fighter program cost cycle.

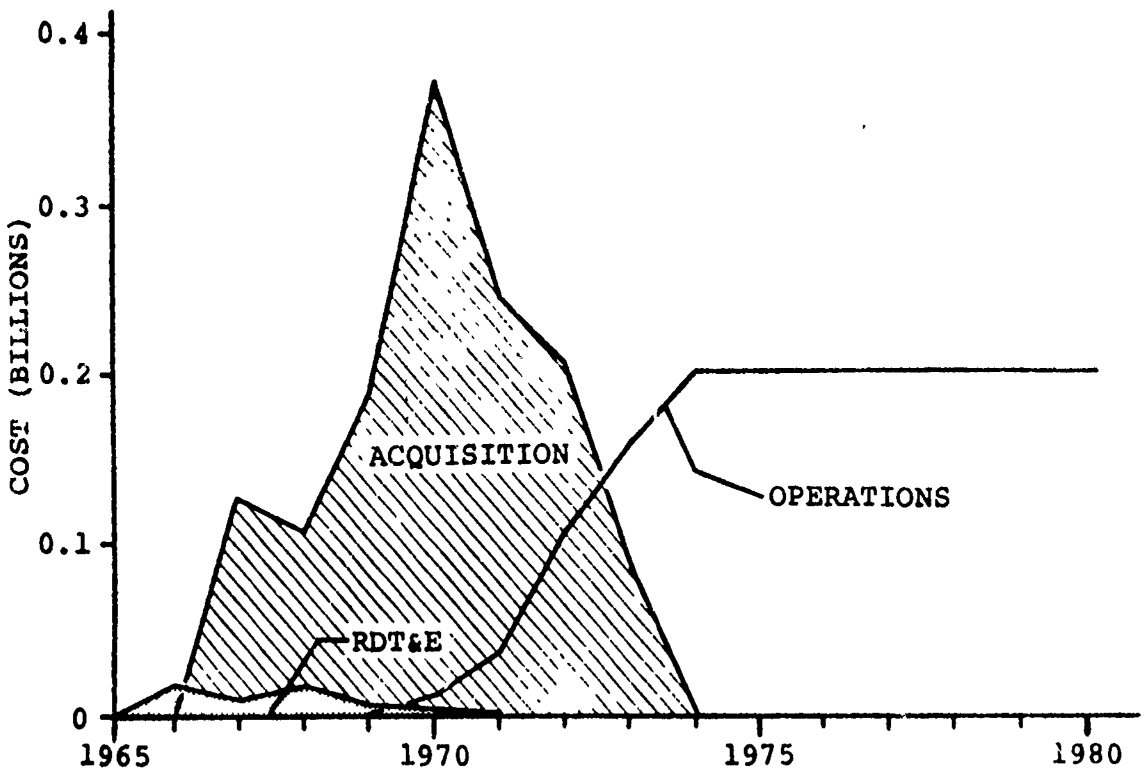


Figure 3: A-7D LIFE CYCLE COST

SOURCES:	RDT&E	- Senate Hearings	1966-1973
	Acquisition	- Senate Hearings	1966-1973
	Operations	AFM 173-10	1973

Cumulative LCC After 10 Years of Operations

	Billions	Percent
RDT&E	$0.584	2.0
Procurement	1.332	45.6
Operations	1.528	52.4
	$3.444	100.0

Figure 4 is a cost breakdown of the operational phase for the F-111, F-4 and A-7D, based on AFM 173-10 factors. The cost of people is most significant for all three systems: 42 percent of the F-111 operational costs, 58 percent for the F-4 and the A-7D. These personnel are used for direct support of maintaining and operating the aircraft and indirectly require additional personnel for their support.

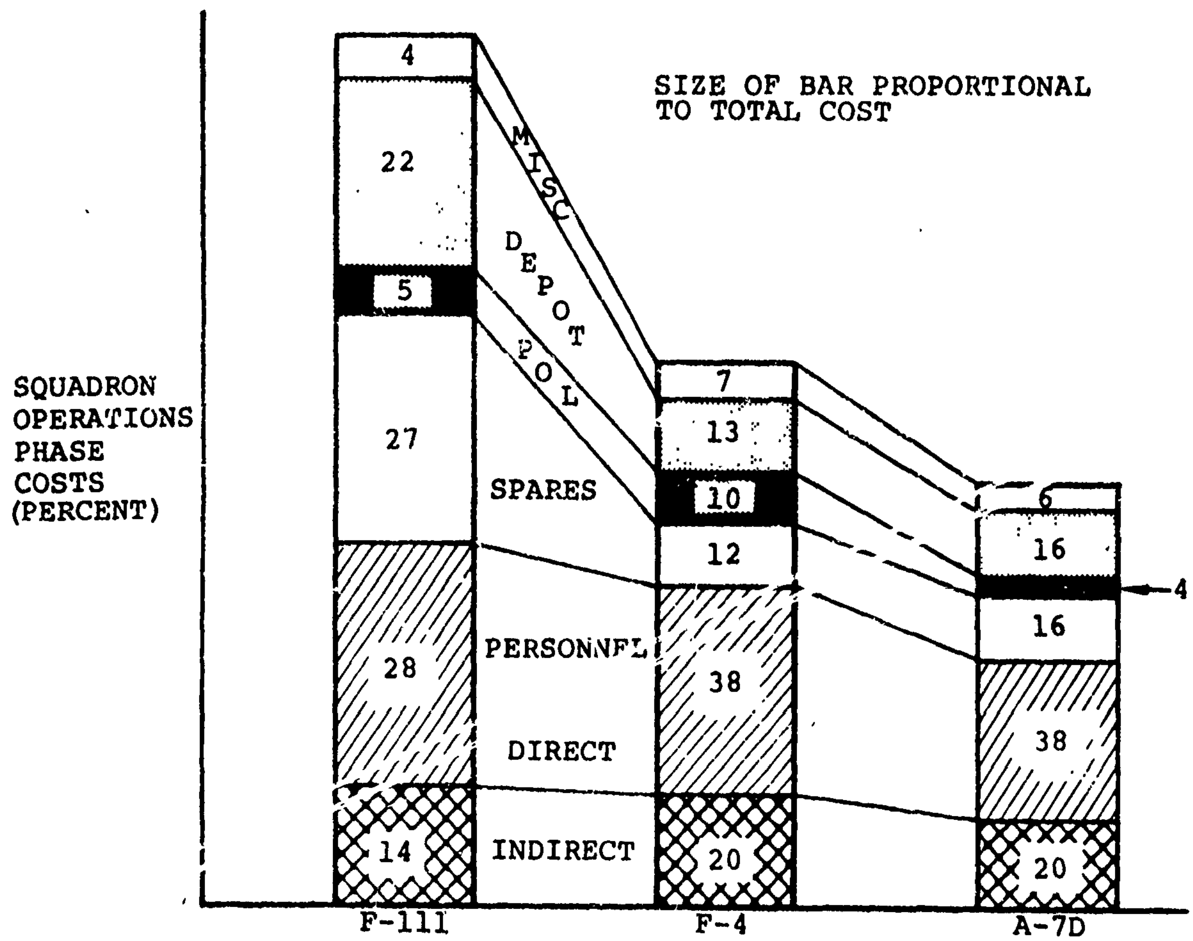


Figure 4: OPERATIONS PHASE - FIGHTER AIRCRAFT

It should also be noted in Figure 4 that spares and depot maintenance contribute significantly to operational costs. The spares cost category includes aircraft replenishment spares, base consumable material, modification parts and AGE spares. For the F-111, spares are 27 percent and depot maintenance 22 percent of operational costs. On the F-4, spares are 12 percent and depot 13 percent. The A-7 spares and depot are both 16 percent, or 32 percent of the operational costs.

2. DESIGN AND INTEGRATED LOGISTICS SUPPORT (ILS)

Total life cycle cost of a weapon system can be substantially reduced by effective application of design and ILS engineering. The largest cost reduction is achieved early on a program through emphasis on design for manufacturing and reliability/maintainability which have major impact on the number of personnel required to produce and maintain the system.

An expanded flow diagram of the life cycle cost phases shows how ILS, as a total function, interfaces with other phases for a new program. As indicated in the diagram, Figure 5, ILS engineers maintain a direct working relationship with project and staff areas to develop new innovations pertaining to detailed logistics support concepts and resource requirements as the system/equipment design progresses. Maintenance actions, times, levels, and locations are defined, in addition to the requirements for spares, facilities, personnel, training, training equipment, technical data, and ground support equipment. The preservation of technical competence and continuity of experience through all life cycle phases are major factors in avoiding unnecessary support expenditures, and therefore a good plan for the maximum use of support resources while assuring required readiness and availablity of the weapon system.

Large core capacity computers are used to perform trade studies evaluating total support cost and operational impact. At Boeing, models have been developed on past programs to identify sensitive support cost elements and to determine trends and perform trade studies. These models are designed to measure support cost impact by changing design, maintenance manhours, reliability, number of people, spares, operational concept, maintenance plan, etc. Using actual field experience data from sources such as Air Force Manual 66-1, Navy 3M and commercial airline operators, realistic trade studies are performed with a high degree of confidence.

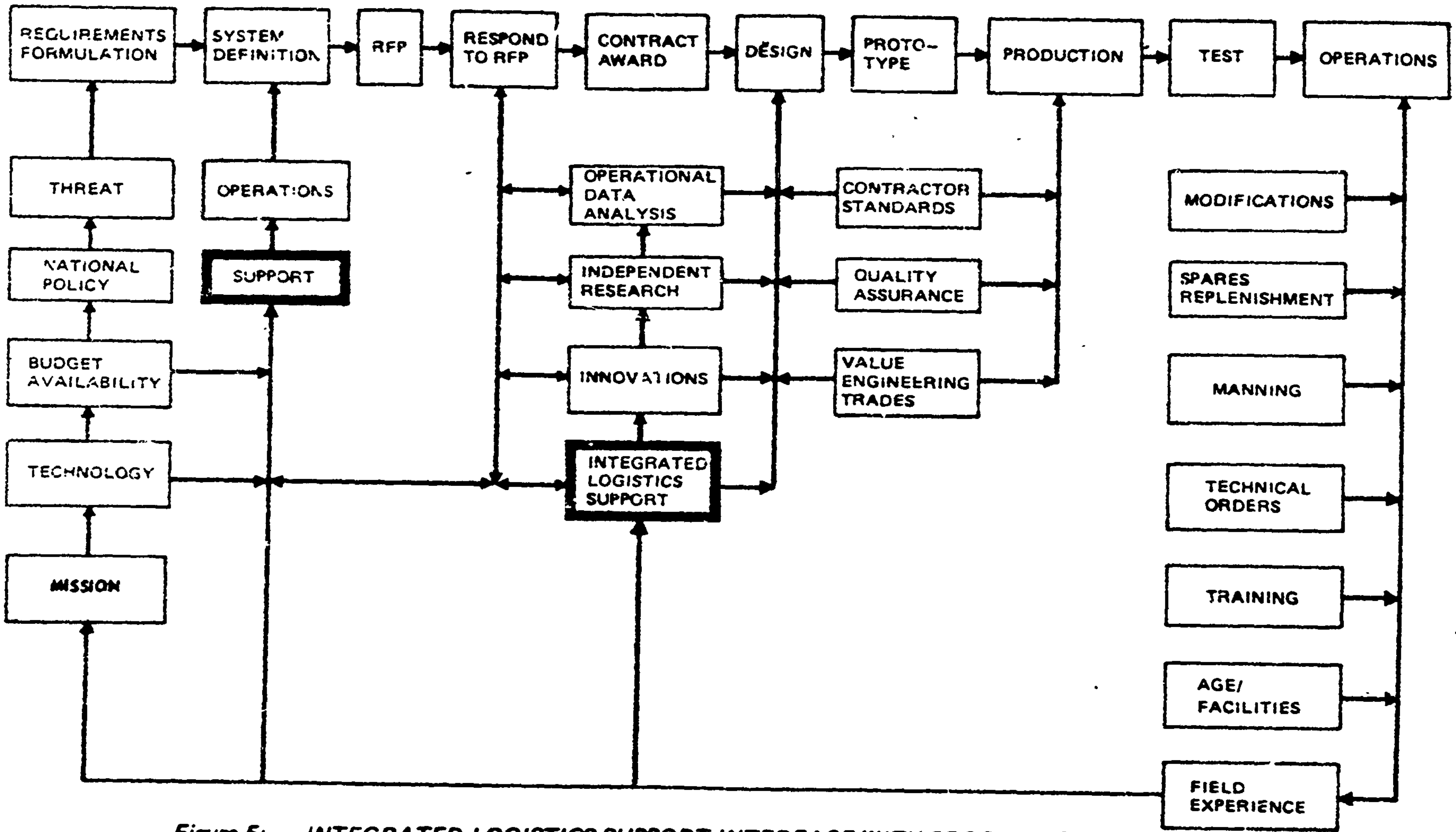


Figure 5: INTEGRATED LOGISTICS SUPPORT INTERFACE WITH PROGRAM PHASES

Major design and logistics elements considered in this study include the following:

- o Maintainability and Maintenance Engineering
- o Reliability
- o Safety
- o Manning
- o Training
- o Technical Publications
- o Ground Support and Test Equipment
- o Supply and Transportation

Numerical allocations are established from field experience information for each of the ILS functional elements and correlated to the cost planning factors shown in AFM 173-10. Using these cost values as a guide, estimated annual costs are calculated for specific aircraft squadron strengths, utilization and mission requirements. Logistic support trade studies on design alternatives are then performed to measure variations from this baseline.

a. Maintainability and Maintenance Engineering

Of the eight design and logistics elements noted, reliability and maintainability applied during initial design have the most impact on cost over the life of a program. On the F-4, F-111, and A-7D aircraft, preventive and and corrective maintenance averages more than 1.6 billion dollars annually. This cost was calculated from 173-10 cost factors as applied against the entire fleet. Analyses indicate this value could probably have been reduced by 12 percent with more engineering effort using today's technology and maintenance planning during the early design process of the programs.

A decrease in maintenance manhours required to support a weapon system is usually an indicator of not only improvement in maintenance techniques, but reduced complexity, and higher reliability of configurations which result in shorter turn-around times, less troubleshooting, fewer people, decreased emphasis on training, less spares, less test and checkout equipment, etc.

From extensive use of field experience data on existing weapon systems, high cost problems can be identified and overcome through research, and improved design, to eliminate or significantly reduce them. Features that have proven successful can be retained, while features that have proven unsuccessful can be eliminated.

There are operational factors that impact maintenance manhours, independent of design. Some of these factors are: time after aircraft entered service; mission length; utilization per month; and the maintenance concept used. These factors are discussed in the following paragraphs.

Field experience on aircraft entering operational service indicates that maintenance manhours per flight hour (MMH/FH) expenditures start relatively low, build to a high point, and then gradually lower to a point which remains relatively stable until the aircraft approaches wearout. See Figure 6.

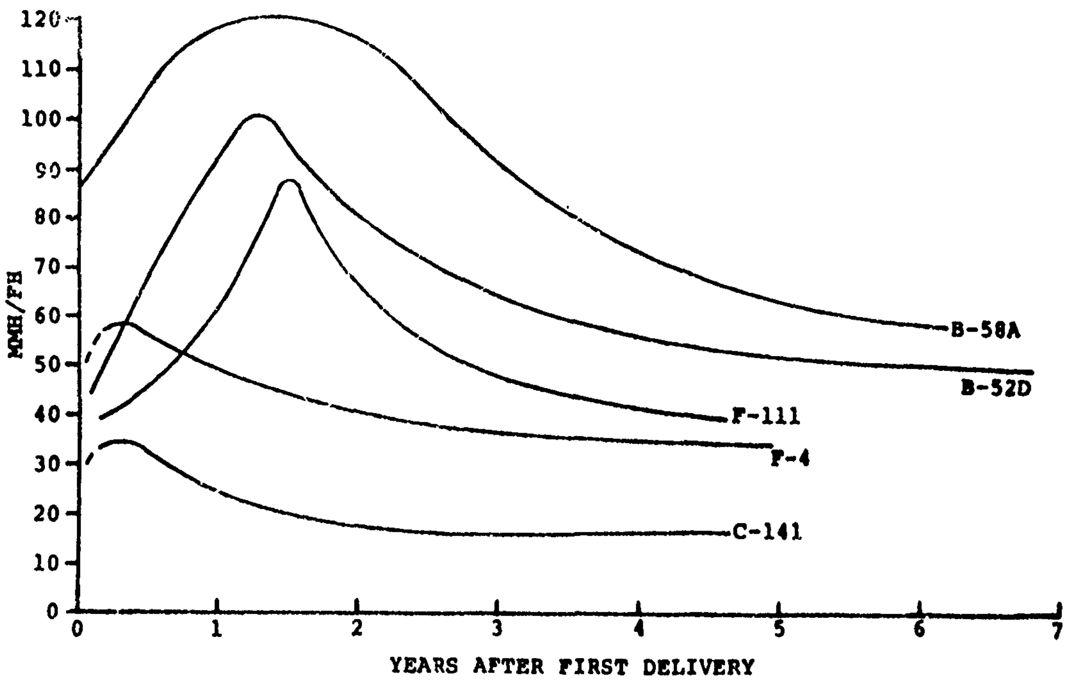


Figure 6: MAINTENANCE GROWTH

The initial low end of the curve is attributed primarily to low service time on brakes, tires, engines, airframe and the lack of major inspections. The rapid early buildup of maintenance is attributed to inexperienced personnel, short training flights with a high rate of takeoffs and landings and the beginning of major inspections. The tapering off of the curve reflects the personnel learning curve and reduction of high use items related to the landing and takeoff cycle as training flights are reduced. Knowledge of this trend is particularly important when formulating a maintainability demonstration plan, because a few hundred flight hours, one way or the other during this part of the program, could make considerable difference in the maintenance manhours per flight hours actually demonstrated. Understanding this trend could permit cost savings by trades pertaining to maintenance policy, flight and ground crew training techniques, etc., early in the program.

Study of the impact of aircraft sortie length on maintenance manhours indicate a trend shown in Figure 7.

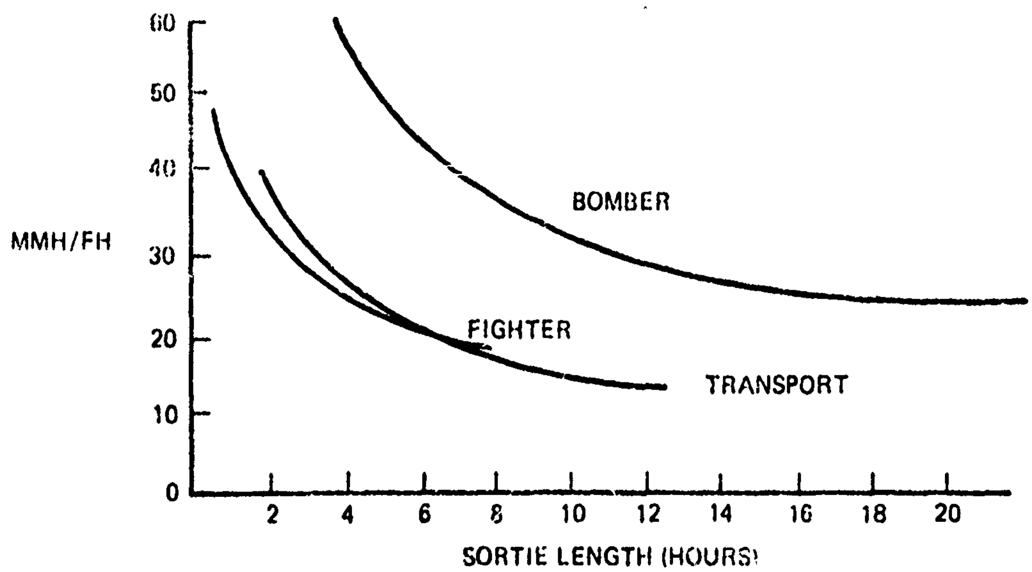


Figure 7: MAINTENANCE MANHOUR - SORTIE LENGTH TREND

This trend shows how maintenance manhours per flight hour decrease with increased sortie length for fighter, transport and bomber aircraft (3).

Although other operational factors affect maintenance manhour requirements, sortie length, even though somewhat limited for fighter aircraft, is still influential. This trend occurs because much maintenance is associated with the number of aircraft takeoffs and landings. Also preflight and postflight inspections are currently based on the number of flights, a concept that could be changed to a measure, such as calendar time or flight hours, without jeopardizing safety for most aircraft types. In addition, maintenance cannot be performed on a failed item until the airplane lands; when the aircraft is flying it continues to accumulate flying hours. Maintenance is also sometimes deferred to a more convenient time. Knowing these trends and effects on manhours, early planning of maintenance concept and sortie length requirements for training and other non-combat flying could establish operational schedules that would cost much less than those required to support most aircraft in the inventory today.

The number of flight hours accumulated per month on the aircraft also affects the maintenance manhours per flight hour (MMH/FH) rate (4). See Figure 8. Although the effect by increasing aircraft utilization is not as dramatic as sortie length, it can be significant. Commercial airlines maintaining 240 to 360 flying hours per month per aircraft receive advantages from this type operation. The C-141 demonstrated a similar trend during the two years the fleet averaged 240 hours per month per aircraft. The C-141 utilization rate is based on the operational bases possessed aircraft as reported per AFM 65-110 and verified by the base maintenance summaries. The B-52's operating in Southeast Asia also experienced a similar reduction in maintenance manhours per flight hour because of increased utilization. B-52D's operating in the CONUS reported aircraft utilization of 47 hours per month and averaged 52.2 MMH/FH, while those aircraft operating at Kadena Air Force base reported a monthly utilization of 127 hours and averaged 37.3 MMH/FH and the aircraft at Andersen Air Force base reported a utilization of 139 hours per month with a 30.3 MMH/FH (5).

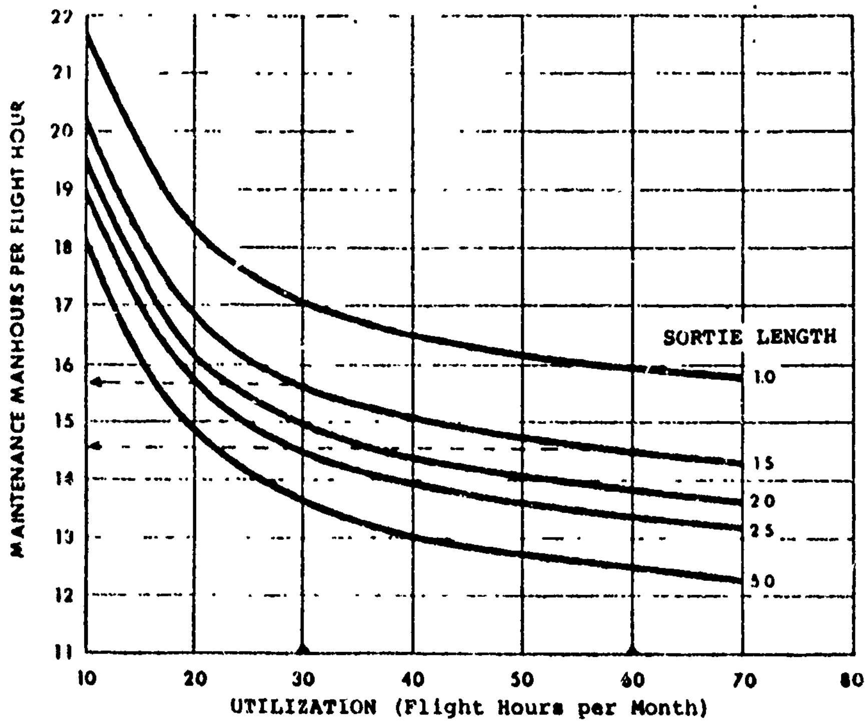
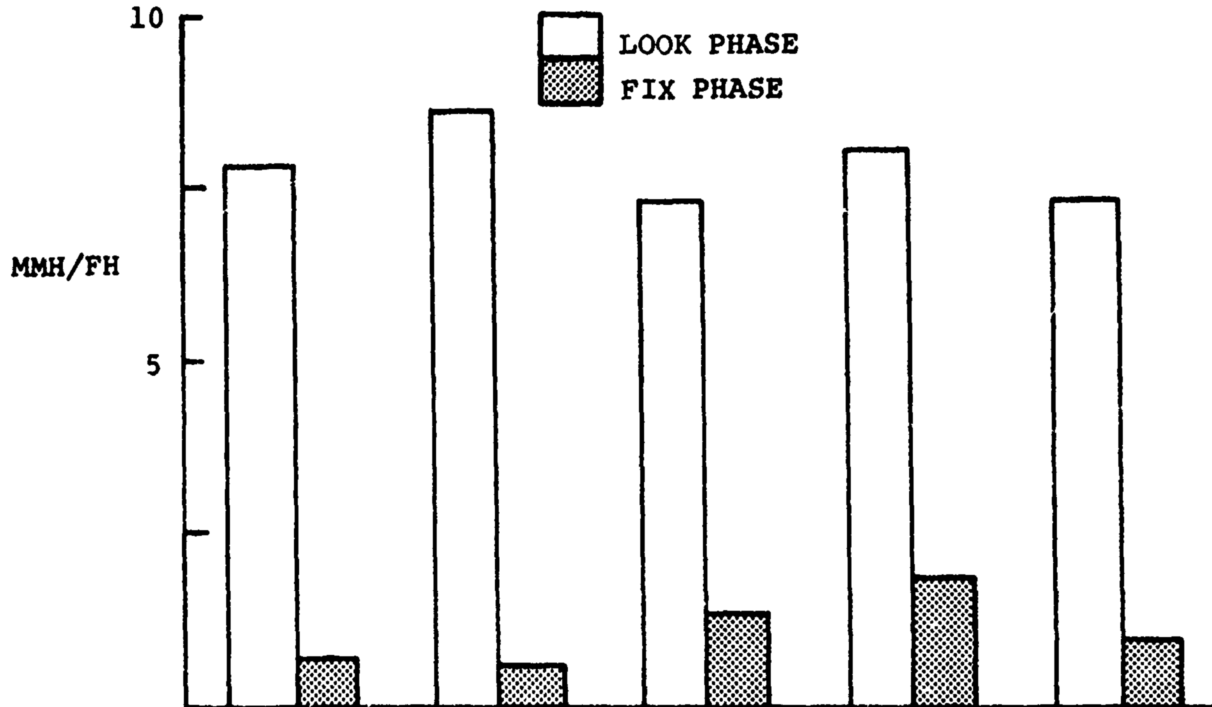


Figure 8: F-4 MMH/FH VERSUS SORTIE LENGTH AND UTILIZATION

This reduction in manhour requirement because of increased utilization is somewhat difficult to explain but can be attributed primarily to three areas. (1) Aircraft systems used daily normally receive better upkeep and experience less failures per flight hour. (2) Aircraft that fly frequently are on the ground less time and require maintenance to be accomplished in a limited amount of time. Because of this pressure, maintenance is accomplished more efficiently and frequently by higher skill level personnel. (3) Aircraft where maintenance is deferred because spare parts are not available; system not essential to the next mission; or minor maintenance deferred to a more convenient time.

Maintenance personnel can more easily retain knowledge of failures and maintenance accomplished the day before; hence, there is better continuity between maintenance tasks. A curve showing the effect of aircraft sortie length is overlaid on this chart to show the magnitude of slope as compared to the utilization curve.

Figure 9 shows the results of a in-house Boeing study on Scheduled Maintenance, and indicates that about 7-1/2 maintenance manhours per flight hour are expended on the look phase of a major inspection on these aircraft even though they are operated by both the Air Force and Navy and have different inspection intervals (3). These manhours are quite significant especially considering the small amount of manhours expended on fix maintenance during this time, indicating an area where cost improvements could be achieved through the application of new maintenance concepts and use of improved NDI (Nondestructive Inspection) techniques.



	F-111A TAC	F-4D TAC	F-4B PACIFIC	A-6A PACIFIC	A-7D TAC
CONCEPT	PHASE	PHASE	CALENDAR	CALENDAR	PHASE
INTERVAL	400 HR	300 HR	20 WEEKS	17 WEEKS	300 HR

Figure 9: LOOK AND FIX MAINTENANCE COMPARISON

Another approach to lowering logistics support costs is through reducing time to repair. Time to gain access, removal and replacement of serviceable components, and troubleshooting extend repair time significantly.

Comparison of accessibility data for fighter, bomber, and transport aircraft shown in Figure 10 indicates that maintenance accomplished to gain access to malfunctioning components increases with increased equipment density for high performance aircraft. Space limitations are more critical in supersonic aircraft, requiring components to be shaped and stacked to fit into less desirable maintenance locations.

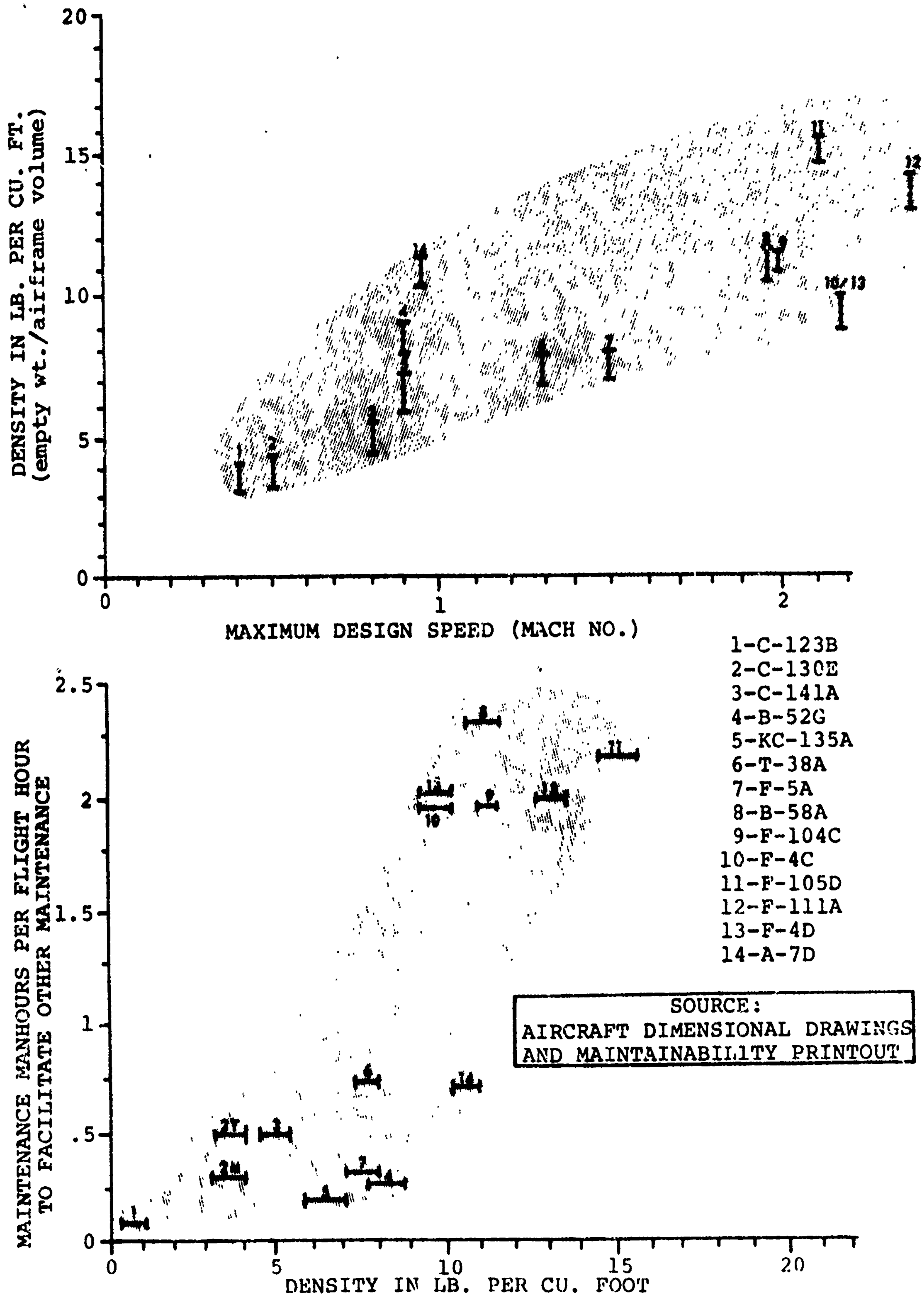


Figure 10: EFFECTS OF EQUIPMENT DENSITY

Limited access, in addition to causing no-defect component removals, extends the maintenance task times. This is verified by the B-58 which ranks fifth in the component removal rate but first in manhours expended per flight hour for gaining access.

The five aircraft (B-58, F-4D, F-104C, F-105D and F-111A) that require the most manhours to facilitate other maintenance are also the highest in terms of equipment density and maximum design speed.

Air Force Manual 66-1 data indicates that 8 to 13 percent of the components removed for failure on the study aircraft are later verified as serviceable in the shop, and of this, nearly 85 percent are generated from avionic systems. This would indicate a need for improved test features and/or troubleshooting techniques and equipment. In the case of the A-7D, it is suspected that the newness of the system and lack of familiarity by maintenance personnel generated an additional impact. See Figure 11.

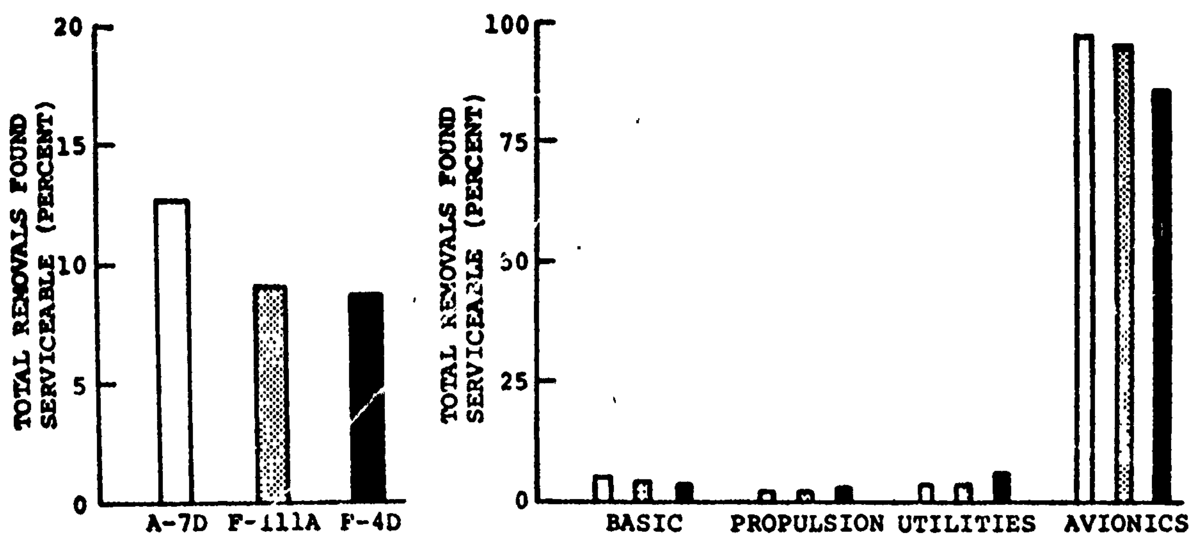


Figure 11: *SERVICEABLE REMOVALS*

b. Reliability

Tradeoff between reliability levels and support costs should be in balance with mission success requirements to achieve optimum life cycle cost. Reliability and maintainability engineering are both expensive and time consuming in terms of manhours and equipment for analysis, testing, and screening. It is not appropriate or economical to apply the same level of effort on all equipment. It is also recognized that equipment failure cannot be reduced to zero; however, application of sound reliability practices early in design will ensure low inherent failure rates and maintenance costs throughout the life of the equipment. Emphasis in this area may result in higher costs during RDT&E but any increased front-end costs are offset many times by long-term savings in manhours and material when properly applied.

Field experience data can be used successfully to identify "high cost burners" and the most promising areas for improvement in existing and new systems. Figure 12 contains examples of inflight failure distribution by airplane system groups on the three fighter aircraft studied. Studies of problem causes within each of the indicated subsystems, coupled with advances in technology, can bring about new and highly reliable designs for chronically unreliable hardware. On the A-7D, for example, the bombing navigation system alone accounted for over 50 percent of all failures discovered inflight.

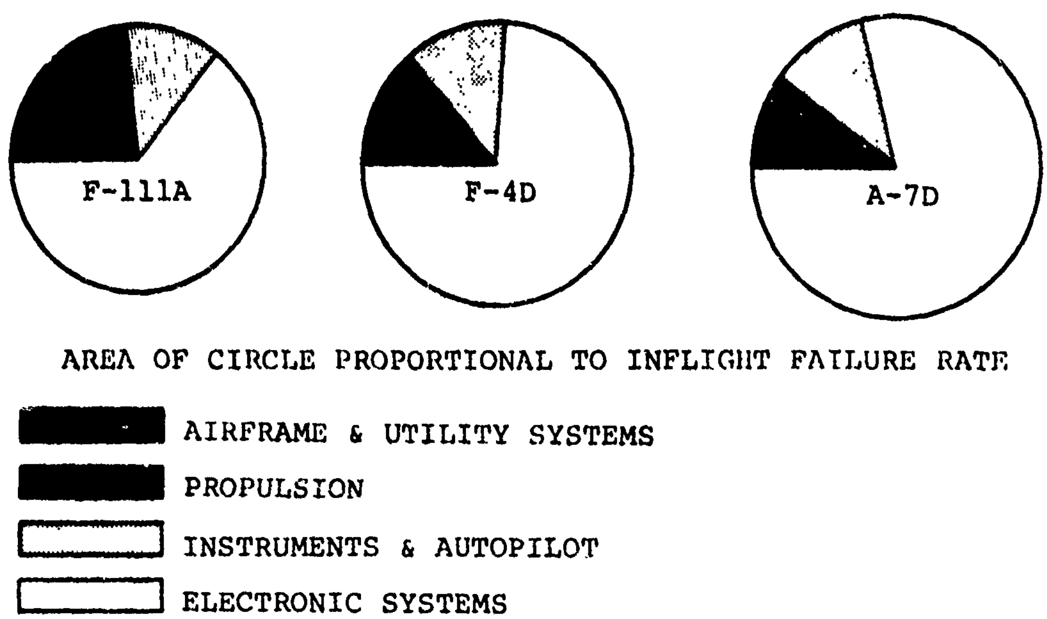


Figure 12: SYSTEM DISTRIBUTION OF INFLIGHT FAILURES

As an example of a significant reliability improvement area involving existing technology, use of electronic part testing and screening techniques can reduce failure rates by as much as five to one. Figure 13 shows a Boeing study on integrated circuit (IC) failure rates that substantiates such an improvement ratio for various levels of quality criteria. Also shown on the chart are cost ranges to achieve failure rates for the various quality levels (6).

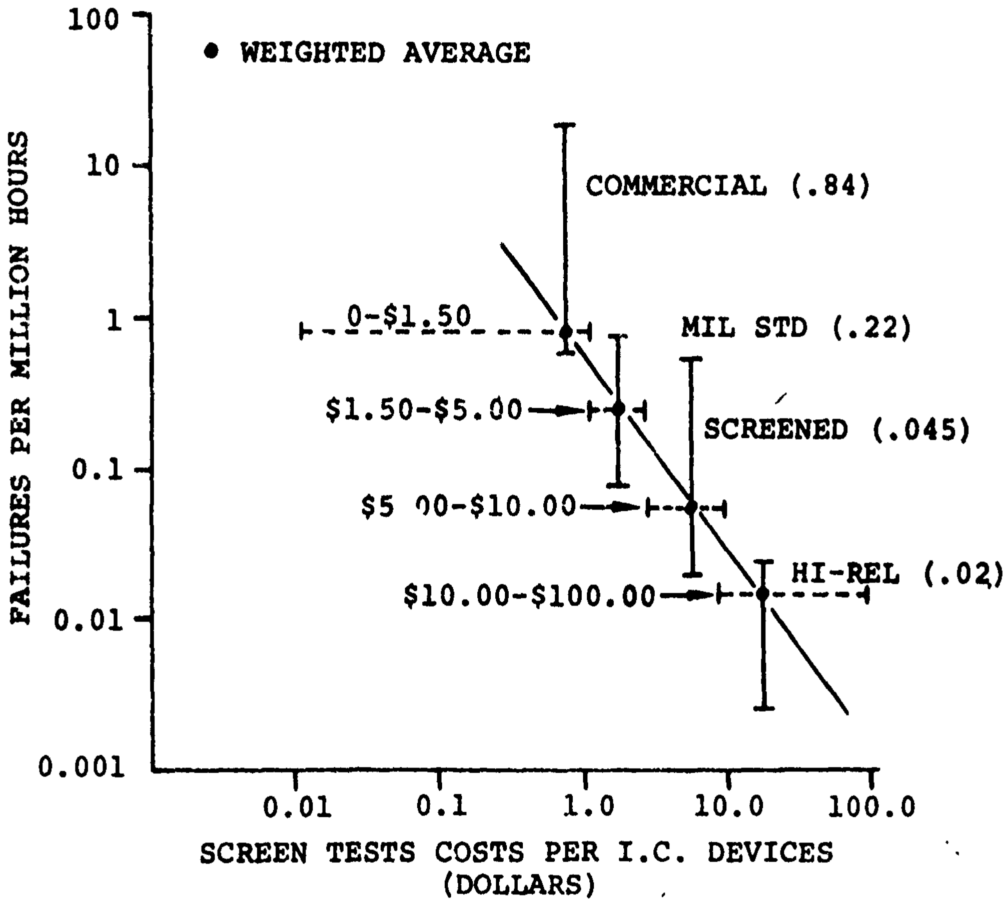


Figure 13: INTEGRATED CIRCUIT QUALITY LEVELS VERSUS COST TO ACHIEVE

As an aid in determining the amount of testing and screening to be applied, the cost of replacing the defective integrated circuits (IC's) should be considered. Figure 14 illustrates the typical replacement cost of four different quality levels of equipment (consumer, industrial, military and space) at four different stages of the life (receiving room, mounted on a board, boards installed into a system, and field use). These curves are based on a study performed by Grumman Aerospace Company in 1971 (6).

It can be seen that the initial replacement costs for parts are low, particularly for consumer equipment, in which subassemblies contain so few components that troubleshooting is easy. After the component leaves the factory, costs increase because entire subassemblies are replaced, rather than just the failed parts. The more complex the equipment, the faster the cost increases. Industrial equipment field-repair charges start at about 20 dollars per hour for a service technician, plus material. Field maintenance costs for military equipment are also high, because elaborate troubleshooting equipment and facilities are usually not available in the field.

Instead spare subassemblies are carried, entire subassemblies are replaced, and faulty modules are shipped back to a central repair facility. The inventory of spares adds to replacement cost. Replacement costs of a spacecraft in orbit are essentially equal to the cost of the entire mission, if the mission aborts as a result of the module failure.

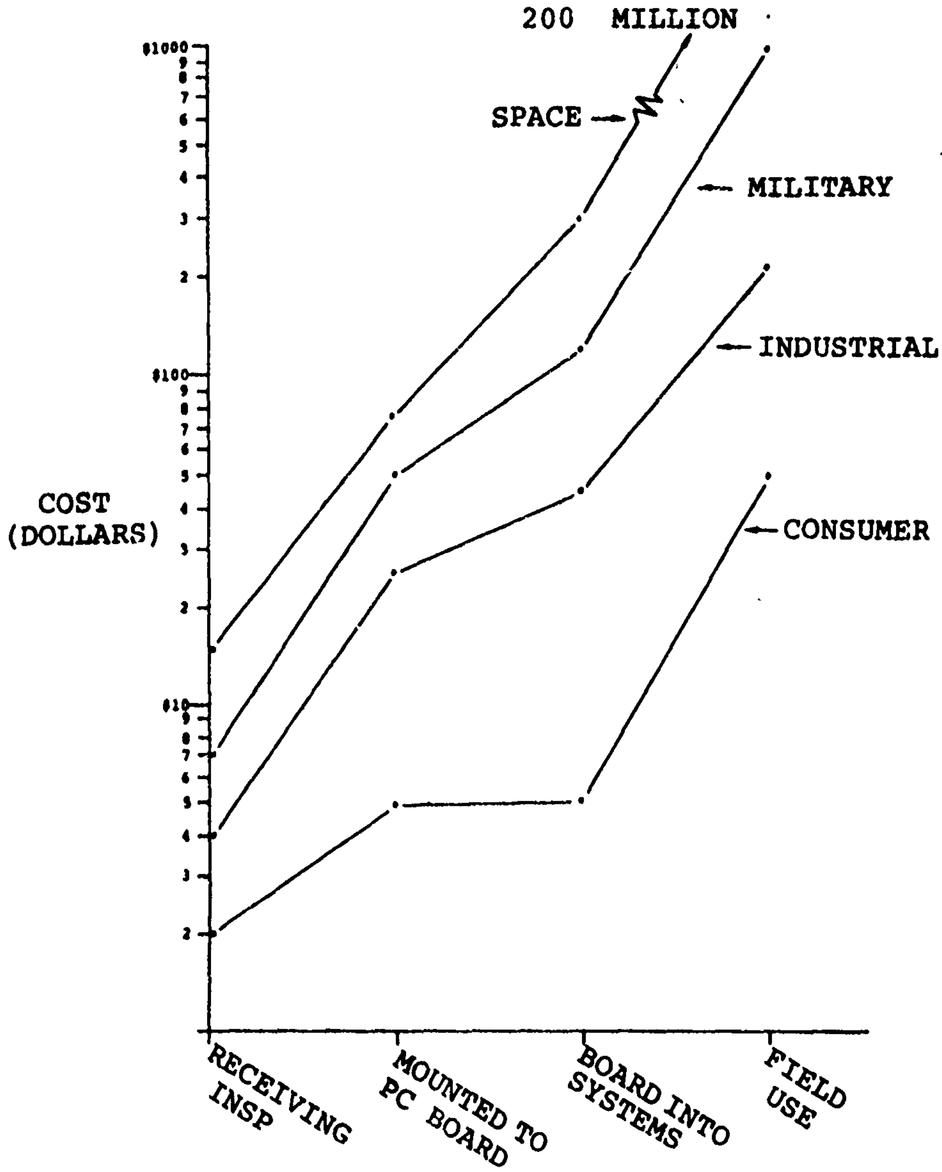


Figure 14: INTEGRATED CIRCUIT REPLACEMENT COST

Although big gains in system reliability can be made by elevating part quality levels, this is only one of several available approaches to system improvement. Others include design simplification (contrary to the current trend toward increasing system complexity), and reduction of part application stresses such as voltage, power, and temperature. In many designs the cause of failure can be traced to high application stress levels. Such abuse can degrade the reliability of the system even though high reliability parts have been used. Continued study of historical problem data is needed so that design misapplications can be identified and reduced through improvements in the standards and specifications that control the design.

Once a design has been created on paper, controls are needed in production and test of the hardware so that high reliability will, in fact, be built in. Test programs, accompanied by aggressive failure reporting and corrective action, must be conducted to disclose weaknesses that still exist in the design, or that have been induced in the manufacturing process. Temperature cycling is especially critical. In fact, an excellent means to catch incipient failures in the factory is to require temperature cycling of each black box before delivery. Test data from seven companies shows that 6 to 10 temperature cycles are required for the elimination of incipient defects. Six cycles appear adequate for black boxes of 2000 parts, while 10 cycles are recommended for equipment containing 4000 or more parts (7). Such test programs give the hardware an opportunity to grow toward its full reliability potential before it is committed to the field.

Figure 15 illustrates the part failure distribution of failures found during F-111 early Agree testings (8). These tests can provide valuable insight to failure causes and direction for corrective actions to obtain desired reliability.

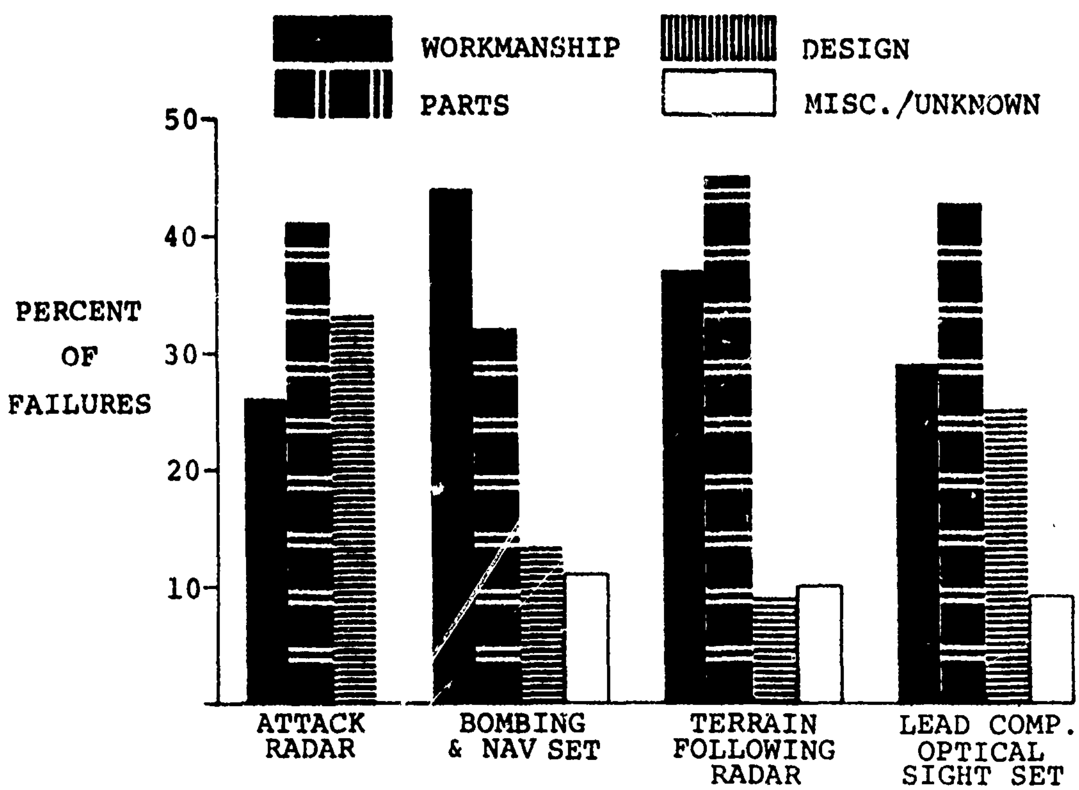


Figure 15: F-111A EARLY AGREE TEST PART FAILURE DISTRIBUTION

To illustrate the effect of growth, Figure 16 shows three hypothetical cumulative cost curves for systems with the same beginning failure rates, but with different amounts of growth.

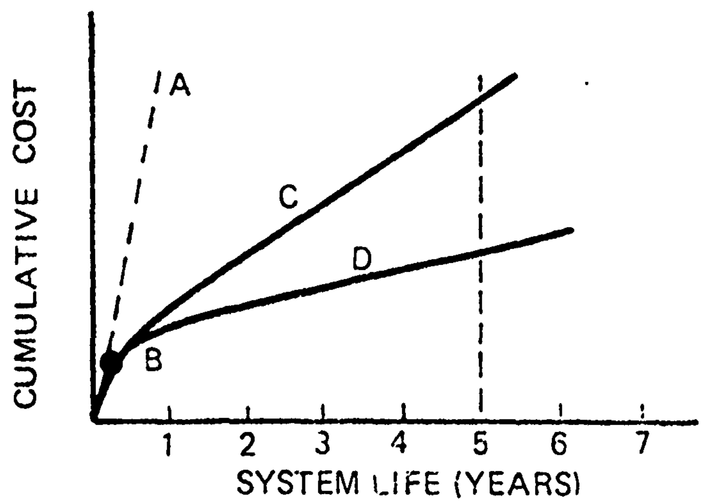


Figure 16: EFFECT OF RELIABILITY GROWTH

Curve A represents the initial rate of failure and shows how cost would skyrocket if there were no debugging or growth. Because there is debugging, the cost curves actually round off to point B. Curve C undergoes no inherent reliability improvement. In Curve D, however, we assume that an effective corrective action system employed early in the system life results in an expenditure rate of less than half that of Curve C.

In actuality, debugging and growth occur simultaneously in military systems and continue into the operational phase because corrective action programs are employed. History shows, however, that there is much room for improvement, and the earlier the improvement is achieved the greater the benefit will be in life cycle cost reduction. For the extremely long system lives, required today, additional effort to promote reliability growth early in the system life will be cost effective.

To determine the effect of reliability on requirements for spare parts, an analysis was conducted on the increased reliability on the cost of provisioning and replenishing a hi-value aircraft spare for an aircraft fleet over a ten year (life cycle) period. The cost was determined for a

10,000 dollar spare with varied mean-time-between-failure (MTBF) of 50 hours to 800 hours using the baseline reflected on Figure 17.

An important point indicated in the chart is the rapid change in support cost for a component with an MTBF of less than 300 hours and conversely, the great potential for cost avoidance in new equipments. This cost estimating relationship can be used regardless of the ground rules for failure criteria. Discussion of high failure items in later sections are based on those items with an MTBF of 300 hours or less.

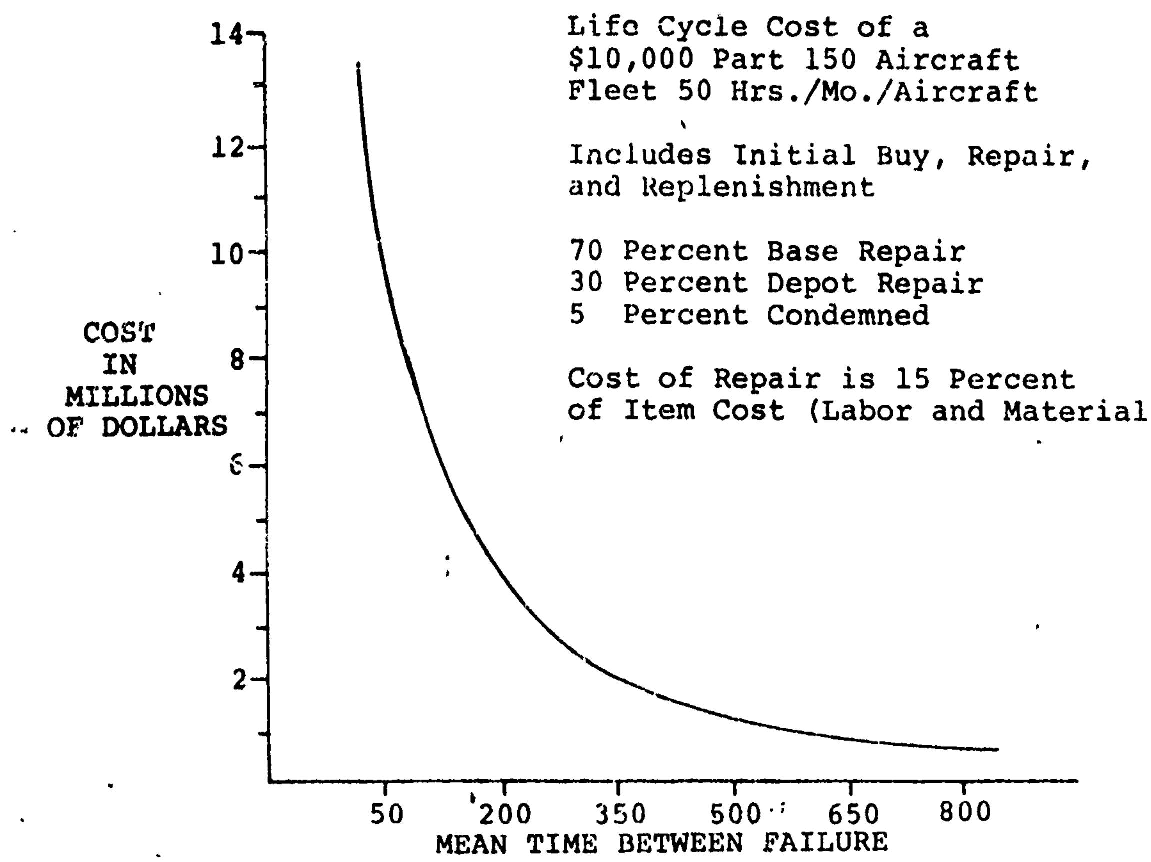


Figure 17: RELIABILITY VERSUS SPARES COST

c. Safety

During the past seven years, an average of 256 major and 75 minor aircraft accidents per year have occurred in the United States Air Force. These accidents have resulted in an average of 282 fatalities, 207 destroyed aircraft, and a minimum annual cost of over 342 million dollars. These statistics verify the tremendous potential savings available through a sustained accident rate reduction, and lower attrition rate. Figure 18 shows the accident rate trend for USAF jet fighter aircraft for a ten year period, along with the two major cause factors; material and personnel. These two curves show that steady improvement has been made in reducing material failure accidents while accidents as a result of pilot and maintenance error have remained relatively constant. Additional cost reductions could be obtained through improved training of new personnel entering the service and would help to lower this trend. Even though the cost for training pilots and maintenance personnel is high (about 150,000 dollars for pilots and 8,000 dollars or more for a maintenance technician), the potential saving in aircraft and equipment, not to mention human lives, is in the millions of dollars.

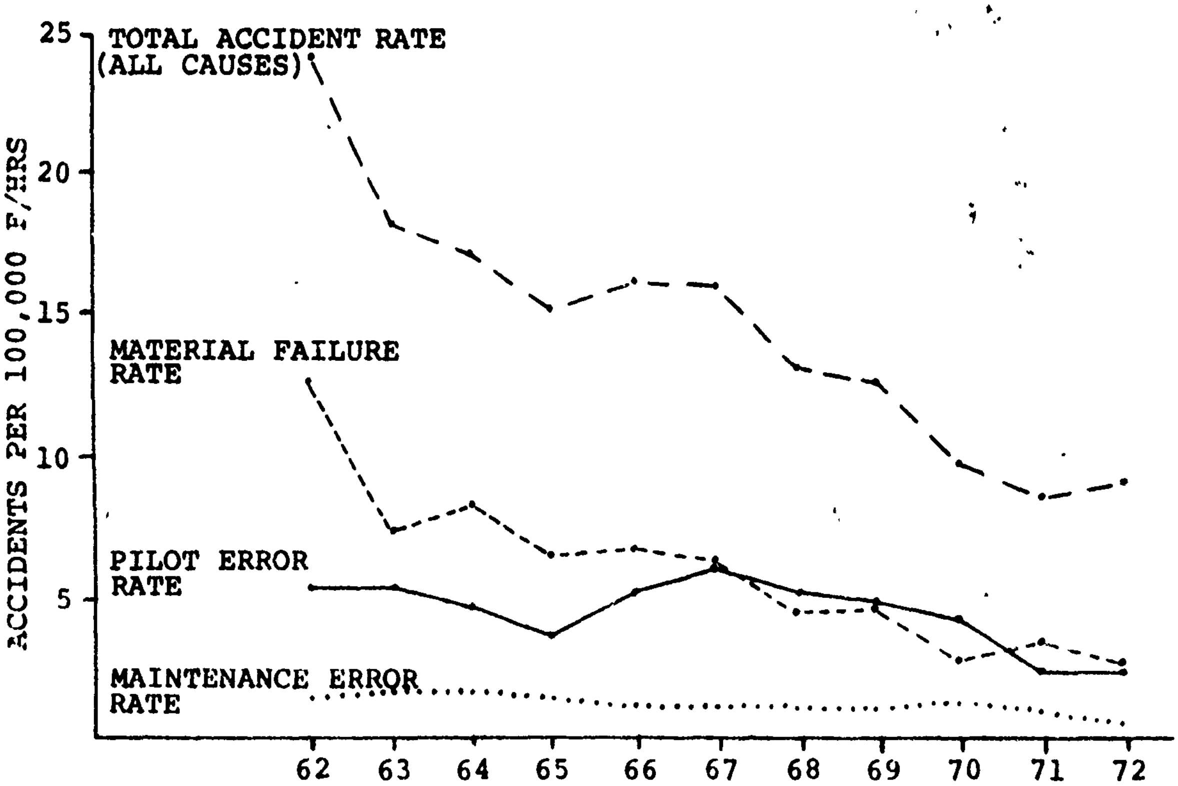


Figure 18: USAF JET FIGHTER ACCIDENTS BY MAJOR CAUSE FACTORS

Analysis of past accident statistics from the Air Force Safety Information Center indicates that design configurations pertaining to landing speed also affect accident rates. Figure 19 shows how the landing accident rate varies with landing speed for various fighter aircraft. As indicated, the A-7D and F-111 aircraft which incorporate current state-of-the-art in flaps and low landing speed characteristics show the lowest accident rate for this phase of flight. Other characteristics such as two engines for the F-101 and "angle of attack" in the case of the F-102 and F-106 appeared to have little impact on this trend.

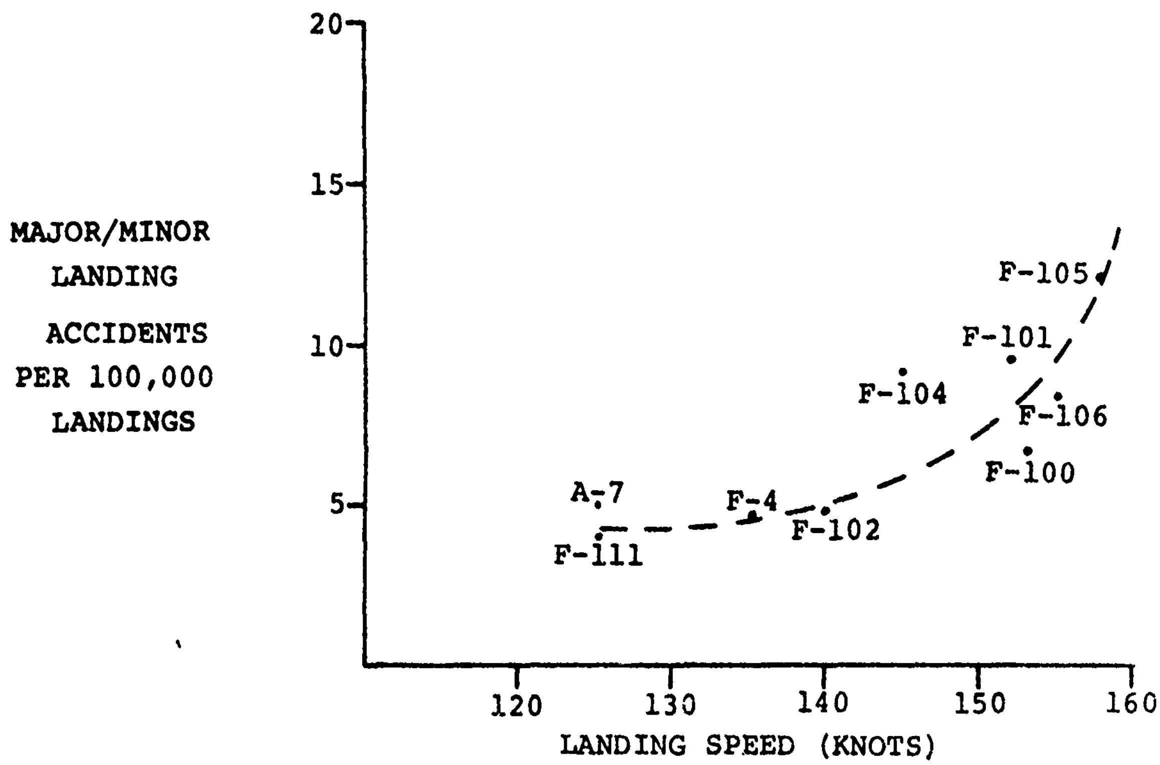


Figure 19: FIGHTER AIRCRAFT LANDING ACCIDENT RATES

Consideration of these safety drivers during conceptual studies and preliminary design, plus application of system safety engineering throughout the design process, would no doubt reduce the number of material failure accidents during the test and operational phases of the aircraft life cycle. Fault tree analysis, one technique frequently used by system safety engineers, applies the "what happens if" game, resulting in an in-depth systematic study of each part in a component, each component in a subsystem and each subsystem in a system (9). Application of fault tree analysis on flight-critical systems such as flight control, electrical and hydraulic power, has been used successfully on recent commercial aircraft and appears to have had rewarding results toward maintaining a lower than normal in-service accident rate.

d. Manning

Introduction of a new weapon system into the operational inventory requires careful definition of personnel manning requirements, including consideration of certain capabilities, skill levels and mixes, and educational levels of the personnel who will operate and maintain the system.

Aircrew manning is based on the number of aircraft assigned, the number of crew positions required per aircraft, and a crew ratio factor (1). The normal crew ratio for tactical fighter operations in peacetime is 1.5. The crew ratio additive allows for normal operations when some crew members are not available for flying duty, i.e., leave, hospital, etc. When flying hours are increased above that for normal operations, the crew ratio is increased to allow for additional aircrew manning.

Ground crew manning for direct support personnel is primarily a function of maintenance manhours per flying hour, the number of flying hours scheduled, and the number of aircraft assigned. Direct support requirements are expressed in manmonths based on 142 available hours per month per man (85 hours per month direct productive time). There is an additive factor of 10 percent allowed for Chief of Maintenance Staff functions (Workload Control, Quality Control, Maintenance Analysis, etc.) Base support manning (Medical, Civil Engineering, Supply, etc.) are in turn established from direct maintenance manning requirements. Standard manning factors are contained in AFM 26-3.

Direct utilization of personnel for flying and maintenance is the result of the quality levels achieved in hardware reliability, maintainability, safety, and the maintenance concept employed. Ideally a squadron should be manned with the right number of people and skill mix to maintain a high ready condition without excessive overtime or slack time. From past Boeing studies, Figure 20 shows the effects that reducing direct support maintenance personnel has on the operational ready rate.

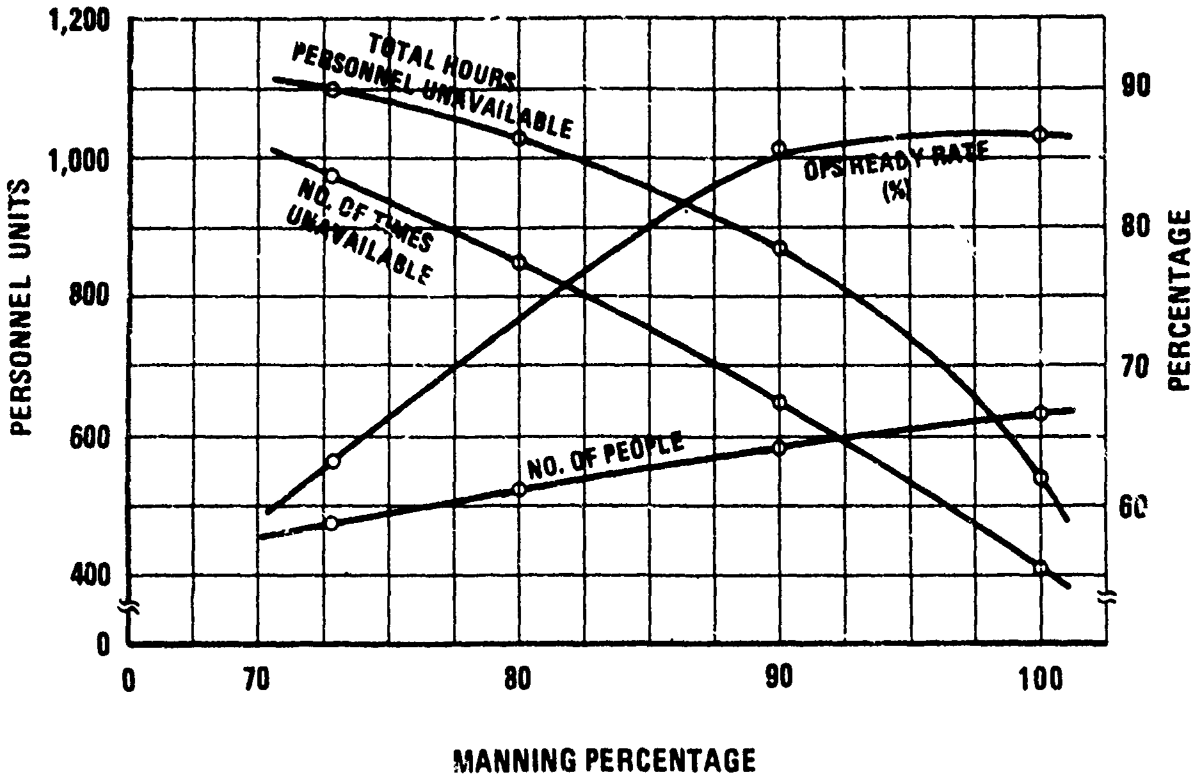


Figure 20: PERSONNEL IMPACT ON READY RATE

The chart is the result of a computer simulation accomplished within Boeing and reflects the relationship of the number of maintenance personnel to the number of times these people were not available, over a 60 day period, to perform a task for existing manning and maintenance concepts (10). A decrease in the manning level to the percentages noted increased the total queues sharply. Reduction in personnel, therefore, without improved reliability or maintainability features, changes in maintenance concept or improvement in other areas could degrade the operational ready rate as shown.

As indicated in Figure 4 earlier in the report, cost for manning is an overwhelming driver of O&M cost and has major impact on total life cycle cost. The trend for increasing salaries and a voluntary service will worsen this condition unless entirely new concepts are developed. Preliminary trade studies on numbers of people and equipment availability, dependablity, and training indicate that sizeable reductions in maintenance manning costs are feasible providing the using command can afford some wait time for maintenance during peak loads. Commercial airlines and contractor maintenance have demonstrated a higher availability of equipment with 30 to 40 percent fewer people for example. As with equipment/system design, it may be cost-effective to spend more during the early part of a man's career and retain him longer, or hire fewer people already trained and looking for a lifetime job. Because maintenance personnel presently comprise approximately one-third of all the people in the Air Force, new concepts such as these should be further evaluated; they could result in substantial cost reductions for both existing and new weapon systems.

e. Training

Complete and adequate training is a major influence on program costs from the development phase through the entire life cycle of the equipment. The major cause factors of USAF fighter aircraft accidents (see Figure 18) indicates that the reduction of accidents has taken place as a function of a lower material failure rate, with little improvement in human error.

A previous Boeing in-house study on human error in field operations on nine programs revealed that the incidence of human error resulting in subsystem or system degradation ranged from 20 percent to as high as 85 percent. Figure 21 also shows how the percentage of total equipment failures decreased during the first six months of manufacturing, and the first four years of operational service on a new system.

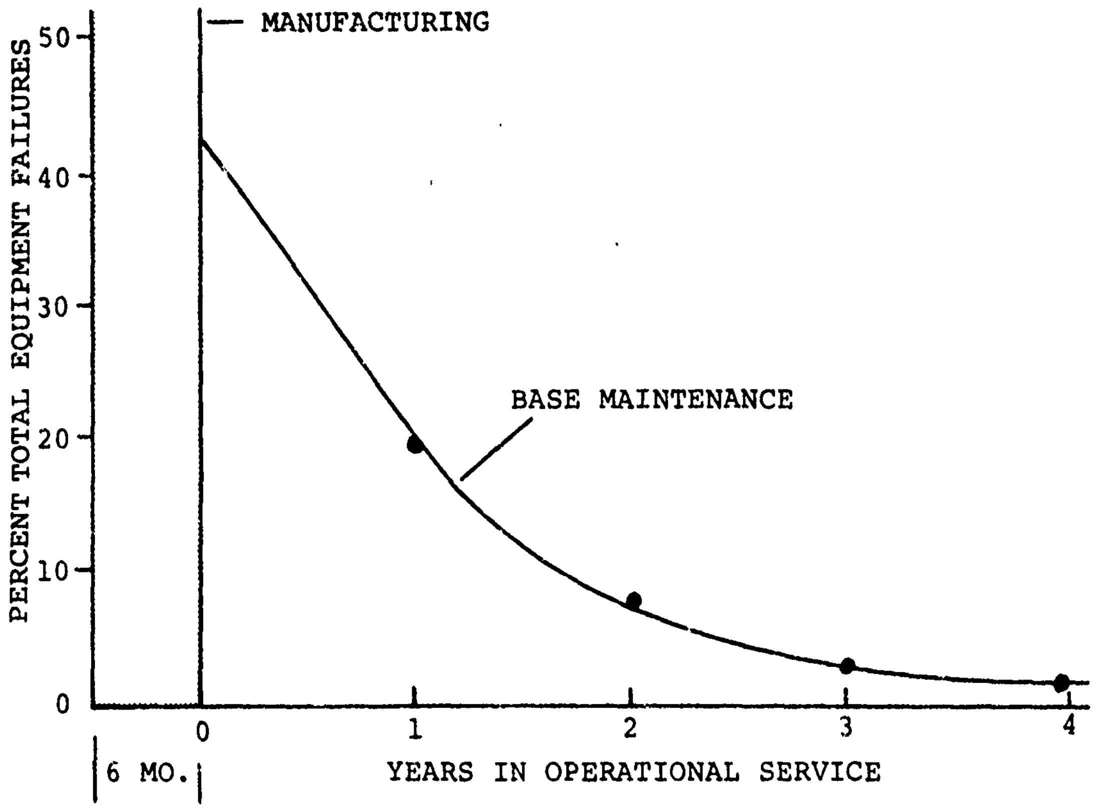


Figure 21: WORKMANSHIP IMPACT ON EQUIPMENT FAILURE

The statistics mentioned are measurable and require attention but an even greater potential support cost savings is the increased maintenance effort required (probably not quantifiable) because of incomplete training. As indicated earlier, maintenance personnel comprise approximately one third of all USAF personnel and account for a large portion of the life cycle cost dollars. It is important, therefore, that additional emphasis be placed on maintenance training, starting early in the program, to provide the best possible trade between numbers of people and training and to reduce this cost. New concepts and new hardware are under continuous development. As a result, the Air Force will continue to introduce new equipment with its hazards and incipient failures. There is also little likelihood that the basic caliber of personnel entering the maintenance system will improve under the present system. Training, under any concept, must be an instrument to mold the unskilled into an effective work force.

In addition to the reduction in maintenance manhour expenditures that could be gained through improved training techniques, a reduction in aircraft attrition rates through reduction in human error is also possible. See Figure 18. A Boeing study (10) of aircraft accidents revealed that in recent years, at least 21 jet and an unknown number of reciprocating engine aircraft have crashed under conditions having several elements in common; all were nighttime approaches to well lighted metropolitan areas; the final approach leg was over a relatively large expanse of dark terrain or water; and the pilots had requested and received clearances to transition from instruments to visual flight rules (VFR). The study revealed that accidents continue to occur under night visual-approach conditions with highly instrumented aircraft. The visual angle which provides information to the pilot was considered. It was found there is a specific flightpath in which the visual angle subtended by the city remains constant. See Figure 22. If the airplane is maintained on this path, the pilot may be losing important closure information without being aware of it. The study concluded that night visual-approach problems may occur with highly instrumented aircraft when such factors as light pattern and topography provide misleading visual information.

Inclusion of these factors in training and proficiency curriculum can help to reduce pilot-error accidents.

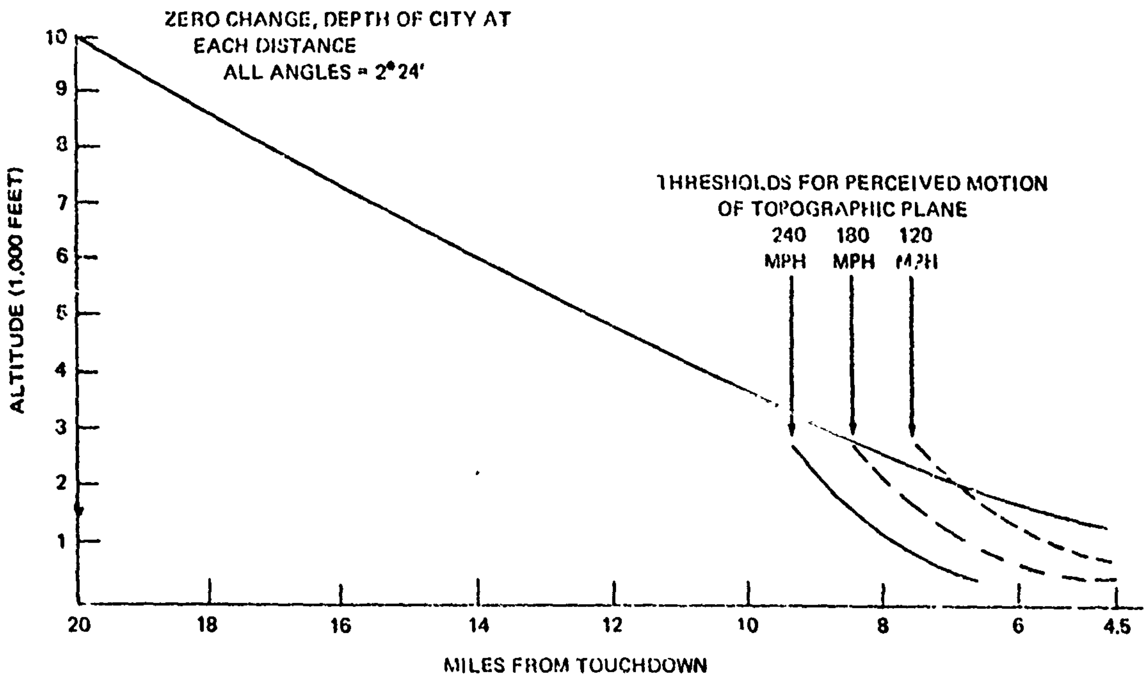


Figure 22: ZERO CHANGE APPROACH PATH AND THRESHOLDS PERCEIVED MOTION

f. Technical Publications

Technical publications serve as the communications link between the designer and the operator. Development and preparation of the major technical publications (operator handbooks, equipment manuals, and maintenance manuals) for new programs is a major support cost. The effectiveness of the publication impacts the cost of ownership throughout the life of the equipment. This impact can be measured in terms of accidents, incidents, time required for fault isolation, and time to repair. Figure 23 shows the relative involvement of the three major types of technical manuals in the accidents, incidents, and hazards reviewed in a Boeing study on this subject (12).

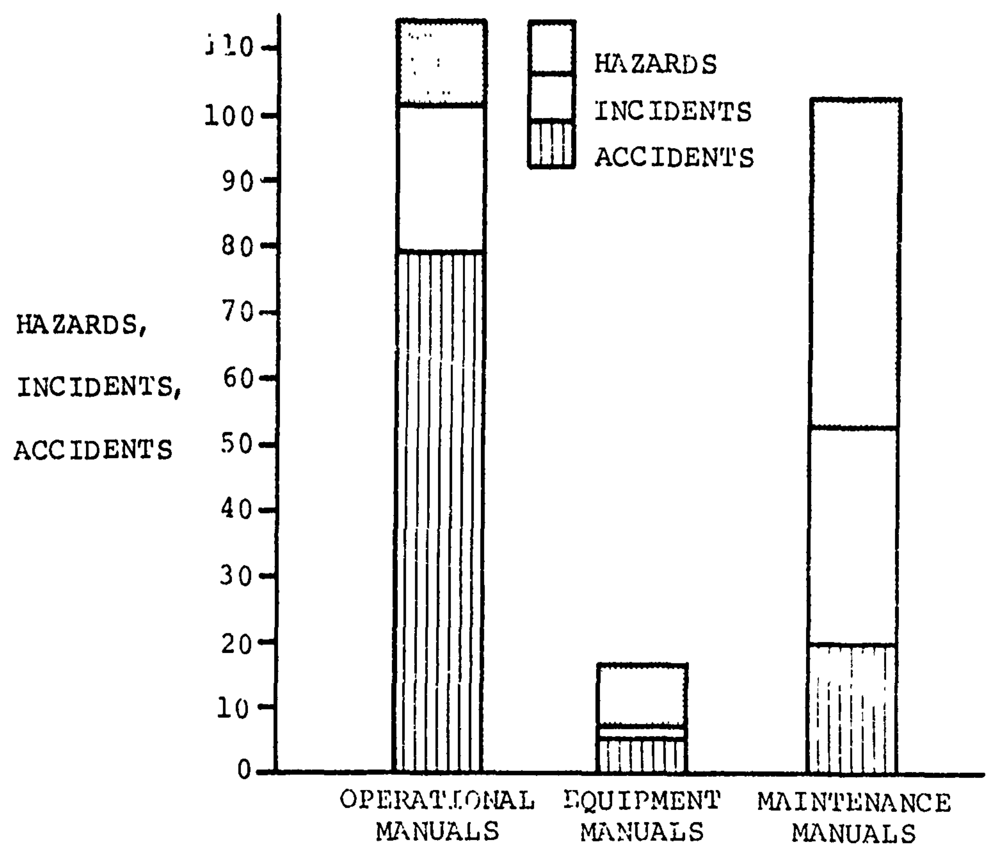


Figure 23: DEFICIENCIES RANKED BY PUBLICATION TYPE

Operator manuals (flight handbooks) are the most prominently associated with accidents, whereas maintenance manuals show a strong association with hazards. Incidents were about evenly divided between operations and maintenance manuals, and equipment manuals were seldom cited for any of the three flight-safety categories. Pilots, rightly or wrongly, are credited with the major responsibility for accidents, therefore, it is expected that their manuals would absorb the heaviest criticism from accident investigators. Because most accidents occur while the aircraft is operated, it is logical to concentrate accident prevention measures in operator manuals.

Past experience indicates that the greatest potential improvements for technical manuals are more compatible with operational, maintenance and training concepts, improved accessibility and understandability, and more rapid updating. A number of studies have been made to establish user criteria for technical manuals. Current educational levels of service personnel were related to reading ease and comprehensibility of existing manuals. A comparison of educational levels for enlisted men shows the educational level has risen and the range has narrowed in recent years. This implies a lower tolerance of material written to a level either too high or to low. The study showed that approximately 90 percent of Air Force enlisted men now have high school educations. Therefore it appears that training aids and technical manuals should be d signed for personnel with approximately 11 years of education.

A Boeing study was made to measure the readability of 12 typical Air Force manuals for three different aircraft models (11). Reading-ease scores were computed by the method developed by Rudolph Flesch. Using this method, textbook level writing that scores between 30 and 50 is defined as difficult to read while writing which scores between 50 and 60 is rated less difficult (on a level of Harper's and Business Week magazines) and considered easy reading for people with a 10th to 12th grade education. Figure 24 illustrates the results of the review. It was concluded that the manuals reviewed would be easy reading for only a minority of the intended readers. Technical manual specifications should call for reading-ease scores of at least 50, as this would be compatible with the reading skills of 90 percent of the current enlisted personnel.

MANUAL	TRANSPORT	TANKER	FIGHTER	AVERAGE
FUEL SYSTEMS	51	51	47	50 (87%)
FLIGHT CONTROLS	46	61	31	48 (25%)
ELECTRICAL SYSTEMS	50	48	40	48 (25%)
RADIO COMMUNICATIONS AND NAVIGATION SYSTEMS	39	45	23	36 (8%)
AVERAGE	46.5 (27%)	51.2 (90%)	35.2 (7%)	44.3 (39%)
NOTE: Numbers in parentheses are percentages of Air Force maintenance men for whom the material would be easy reading.				

Figure 24: READING EASE SCORES

Improved readability of technical manuals, particularly in the area pertaining to troubleshooting methodology, could result in significant reduction in support costs throughout the operations phase of a program.

A new approach presently being investigated by the National Security Industrial Association (NSIA) Subcommittee on Technical Data is the availability and use of microfilmed technical data on the flight line. This system has been tested at Homestead Air Force Base, with encouraging results. The concept uses a microfilm reader/printer and a microfilm technical order library mounted in a van that cruises up and down the flight line. This concept results in less time out from the job for manual reference, which may result in fewer direct maintenance manhours per task. In addition to making technical data more readily available and reducing maintenance manhours, the microfilm technical order concept would save an estimated 20 million dollars annually for the Air Force through the total printing and distribution process.

g. Support and Test Equipment

Support cost reduction can be achieved in the support and test equipment area through improved compatibility with the equipment it is designed to test, increased availablity and its effectiveness to fault isolate.

There have been many documented cases in which the test equipment has had wider or narrower tolerances built in than the equipment it was designed to test, thus indicating acceptable or non-acceptable performance of equipment being tested when in either case, the opposite was true. In other cases, the test equipment was improperly calibrated. Imcompatible test equipment causes additional maintenance manhour expenditures, extended periods of downtime, and degraded system performance. Results of test equipment unavailability because of failure are obvious. Also, if the test equipment is ineffective for troubleshooting, it will not be used.

A trade study within Boeing (3) indicated that little savings result from the reduction of the quantity of AGE items without an adversely affecting operational ready rates and sortie departure rates. Consideration should be given, however, to upgrading AGE reliability at least to or above the level of the equipment being tested or supported. Automatic Test Equipment must be designed with the user in mind, because he is usually a semi-skilled technician with generally no more than a high school education. As weapons systems become more complex, so does the test and checkout equipment to support it. It is necessary, therefore, that AGE receive the same emphasis on reliability, maintenance, and the man-machine interface during initial design as does the weapon system itself.

Air Force investment costs in automatic test equipment hardware approached two billion dollars in 1970, and it was estimated that an annual budget of over 80 million dollars would be needed for the next decade (13). This does not include the software costs. It is therefore advisable that the entire area of test and checkout techniques and related hardware be examined to identify areas where technological gaps exist, and where potential cost savings can be accomplished.

h. Supply and Transportation

Operational readiness and efficient maintenance depend on the availability of supplies at the proper time and place. Supply support is essential to total integrated logistics support. The prediction of the number of spares or spare parts is a problem recognized in almost every publication on Integrated Logistics Support planning. This was again confirmed in a 1972 Comptroller General Report to Congress in which an investigation revealed that nearly 10 million dollars worth of excess F-111 spares had been purchased under the initial provisioning program because actual use did not meet projections (14). Use of experience data from other related programs and an effective data collection and feedback on spares usage early in a program to verify and adjust spares provisioning for follow-on production buys could result in substantial dollar savings.

Another method of achieving significant cost savings may be for the procuring agency to purchase selected subsystems, components or spare parts directly from the manufacturer, rather than through the weapon system prime contractor. In a recent report, it was estimated the Air Force paid a prime contractor a markup of 56 million dollars on 291 million dollars worth of spare parts (14). This method can sometimes backfire. Effect on configuration management, engineering change proposals (ECP's) and the integrated support program must be carefully considered to prevent adverse effects and false savings.

Figure 25 illustrates the amount of the operations and maintenance costs consumed by replenishment spares. For the purpose of this study, airframe, avionics, and engine spares were assumed to be equal in cost percentage, because AFM 173-10 does not give a detailed breakdown of the spare costs. This probably is not the case for most current programs. The percentages for modification spare parts, AGE spares and material (consumables), however, are based on AFM 173-10 planning factors. Substantial reductions in replenishment spares costs can be achieved through increased component reliability, as shown in Figure 16.

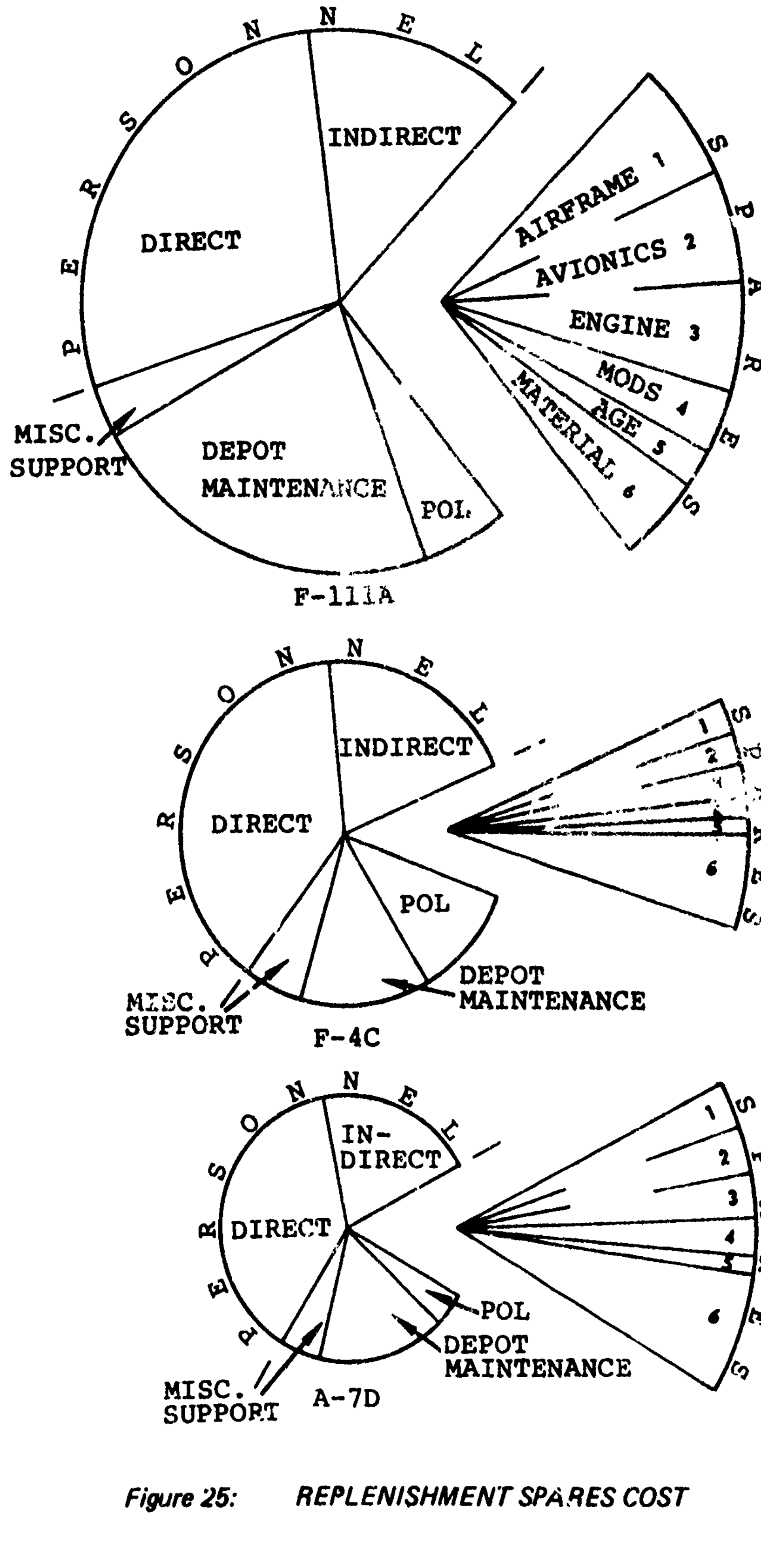


Figure 25: REPLENISHMENT SPARES COST

Although initial spares are a fraction of the total weapons system cost, more accurate initial spares provisioning could save millions of dollars on new programs. As an indication of the amount of money involved, Congress, during the fiscal years 1968 through 1970, appropriated over one billion dollars to the Air Force for initial spares provisioning on new programs.

SECTION IV

SUPPORT COST ANALYSIS

This section discusses field experience data, support improvement objectives, and potential cost reductions as a result of these improvements. A cross-section of experience collected by the Air Force 66-1 data system on the F-4D, F-111 and A-7D aircraft was used as the data base for this analysis. The data was evaluated to identify where high support costs were being generated. Equating these high support cost candidates to known state-of-the-art advancements, improvement objectives were established and applied to cost factors from AFM 173-10 to arrive at a overall cost reduction per squadron per year for each of the three aircraft.

1. FIELD EXPERIENCE DATA

To reduce time and cost in performing this study, it was agreed by the customer that field experience data already on-hand and processed for analysis would be used. The AFM 66-1 data previously received had been processed through 13 basic computer programs. This process provided individual incremental printouts which permitted detailed validation and correction as necessary, to such items as work unit codes, record count, manhours, failures, cause of equipment removal, etc. Therefore, the data used in the analysis for this report had been upgraded from the raw data initially provided to The Boeing Company from the bases through AFLC.

The data base used consisted of the following:

AIRCRAFT MODEL	NUMBER AIRCRAFT	NUMBER OF FLIGHT HOURS	DATA TIME PERIOD
F-4D	240	58,480	Jan-Sep '69
F-111	56	13,950	Jan-Jun '69
A-7D	120	38,508	Mar '71 - Feb '72

The traditional Boeing approach was used to identify high support cost or potential high pay-off areas. This approach consisted of evaluating the data using five criteria; failures, aborts, removals, maintenance manhours per flight hour and troubleshooting times to evaluate the overall aircraft, each system in the aircraft and each component within those systems as illustrated in Figure 26.

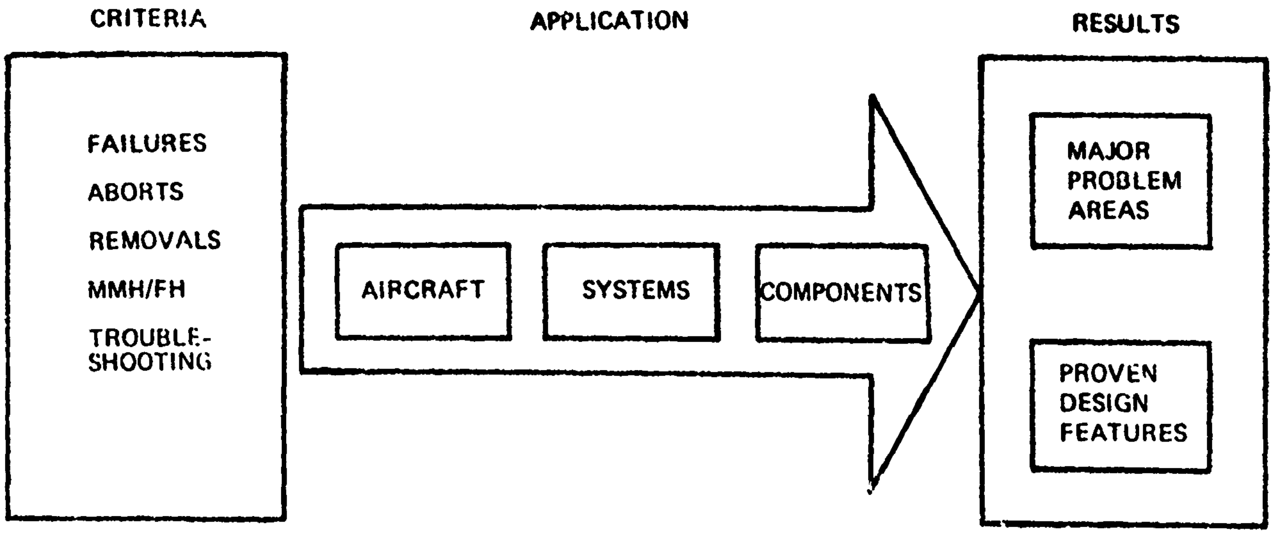


Figure 26: ANALYSIS APPROACH

One of the computer programs used in this analysis was a ranking program that arranged the data for each of the five criteria by work unit code, by aircraft system for each of the three aircraft. This listing shows the data in descending order of number of actions for each of the five headings beginning with the highest number to display a graphic presentation as well as a statistical correlation of potential maintenance and reliability problems at the system and component levels. Figure 27 shows an example of this output.

F-111(T)US ON EQUIPMENT AND SHCP PRIORITY
JAN 69 - JUN 69

13,950 FLIGHT HOURS

SYSTEM 14

REMOVALS		FAILURES			MANHOURS			TROUBLESHOOTING			ABORTS	
WUC	UNITS	WUC	TOTAL UNITS	ATTACH PARTS	WUC	TOTAL HOURS	SHOP HOURS	WUC	TOTAL HOURS	SHOP HOURS	WUC	UNITS
14EAE	69	14CEA	68	5	14E00	2004.2	5.5	14D00	188.1	.0	14ECA	13
14EAA	61	14FAC	68	15	14FAD	919.4	6.3	14DBA	154.3	3.0	14E00	10
14HAM	34	14EDO	67	2	14BCA	646.5	28.7	14E00	149.3	.0	14DBA	9
14BCA	30	14ECA	64	12	14GDA	604.3	4.3	14000	95.8	.0	14EAA	9
14HAA	28	14EAE	64	13	14DBA	603.2	25.6	14A00	65.3	.0	14EAB	8
14ECD	27	14ECE	59	40	14D00	592.6	.0	14GBA	57.5	34.8	14D00	8
14CBD	26	14FAG	58	5	14EAA	563.9	9.3	14G00	40.3	.0	14DCA	8
14BCB	22	14ECD	57	16	14EAE	540.3	61.4	14FAD	38.9	.0	14FAD	7
14GDB	21	14ECF	51	12	14FAG	453.4	43.8	14EAA	34.6	.0	14ECD	6
14GDA	19	14DCR	46	45	14ECA	430.8	5.2	14HAM	31.0	.0	14BCC	6
14DCN	18	14DCC	44	25	14BDA	425.3	127.9	14FAG	30.0	.0	14ECF	5
14DBA	16	14BDA	42	26	14BCB	386.2	33.7	14ABB	30.0	.0	14HAD	5
14ECL	15	14ECH	39	10	14ECD	354.1	5.6	14EBB	29.4	.0	14000	5
14ECM	13	14BCA	37	7	14000	339.0	.0	14B00	29.0	.0	14HAM	4
14ECQ	13	14CBC	36		14GCA	299.9	.0	14HAR	27.4	.0	14ECP	4
14HAB	13	14ECJ	34	14	14ECF	285.7	10.8	14CCD	24.5	.0	14ECM	4
14BDA	13	14EBE	33	1	14EBB	283.6	26.4	14FAC	24.1	.0	14BCB	3
14HAD	12	14ECM	33	14	14CCA	276.8	57.0	14B[illegible]	22.6	.0	14EAE	3
14FAD	12	14ECG	32	19	14CBA	275.6	13.6	14DBB	15.5	.0	14HAH	2
14ECP	11	14HAM	31		14HAA	271.0	24.9	14HAN	14.8	.0	14HAB	2
14ECF	11	14ECC	28	20	14ECB	267.9	91.7	14FAA	13.5	.0	14FAE	2
14EAD	10	14B[illegible]	28	14	14ECH	246.1	7.0	14CBA	12.5	.0	14EBB	2
14DCU	10	14DCA	27	16	14BDB	237.3	110.1	14ECA	12.0	.0	14DAF	2
14FAA	10	14EAA	26	3	14DCL	226.6	6.2	14CDA	12.0	.0	14DAE	2
14DCJ	9	14HAH	22		14HAM	224.3	50.8	14ECA	11.8	.0	14DAB	1
14FAG	9	14ECB	21	8	14ECE	219.7	25.6	14GCA	11.2	.0	14AFE	1
14EAB	9	14FAC	20	5	14ECM	216.1	.6	14HAJ	10.7	.0	14BB9	1
14ECH	9	14EAB	20	1	14ECJ	210.0	8.2	14AFB	10.0	.0	14B00	1
14ECC	9	14ECQ	19	3	14HAH	205.8	.3	14DAB	9.0	.0	14ECJ	1
14ECK	8	14FAA	18	5	14HAB	203.2	26.8	14HAB	8.5	.0	14ECH	1
14BAA	8	14HAN	17		14GBA	191.6	66.3	14FAE	8.0	.0	14DCK	1
14DAE	8	14BCB	17	2	14ECC	183.1	.0	14CA9	8.0	.0	14EC8	1
14DCM	8	14DCJ	17	4	14ECP	181.1	5.9	14DAL	8.0	.0	14FAC	1
14DCF	7	14HAL	16	1	14ACA	178.1	9.5	14HAG	7.3	.0	14HAN	1
14CAA	7	14GCA	16	9	14FAA	174.0	.0	14GA9	6.0	.0	14FAA	1
14DCD	7	14DCB	14	12	14DAE	173.1	2.1	14DAE	5.6	.0	14C9B	1
14EC9	7	14ECP	13	2	14HAN	166.8	12.2	14CAE	5.5	.0	14FAG	1
14HAJ	6	14HAB	13	3	14GDB	163.1	.0	14DCM	5.3	.0		
14EC8	6	14DCM	12	7	14FAC	153.7	.5	14GDD	5.0	.0		
14DCV	6	14DCF	12	4	14CBD	151.1	9.3	14FOC	5.0	.0		
14ECE	6	14CCA	12	9	14G00	148.1	.0	14ECC	4.0	.0		
14BDB	6	14FAE	12	10	14ECQ	144.4	.5	14HAD	3.5	3.0		
14BD9	6	14EAC	12	11	14DAB	143.3	2.4	14CBC	3.4	.0		
14DAB	6	14EAF	10	1	14ECG	140.1	30.0	14BEA	2.8	.0		
14DAA	5	14EC9	10	4	14DCJ	140.0	71.4	14ECB	2.3	.0		
14CBB	5	14BCC	10	10	14CDA	139.3	65.5	14ACB	2.3	.0		

14DBB : FLAP SYSTEM ASYMMETRY DEVICE, FLAP DRIVE MECHANISM

Figure 27. EXAMPLE OF FIELD DATA RANKING REPORT

Figure 28 shows graphically the results of this analysis approach on the F-111. As indicated, a low percent of the work unit codes, or equipment items, generated a high percent of the effort in each of the five criteria areas.

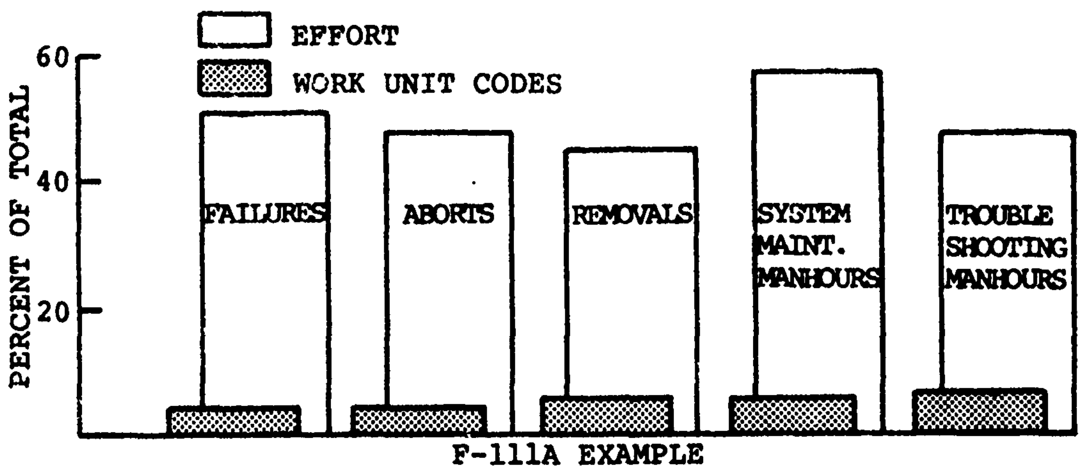


Figure 28: PROBLEM IDENTIFICATION

The tabulation below highlights the results of these statistics in the failure category.

AIRCRAFT MODEL	PERCENT OF TOTAL WORK UNIT CODES	EQUIVALENT NUMBER OF EQUIPMENT ITEMS	PERCENT OF SYSTEM FAILURES
F-4D	2.6	88	49.1
F-111	2.0	88	49.5
A-7D	1.8	57	55.0

For the purpose of this study, emphasis was placed on component reliability. Based on the trend reflected in Figure 17, all components with an MTBF of 300 hours and below were considered candidates for improvement.

To assist in this part of the analysis, another ranking program was written to provide a priority listing of the top 400 components (work unit codes) in failures and manhour rates per 1000 aircraft flight hours for each of the three aircraft models. Table I shows an example of this listing.

TABLE I: COMPONENT RANKING LIST

PRIORITY LISTING OF TOP 400 WORK UNIT CODES

FAILURES RANK	WUC	RATE	MAINT. MANHOURS RANK	WUC	RATE
1	75AB0	43.154	1	23000	687.240
2	75DAC	42.437	2	73AB0	596.272
3	23VFA	33.118	3	73DB0	472.043
4	73DB0	31.183	4	75AB0	348.029
5	73AB0	23.441	5	73AA0	299.857
6	23SBB	20.502	6	11BAB	299.211
7	13GBG	15.269	7	23XAD	271.756
8	75ABD	15.125	8	52BAA	261.147
9	13GAH	14.624	9	73DAA	216.129
10	23VBA	13.405	10	73BD0	211.828
11	11ADW	11.971	11	73B00	202.867
11	73AA0	11.971	12	71BA0	197.276
13	11ACA	11.613	13	75DAC	188.172
14	11BAL	11.541	14	73BK0	156.559
15	11ABG	11.470	15	23SAA	156.201
16	11AGD	10.824	16	73BF0	155.914
16	73DAA	10.824	17	14E00	143.656
18	73BF0	10.681	18	71AA0	141.792
19	23XAE	10.466	19	52ADA	[illegible].910
20	23YBA	10.179	20	63AA0	124.014
21	63AA0	9.892	21	23VFA	122.509
22	23XAD	9.821	22	11AHG	119.928

2. IMPROVEMENT OBJECTIVES, F-111, F-4 AND A-7D

The following paragraphs discuss improvement objectives for the high support cost areas identified from the field experience data. Improvement objectives have been established for each of the design and integrated logistic support elements which include maintainability and maintenance engineering, reliability, safety, maintenance manning, training, technical publications and support and test equipment. The magnitude of impact these improvements had on each element is summarized for each aircraft and the rationale for that improvement discussed.

It is important to note that the objective here is to demonstrate a support cost analysis technique and not arrive at figures that could be directly applied to present operations of these three fighter aircraft. The scope of this study did not permit detailed problem identification and resolution of these problems by recommended corrective action. However all assumptions are believed conservative and practical. They are based on known advancements presently in use on current military and/or commercial aircraft, or available to industry for application to new design. Total cost savings generated in this report are based on the premise that the design analysis, equipment improvements and maintenance concepts were applied during the early design phase and impacted the total operations phase through the life cycle of the aircraft to date.

Total results of these assumed improvements, in terms of maintenance manhours and failures for all the design and integrated logistic support elements for the three aircraft are summarized below:

	MANHOUR REDUCTION		FAILURE REDUCTION	
AIRCRAFT MODEL	MMH/FH	Percent	Failures/ 1000 FH	Percent
F-111	12.17	29.8	407	28.0
F-4	11.41	29.8	475	29.3
A-7D	8.77	28.6	377	33.6

a. Maintainability and Maintenance Engineering

Improvement objectives for maintainability and maintenance engineering pertain to accessibility, Central Integrated Test System (CITS), inspection techniques and maintenance concepts including structural sampling. Total savings estimated by employing these improvements are:

AIRCRAFT MODEL	MMH/FH	PERCENT REDUCTION
F-111	5.88	14.4
F-4	6.87	18.0
A-7D	4.45	14.5

(1) Accessibility

Accessibility is one of the major factors affecting maintainability and requires more consideration in high performance, compact aircraft than in larger aircraft such as transports and bombers. Figure 9 illustrates the impact of high equipment density on maintenance manhours to facilitate maintenance (gaining access). Field experience data indicates that 1.95 maintenance manhours per flight hour were expended on the F-111A to gain access and 1.94 on the F-4D. During a previous field survey, personnel in the field indicated they felt accessibility was a major consideration during design for F-111A avionics equipment, but other areas apparently did not receive the same consideration. For example, to remove and replace the auxiliary flotation pressure source, a time-change item on the F-111, the right windshield must first be removed. Examination of AFM 66-1 data indicates approximately 600 additional manhours per month are expended on the F-111 fleet for this problem. The windshield also had to be removed to replace a windshield defog nozzle. Installations such as this extends maintenance task times and can, in addition, affect failure rates of the components removed for access. Another component with difficult access is the wing sweep position transmitter. This component is located under the overwing fairing and the mounting bolts require the insertion of cotter pins in a completely blind area to maintenance personnel.

Some of the components on the F-4 having difficult access are the Brake Drive Tube which requires removal of the brake stack. This installation has resulted in nearly 3500 additional maintenance manhours per month on the F-4 fleet. Another item is the UHF receiver-transmitter which requires removal of the rear cockpit seat bucket. This design requires 2200 additional manhours per month on the F-4 fleet. Still another example of poor accessibility is the early design configuration of the aileron power control cylinders; these required lubrication with a hypodermic needle.

An improvement objective of 50 percent or 0.97 maintenance manhours per flight hour was established for accessibility on the F-111 and the F-4 aircraft. Improvements can be made in such areas as: Location of components in equipment centers based on frequency of access, mission or maintenance delay cause history and improved repairability to the airplane power systems components - electric and hydraulic, fuel flight controls, landing gear, power plant, and avionics. For example, design for flight control component replacement without need for system rerigging, replacement of fuel booster pumps without defueling the aircraft, better accessibility to the liquid oxygen converter for servicing, hydraulic lines with swaged sleeves and reconnectable joints, independent replacement of large components such as constant speed drive and generator, batteries that incorporate electrolyte level indicators so they can be checked without removal, quick change hydraulic pumps with self-sealing disconnects, and separation of equipment to allow concurrent maintenance.

Frequently, it is necessary to correct deficient design through Engineering Change Proposals (ECP's), however, this procedure is costly to the customer, particularly if maintainability guarantees have been demonstrated. Much can be saved through the prevention of these types of deficiencies by proper emphasis on accessibility and using the evidence from field experience information during the design process.

The A-7D appears more reasonable in manhour expenditures to facilitate maintenance than most other smaller dense aircraft. Review of AFM 66-1 shows that A-7D manhours to facilitate maintenance were 0.6 maintenance manhours per flight hour, compared to 1.95 on the F-111A and 1.94 on the F-4D, or approximately three times lower. Accordingly, accessibility is not considered a candidate for support cost reduction on this aircraft.

A summary of accessibility experience and improvement objectives are as follows:

AIRCRAFT MODEL	EXPERIENCE (MMH/FH)	PERCENT IMPROVEMENT	IMPROVEMENT OBJECTIVE (MMH/FH)
F-111	1.95	50	0.98
F-4	1.94	50	0.97
A-7D	.60	0	0

(2) Central Integrated Test System (CITS)

Field data indicate troubleshooting and maintenance on serviceable items (components removed, replaced and subsequently found serviceable) accounts for a substantial amount of additional maintenance; see tabulation.

AIRCRAFT MODEL	TROUBLESHOOTING MMH/FH	BENCH CHECK OK MMH/FH	TOTAL MMH/FH
F-111A	1.91	0.90	2.81
F-4D	1.22	0.93	2.15
A-7D	1.16	0.80	1.96

Figure 10 depicts the maintenance manhour expenditures and distribution of maintenance on serviceable items.

On the F-111, nearly 65 percent of the troubleshooting manhours were spent in the avionics systems. The data shows the largest portions of troubleshooting were expended on the AN/APQ-113 attack radar, AN/AJQ-20 inertial bomb navigation, AN/APQ-110 terrain following radar, and AN/ARN-52(V) tacan subsystems. Some of the high components were the tacan receiver-transmitter, CP812/AJQ-20 navigation computer, MX-6767/AJQ-20 stabilization platform, and the AS-1717/APQ-110 terrain following radar antenna receiver.

A previous field survey conducted by Boeing personnel indicated some self-test features on the F-111A were good, such as the central air data and autopilot computers, but self-test in other systems was not as satisfactory. For example, the terrain following radar self-test was considered marginal because of wide tolerances in visual indicators but small tolerances in equipment performance.

Examination of F-4C data for a data sample three years ago showed these expenditures to be nearly identical with those for the F-4D. Certain problems were associated with the F-4D: Maintenance personnel believed the test equipment to be unreliable because depot test equipment was not calibrated in the same way, in addition to being complicated, time consuming to use, and unreliable.

Although the A-7D total expenditure is lower than those of the F-111A or the F-4D, it is believed it is still excessive and can be reduced. Review of the A-7D data also shows the avionics systems were the largest consumer of troubleshooting (60 percent). The bombing navigation system alone accounted for one third of all troubleshooting and over 40 percent of the serviceable removals, indicating lengthy, time-consuming fault isolation procedures and inability to identify the proper failed component. Within the bombing navigation system, the AN/APQ-126 forward looking radar required the most troubleshooting time, followed by the AN/ASN-90 inertial measurement set.

It is estimated that a 40 percent reduction in maintenance manhours expended for troubleshooting, removal and subsequent checkout of serviceable components can be realized on the F-111 and A-7D and 50 percent on the F-4 through an efficient central integrated test system. A larger improvement is estimated on the F-4 as it reflects an earlier design state-of-the-art.

The central integrated test system approach reduces fault isolation times and increases aircraft availability (17). The increase in aircraft availability equates to a 40 percent reduction in unavailability because nearly all troubleshooting (fault isolation) is accomplished during unscheduled maintenance periods (unavailability); therefore, reduction in troubleshooting is in direct proportion to the decrease in unavailability. The central integrated test system monitors some 16 aircraft sybsystems through periodic testing by the flight crew and fault isolation to the failed line replaceable unit (LRU), in flight and on the ground.

Test equipment, to be effective, must have the confidence of the user, be simple and rapid to use, or the repairman tends to fault isolate by removing and replacing components until the failed item is located. Use of the central integrated test system is discussed further under the heading (3) Inspection Techniques.

A summary of maintenance manhours required to troubleshoot and bench check serviceable items and the objective improvement expected through the use of a system such as CITS is tabulated below:

AIRCRAFT MODEL	EXPERIENCE (MMH/FH)	PERCENT IMPROVEMENT	IMPROVEMENT OBJECTIVE (MMH/FH)
F-111	2.81	40	1.12
F-4	2.15	40	1.08
A-7D	1.96	50	.78

(3) Inspection Techniques

As shown in Figure 8, a disproportionate amount of maintenance is expended on the inspection "look" phase compared to the amount of corrective "fix" maintenance time. In the case of the F-111A, the data showed that 7.58 maintenance manhours per flight hour were expended to discover discrepancies that required 0.51 maintenance manhours per flight hour to correct. For the F-4D, the "look" phase amounts to 9.04 maintenance manhours per flight hour and the "fix" 0.99 MMH/FH. On the A-7D, the "look" phases amount to 7.35 maintenance manhours per flight hour compared to 0.97 maintenance manhours per flight hour for the "fix" portion, or a ratio of 7.5 to one.

Only a small amount of this corrective maintenance would prevent a subsystem failure because most of the inspection effort is a visual effort which identifies conditions such as leaks, dirty, and exposed mechanisms out of adjustment, etc. Latent failures within components or black boxes cannot be identified in this manner. The "look" manhour expenditures is believed to be more a function of outdated philosophy, than it is a necessity or based on hardware (aircraft) failure history.

Results of trade studies conducted within Boeing indicate that substantial improvement can be made in inspection maintenance manhours (18). It is estimated that inspection "look" time could be reasonably reduced by 50 percent on the F-111 and A-7D, and 55 percent on the F-4, because of the higher expenditures.

A summary of the maintenance manhours required to perform major inspections on these aircraft and the improvement objective expected through the application of the changes discussed are as follows:

AIRCRAFT MODEL	EXPERIENCE "LOOK" INSP. (MMH/FH)	PERCENT IMPROVEMENT	IMPROVEMENT OBJECTIVE (MMH/FH)
F-111	7.58	50	3.79
F-4	9.04	55	4.97
A-7D	7.35	50	3.67

The improvement objectives are based on wider use of Non-Destructive Inspection (NDI) techniques, and the use of a Central Integrated Test System (CITS) or equivalent. Preflight, postflight and turnaround inspections would consist only of items not monitored by CITS and items critical to flight safety and/or mission accomplishment. Phase inspection items would be based on frequency of failure (probability of finding a failure), and latent failure impact on the mission. It is apparent from the ratios of "look-to-fix" maintenance, that many items are inspected visually for which no failure exists or detection is not possible. Also reduction of the amount of inspection items and/or frequency could have a collateral effect on the number of failures and maintenance manhours required for repair of access panels and fasteners as a result of gaining access to equipment and systems.

(4) Structural Sampling

It is believed that altering the present depot IRAN (Inspect and Repair As Necessary) to an optimized frequency through the use of structural sampling, similar to that used by commercial airlines, could reduce this effort by approximately 50 percent. The suggested progressive IRAN concept is tailored after the FAA-approved 9,000 flight hour program used by commercial operators and planned for the 747 Advanced Airborne National Command Post (AANCP). The T-43 navigation trainer aircraft is also starting to use this structural inspection. For the 747 aircraft, approximately 350 stress sensitive areas were identified and analyzed for resistance to corrosion, fatigue, stress corrosion and crack propogation, in addition to the fatigue testing rating and degree of redundancy. The structural inspection requirements are Non-Destructive Inspection (NDI) sampling type and broken into work packages of four areas. Each aircraft receives two different area inspections each cycle and after two aircraft have been inspected, the entire inspection is considered complete. This eliminates the requirement to inspect all areas on all aircraft. Analysis of inspection results at any predetermined point provides insight to total fleet conditions. It may be deemed necessary to inspect hyper-critical areas on each aircraft, in some cases, such as wing pivot points on variable geometry aircraft. With a 50 percent reduction in IRAN efforts on each aircraft, the same proportion in annual depot IRAN would accrue. Typically, IRAN accounts for approximately one third of annual depot costs, therefore the structural sampling program could reduce depot costs by 16.5 percent on the F-111 and F-4.

According to Technical Order 00-25-4, Depot Level Maintenance of Aerospace Vehicles, an IRAN schedule has not been established for the A-7D. Therefore, it is considered inappropriate to estimate reductions in non-existent maintenance. The A-7D, however, presents an ideal opportunity to test the progressive IRAN concept discussed here.

b. Reliability

Increased reliability reduces the cost of spares, maintenance, facilities, and ground support equipment. Higher reliability levels also may result in the need for fewer people and could even reduce the size of an aircraft fleet that must be acquired, manned and supported. Feedback to the designer on past experience, in terms of unreliability and proven design features, is useful in achieving reliability improvement. Boeing uses carefully validated and analyzed Air Force Manual 66-1 data presented in the form of design data packages to help determine where greater improvements in design should be made.

Emphasis on reliability throughout the design process could achieve substantial maintenance cost reductions. As shown in Figure 16, large potential cost savings are available in components with a mean-time-between-failure (MTBF) of 300 hours or more. Greater cost savings can accrue through assurance of a satisfactory MTBF at introduction of the item into the inventory; otherwise the customer would have to modify the component because of high support costs, through programs such as the AFLC IROS (Increased Reliability of Operational Systems). Figure 29 shows an actual support cost reduction achieved on the A-7D Air Data Computer through modification as computed in a life cycle cost analysis accomplished by Air Force Systems Command (19).

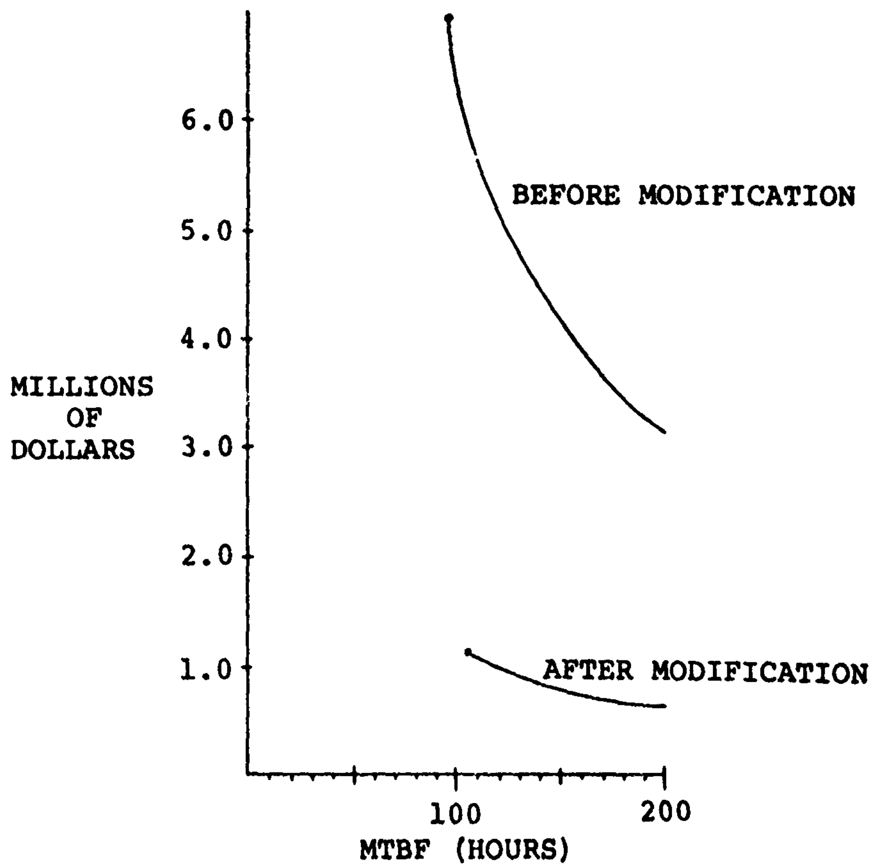


Figure 29: A-7D AIR DATA COMPUTER TEN-YEAR LOGISTIC SUPPORT COSTS VERSUS MTBF

The reliability improvement objectives are divided into two areas; avionics and mechanical equipment. Discussion of these improvements along with the rationale is presented in the following paragraphs. A summary of the total reliability improvements in terms of reduced maintenance manhours and failures are tabulated here for ready reference.

AIRCRAFT MODEL	MAINTENANCE REDUCTION		FAILURE REDUCTION	
	MMH/FH	Percent	Failures/ 1000 FH	Percent
F-111	6.29	15.4	407	28.0
F-4D	4.54	11.8	475	29.3
A-7D	4.32	14.1	377	33.6

(1) Avionics

Figure 12 indicates the part quality level improvement trend available through use of medium or high quality piece parts (semi-conductors subjected to additional screens) in avionics line replaceable units (LRU). As indicated in the Figure 12 discussion, previous studies show approximately a 5 to 1 ratio of reliability (MTBF) improvement with screening and burn-in of parts (semiconductors) over and above the reliability required by MIL-STD parts. Because not all piece-parts in an LRU will be medium-reliability parts and considering the parts-mix ratio, it is estimated that this equates to a 2.2 to 1 reliability improvement at the avionics LRU or black box level.

Study of AFM 66-1 data shows the following experience on avionics systems in terms of failures and maintenance manhour expenditures.

AVIONIC SYSTEM EXPERIENCE

AIRCRAFT MODEL	Failures per FH	MMH/FH
F-111A	0.415	6.154
F-4D	0.515	5.472
A-7D	0.477	5.966

Two avionics systems on the F-4D (radio navigation and fire control) accounted for nearly 24 percent of the total aircraft failures during the time period studied. Of the twelve high failure components in the F-4 fire control system, eleven were APQ-109 components (16). Over 45 percent of the A-7D failures and 65 percent of the maintenance manhours expended were caused by the bombing navigation system alone. This system experienced failure eight times more often than any other A-7D avionics system.

Application of the 2.2 to 1 improvement ratio to the avionics failures and maintenance manhour expenditures yields the following reduction:

AVIONIC SYSTEMS IMPROVEMENT OBJECTIVE

AIRCRAFT MODEL	Failures per FH	MMH/FH
F-111	0.226	3.357
F-4	0.281	2.985
A-7D	0.261	3.250

As shown in Figure 16, the greatest potential support cost savings is in the components with a mean-time-between-failure (MTBF) of 300 hours or lower. The lower the MTBF, the greater potential cost savings available, with the proper tradeoffs.

Based on field data, the avionics components listed in Tables II through IV were identified as having high failure rates equivalent to 300 hours or less MTBF. It is noted that the listed MTBF may not agree exactly with data from other sources. This may be the result of different failure criteria, different data samples, etc. The rationale for identifying potentially high payoff items should remain the same, however, regardless of the failure criteria.

TABLE II: F-111 AVIONICS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Autopilot	Feel Trim Assy	174	7.05
	Central Air Data Computer	196	11.21
	Flight Control Pitch Computer	229	4.50
HF Communications	RT759/ARC112 Receiver-Transmitter	164	5.07
UHF Communications	RT749/ARC109 UHF Receiver-Transmitter	101	4.24
Radio Navigation	RT694/ARN74 Tacan Receiver-Transmitter	104	6.98
	RT384/ARN52 Tacan Receiver-Transmitter	172	5.82
Bombing Navigation	Terrain Following Antenna Receiver	32	6.68
	CP-812 Navigation Computer	43	6.41
	Stabilization Platform MX6767	84	7.95
	Terrain Following Computer CP-799	92	4.81
	Attack Radar Indicator Recorder IP-777	94	5.71
	Radio Altimeter Receiver-Transmitter RT-771/APN67	138	3.76
	Attack Radar Receiver-Transmitter Modulator MD608	153	9.69
	Attack Radar Indicator Recorder Magazine	196	0.76
	Terrain Following Amplifier Power Supply AM4240	208	4.51
	Terrain Following Synchronizer-Transmitter SN379	221	4.79
	Attack Radar Antenna Control C-6498	245	6.30
	Attack Radar Synchronizer SN380	249	7.35
	Terrain Following Indicator IP-773	249	5.41
	Radar Altimeter Indicator	258	2.51
Electronic Countermeasures	APS-109 Forward Receiver R-1304	177	3.18
	APS-109 Control Indicator	194	4.60
	APS-109 Video Signal Processor	249	4.79

TABLE III: F-4 AVIONICS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Instruments	MC-3 Altimeter	102	1.66
	Angle-of-Attack Transmitter	228	2.17
	Indexer Light Assemblies	234	2.11
Autopilot	Control Amplifier	94	2.52
Radio Navigation	CP733 Navigational Computer	67	4.42
	Receiver-Transmitter RT-793/ASQ	77	4.32
	Inertial Navigation System	88	2.69
	Control Computer CP-723B	116	2.51
	C-6684/ASQ Control	116	2.07
	Inertial Navigation Gyro Stabilized Platform	118	3.26
	Amplifier, Computer AM3734	132	2.46
	Receiver-Transmitter Pulse Decoder KY-312/ASQ19	140	2.87
	Amplifier, Power Supply Receiver AM2349	165	3.35
	Tacan Receiver-Transmitter, RT-547	170	4.52
	Intercom Station LS-460	182	1.48
	KY-532/ASQ Coder	253	3.44
	UHF Receiver-Transmitter, RT-546	255	4.04
Radar Navigation	Radar Altimeter Receiver-Transmitter, RT-689/APN-155	51	3.70
Bombing Navigation	Ballistics Computer C-6480/ ASQ-91	160	3.37
	ML-1 Compass Transmitter	184	2.50
Fire Control System	APQ-109 Control, Indicator	368	3.00
	APQ-109 Electrical Synchronizer SN-377	36	3.77
	RT-755/APQ-109 Receiver-Transmitter	40	4.24
	Control, Power Supply C-64412/APQ-109	56	3.35
	Control Indicator, C-8112/ APQ-109	65	3.03
	Antenna AS-1694/APQ-109	67	4.55
	Indicator IP-772/APQ-109	102	3.15
	Lead Computing Sight Optical Display Unit	109	2.60

TABLE III: F-4 AVIONICS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT (Continued)

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Fire Control System (Cont'd)	Indicator, Azimuth, Elevation and Range IP-771/APQ-109	170	3.46
	Control, Antenna C-6409/ APQ-109	177	2.16
	Indicator, AZ-EL-Range IP-842/APQ-109A	182	2.92
	RT-755/APQ-109 Control Chassis	267	3.12

TABLE IV: A-7D AVIONICS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Instruments	Transducer, Angle-of-Attack	173	3.10
	Altimeter (Pitot-Static System)	255	2.38
Integrated Guidance and Flight Control	Roll Control Amplifier AM-4353/ASW-26	134	3.00
	Pitch Control Amplifier AM-4352/ASW-26	170	3.08
	Yaw Control Amplifier AM-6133/ASW-30	185	3.27
VHF Communi- cations	Radio Set Receiver-Transmitter FM622A	145	2.47
UHF Communi- cations	Receiver-Transmitter, RT-742B/ARC-51BX	50	5.23
	Control Unit C-7916/ARC-51C	95	2.02
IFF	Receiver-Transmitter, RT-859/APX-72	238	3.07
Radio Navigation	Receiver-Transmitter, RT-893/ARN-52(V)	55	3.05
	Horizontal Situation Indicator AQU-6/A	257	2.47
Radar Navigation	Receiver-Transmitter RT-601B/APN-141(V)	72	1.92

TABLE IV: A-7D AVIONICS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT (Continued)

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Bombing Navigation	Inertial Measurement Set AN/ASN-90(V)	35	3.11
	Antenna/Receiver AS-2272/ APQ-126(V)	38	3.40
	Radar Receiver-Transmitter RT-927/APN-190(V)	44	2.99
	Air/Navigation Multiple Indicator IM-952/APQ 126(V)	47	2.80
	Head-Up Display Unit IP-938/AVQ-7(V)	56	3.54
	Sweep Generator SG-811/ APQ-126(V)	70	3.28
	Inertial Measurement Unit CN-1260/ASN-90(V)	74	5.68
	Air Data Computer CP-953A/AJQ	79	4.20
	Tactical Computer CP-952/ ASN-91(V)	79	3.41
	Power Supply-Programmer PP-6130/APQ-126(V)	113	3.73
	Signal Data Processor CP-951/AVQ-7(V)	132	4.53
	Power Supply Adapter PP-6141/ASN-90(V)	165	3.59
	Radar Transmitter T-1091/APQ-126(V)	173	4.46
	Air Navigation Computer CP-954/APQ-126(V)	235	4.76
	Tactical Computer Control C-7831/ASN-91(V)	275	3.51
	Forward Looking Radar Set AN/APQ-126(V)	281	3.34
	Panel Test, Elevation, Antenna/Receiver	281	1.73
	Projected Map Display Unit	296	2.41

(2) Mechanical Systems

Additional cost improvement is available through increased reliability of mechanical systems. Previous studies have shown that five mechanical systems --- airframe, power plant, landing gear, flight controls, and hydraulics --- are consistently high in maintenance required on both military and commercial aircraft (3). Examination of AFM 66-1 data for the three aircraft support this.

F-111 potential improvement areas are: fasteners in airframe, account for 70 percent of airframe failures; leaks in hydraulic systems account for 46 percent of the failures and 34 percent of the MMH; improper adjustment of mechanisms in flight control systems, account for 40 percent of the failures and 24 percent of the MMH.

In the area of fasteners, experience data on the F-111A indicates that 71 percent of the failures generated by the airframe system were attributed to fasteners (loose or missing bolt, nut, screw, rivets, safety wire, etc.) The data reflected that maintenance of access doors and panels alone consumed 1.6 MMH/FH, which is a high percentage of the effort expended on fasteners at base-level. Maintenance of access doors and panels cannot be eliminated, but a sizable reduction can be made through judicious use of fasteners. There have been several typical complaints reported from the field, among them: the same panels using several type fasteners, or in many cases the same type, same diameter fastener in different lengths. In high performance aircraft, titanium hi-torque screws extend maintenance task times because special drill bits, and slow drilling were required. With increased emphasis on fasteners and methods of protective coating and installing rivets, securing access doors and panels, it is estimated that a 60 percent reduction in F-111A access panel failures and maintenance could be achieved, as opposed to a negligible reduction on the F-4 or A-7D in this area. Applying the 60 percent reduction objective, maintenance could be reduced 0.96 MMH/FH on the F-111A airplane at base-level. Depot maintenance is not considered here because of the lack of data pertaining to the fastener area. Practically no improvement potential appears to exist for F-4 or A-7D in comparison.

Methods to achieve the reductions mentioned include use of unstressed panels in areas where frequent access is required, larger size fasteners to reduce the number of fasteners, minimize types, sizes, and quantity of fasteners, provide captive quick release fasteners or removable panels and avoid piano wire hinges where frequent use and vibration could cause excessive wear. The F-111A has improved over past designs in fastener standardization but still has areas where one, two, three and sometimes four different fasteners are used in the same access panel.

Field reporting on the F-4D reveals that 54 percent of the airframe failures were attributed to fasteners. This amounts to 137 failures per 1000 flight hours and 0.25 MMH/FH (12). The largest concentration of this maintenance was on the center fuselage section and center wing section doors and panels.

The A-7D access doors and panels do not require the maintenance expenditures found on the F-111. The data shows that access door/panel maintenance amounted to 0.53 MMH/FH, of which 0.25 could be attributed to fasteners. It appears these expenditures are probably as low as can be expected, and not within the scope of support cost objectives. It is suggested that the A-7D be included in any future fastener study to evaluate the improvements contributing to the low fastener manhour expenditures.

Most F-111A flight control failures were concentrated in the secondary flight controls (flaps, slats, etc.). Brakes were high items in the landing gear system; in the power plant system, engine nozzle position indicator, translating cowl assembly, engine controls rack, engine push-pull control, main fuel control, and turbine 1st-stage vanes were high failure items.

Cost of some F-4 failures has been astronomical. Some of these are: failure of early configuration aileron power control cyliners, allowing depletion of both power control systems hydraulic fluid, and subsequent loss of ten aircraft or approximately 17 million dollars. Reversion of potting compound used in electrical connectors required repotting of connectors in the entire fleet. The cost for correcting this problem was quoted as 14,000 manhours per aircraft in the 1972 Congressional DOD Budget Hearings. Voltage regulator supervisory panels (AC control panel) were not isolated so that failure of one generator could cause loss of both generators. Many mission aborts were attributed to this component. Excessive failures of this unit requires approximately 1850 manhours per month on the F-4 fleet. Leaking actuators, and mechanisms out of adjustment account for 31 percent of flight control system failures; wheels, and brakes were high in the landing gear system, ignition and combustion liners cracking and constant speed drive failures were predominant in the power plant system, and hydraulic pumps and filters in the hydraulic systems.

On the A-7D, high failure items were the aileron in flight controls, main fuel control in power plant, fuel quantity indicator, and the liquid oxygen converter.

It is estimated that the failure frequency of mechanical systems can be reduced by 60 percent in the area of fasteners and 20 percent for other mechanical equipment based on previous analyses and existing state-of-the-art improvements. Field data shows the failure rate of mechanical systems as follows:

MECHANICAL SYSTEM EXPERIENCE

AIRCRAFT MODEL	Failures per FH	MMH/FH
F-111	0.886	11.490
F-4	0.971	7.763
A-7D	0.553	5.355

The 20 percent overall reliability improvement for mechanical systems is based on the following:

1. Improved fasteners and reduction of the number and sizes of fasteners in one panel, improved access door design in the airframe system and improved protective coating and installation techniques of rivets.

2. Use of welded joints and swaged sleeves with reconnectable joints and the improved "T" seals over the common "O" ring to reduce failures and the manhours expended for leaks in the hydraulic, flight control and landing gear systems. These seals are now in use in limited applications for F-4 problem components.

3. Use of permalube bearings, corrosion free universal joints, leak detectors, and simplified rigging design to provide additional improvement.

4. Use of higher reliability switches such as proximity switches and removable-pin crimp-type environmental connectors in electrical circuitry will also add to the improvement.

5. Use of life cycle costing procurement for short-life components can provide higher reliability. This concept requires that sample sets of each vendors product be proven in the field under actual operating conditions, and the unit be cost measured against actual performance. Use of this procedure by the Ogden Air Material Area has reduced tire procurement costs substantially.

Improvements of the type mentioned in the mechanical systems is estimated to be 20 percent of the failure frequency. Predicated on the listed failure rates, this provides the following improvement objective in failures and the maintenance manhours expended on those systems.

MECHANICAL SYSTEM IMPROVEMENT OBJECTIVES

AIRCRAFT MODEL	Failures per FH	MMH/FH
F-111	0.177	2.298
F-4	0.194	1.552
A-7D	0.111	1.071

Based on the field experience data, mechanical systems components listed in Tables V through VII were identified as potential high payoff candidates having 300 hours or less mean-time-between-failure (MTBF). The list is not inclusive, in that items such as tires and hydraulic filters are omitted because they are inherently high usage items and offer little improvement potential at the present time. The listed MTBF may not agree exactly with other data sources because of possible differences in failure criteria, data samples, etc. The 300-hour MTBF selected was based on potential payoff indicated in Figure 16.

TABLE V: F-111 MECHANICAL SYSTEMS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Airframe	Fuselage Center Section Frame	86	2.94
	Stabilizer Actuator Cover	92	2.14
	Wing Skin	134	35.68
	Aft Section Frame	191	4.08
	Aft Section Skin	205	6.46
	Center Section Skin	211	5.13
	Wing Trailing Edge	241	6.36
	Fuselage to Wing, Seals R.H.	249	6.41
	L.H. Overwing Fairing	254	2.95
	Fuselage to Wing, Seals L.H.	254	2.81
Landing Gear	Brake Assy	172	5.53
Flight Control	Flap Asymmetry Device	205	5.80
	Flap Main Drive Gearbox	205	8.51
	Slat System	208	9.73
	Slat Torque Shaft	218	2.76
	Rotating Glove	218	5.45
	Nose Slat #2	236	3.09
	Position Mechanism	241	5.96
	Aft Slat #2	245	4.27
Escape Capsule	Canopy Counterpoise	202	2.58
Turbo Jet Power Plant	Engine Nozzle Position Indicator	30	3.37
	Secondary Manifold Fuel Strainer	49	1.14
	Translating Cowl Assy	75	3.24
	Engine Controls Rack	96	2.22
	N1 Overspeed Tachometer	98	1.40
	Push-Pull Control	102	10.62
	Main Fuel Control	123	10.85
	A/B & Exhause Nozzle Control	134	12.45
	Turbine 1st Stage Vane	166	0.31
	EPR Transmitter	249	3.17
	Engine Nozzle Transmitter	258	2.50

TABLE V: F-111 MECHANICAL SYSTEMS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT (Continued)

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Electrical Power Supply	Constant-Speed Drive	241	2.59
Hydraulic Power Supply	Hydraulic Pump, Primary System	160	1.75
	Hydraulic Pump, Utility System	202	1.48
Fuel System	Fuel Quantity Indicating Intermediate Device	221	2.00

TABLE VI: F-4 MECHANICAL SYSTEMS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Airframe	Fuel Tanks, Integral Wing	23	2.80
	Aft Wing Tip	92	3.05
	Radome Assy, Nose	177	1.31
	Pylon Assembly	184	2.10
	Forward Wing Tip	231	2.92
	Structural Assembly, Forward	237	3.01
Landing Gear	Brake Rotating Disc	67	0.23
	Brake Stationary Disc	84	0.22
	Arresting Gear Fairing	111	1.84
	Drive-Tube Assembly	143	2.86
	Main Landing Gear Wheel	147	0.65
	Nose Landing Gear Wheel	165	2.20
	Brake Assembly	227	1.86
	NLG Steering Follow-up Potentiometer	273	2.97
Flight Controls	Stabilator Assembly	86	2.22
	Aileron Assembly	122	2.99
	Stabilator Steel T.E. Honeycomb	181	3.17
	Switch, Flap Limit	200	5.05
	T.E. Flap, L.H. and R.H.	226	4.62

TABLE VI: F-4 MECHANICAL SYSTEMS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT (Continued)

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Turbo Jet Engine	Inner Combustion Liner	62	1.31
	Constant Speed Drive (Sunstrand)	153	4.58
	Exhaust Nozzle Cam Link Actuator	189	0.23
	Inner Ignition Liner	230	1.79
Electrical Power Supply	AC Control Panel	226	2.85
	30 KVA Generator System	247	3.94
Hydraulic Power Supply	Utility Hydraulic Pump	205	2.92
	Utility System	196	2.55
Fuel System	Fuel Tank, External L.H.	136	10.24
	Fuel Tank, External R.H.	163	10.30
Oxygen Sustem	Liquid Oxygen Converter	192	2.86

TABLE VII: A-7D MECHANICAL SYSTEMS CANDIDATES FOR HIGH PAYOFF IMPROVEMENT

SYSTEM	COMPONENT	MTBF (HOURS)	MMH/ TASK
Flight Controls	Aileron Assembly	120	1.75
Turbofan Power Plant	Control, Main Fuel	195	8.36
Electrical Power Supply	Battery	54	4.10
	Constant Speed Drive Oil Filter	281	3.98
Fuel System	Indicator, Fuel Quantity	300	3.83
Oxygen System	LOX Converter	287	2.69

c. Safety

Figure 17 depicts the jet fighter accident rate by primary cause factor, and points out the need for continued accident reduction. As shown in this illustration, reductions in accident rates have been more a function of reduced material failure causes than reduced human error. Continued improvement in material failure caused accidents is considered not only achievable but necessary to retain the required force posture within ever-increasing budget constrictions. The increased complexity of each generation of aircraft also dictates that safety standards be more stringent.

The known precedent is the basis for recognizing accident-incident cause factors and potentials. The identified cause factor can be expected to create similar accidents in the future. Aircraft accidents, like history, tend to repeat, as long as the cause factors persist. Fault tree analysis identifies and evaluates the relative hazard of each fault path to allow corrective action to be focused on specific human and hardware events involved, and eliminate interfaced man-machine events that lead to accidents or catastrophic failures (9).

Based on application of fault tree analysis to all flight critical systems and proper consideration of hazardous conditions that would probably occur during the fleet lifetime, an improvement objective of 50 percent reduction in material-failure-caused accidents was established. Of course this should be achieved on a new program during the design phase and only if the program management allowed changes to be made to the necessary specifications, drawings, etc. to overcome those conditions identified during the above analysis.

Evaluation of USAF accident data indicates that material failure accounted for 40.9 percent of the accidents on the F-111, 30.0 percent on the F-4 and 33.0 percent on the A-7D aircraft. These material failure percentages cover from the year of entry into inventory through 1972.

Air Force Manual 173-10, Table 13, Aircraft Peacetime Attrition Losses for Selected Flying Hour Intervals, shows trend attrition rates in increments of 138,000 flighthours for the F-4 and 90,000 flighthours for the A-7D. Table 8a, AFM 172-3, was used for the F-111 as it combines all models in 100,000-flighthour increments. Losses were calculated for each of the flying hour intervals for a period of eight years (approximate fleet life), by entering the tables at the cumulative flying hour interval equal to the flying hours the aircraft fleets have accumulated through approximately mid-1973.

To measure the postulated savings for the purpose of this analysis the following airplane fleet size and flying hour schedule were used.

AIRCRAFT MODEL	FLEET SIZE (NUMBER OF AIRCRAFT)	UTILIZATION (HOURS/YEAR/AIRCRAFT)
F-111(A-F)	350	300
F-4	460	300
A-7D	300	300

Applying the 50 percent improvement objective yields a reduction in material-failure-caused accidents of 20.5 percent for the F-111, 15.0 percent for the F-4 and 16.5 reduction for the A-7D. This improvement equates to a cummulative number of 14.15 F-111 aircraft; 7.90 F-4 aircraft and 6.06 A-7D aircraft.

d. Manning

As shown in Figure 3, personnel costs are a large portion of operations and maintenance costs. As such, they also represent a great improvement potential, particularly direct aircraft maintenance support. The cost reductions discussed in maintainability-maintenance engineering, and reliability (SECTION III) represent a total of 12.17 MMH/FH on the F-111 11.41 on the F-4 and 8.77 on the A-7D, and 16.5 percent of annual depot costs, the majority of which is personnel costs, and directly related to reductions in maintenance manning.

Hardware design and maintenance concepts dictate personnel requirements. Additional maintenance manning improvements can be achieved through a better knowledge of personnel requirements, skills, utilization, or concepts in performing maintenance.

A personnel utilization and efficiercy feedback system is needed to build a personnel requirements data base, similar to hardware experience reporting, so as to more accurately measure requirements for personnel and determine optimum utilization of skill types and levels.

Adaptation of the existing field experience data reporting to include Air Force specialty code for personnel accomplishing work would provide a quantum improvement in the ability to measure personnel utilization and requirements.

e. Training, Technical Publications and Test Equipment

Reduced support costs are also possible through optimized manning by effective cross-training, improved training techniques, and improved job aids.

As shown in Figure 5, Maintenance Growth Trend, early peaks in the maintenance manhour per flight hour is partially attributed to inexperienced personnel, and short training flights. Figure 7 shows that longer sortie lengths result in fewer MMH/FH. Understanding these two curves could lead to innovative ways to maximize the effectiveness of a training sortie and at the same time reduce MMH/FH. Figure 20 shows the effect of workmanship on equipment failure and points out the potential reduced support costs through advancements in training programs. Previous Boeing studies indicate that more optimum manning and better utilization of personnel can be achieved through cross-training so that surplus manhours in one specialty code can be utilized to offset deficits in related shops or speciality codes.

Figure 22 shows the involvement of technical publications in relation to a Boeing study of accidents, incidents and hazards. The other aspect to be considered is the incomplete or extended task times that occur as a result of technical data not being easily understood or available. Figure 23 shows the reading ease of technical publications issued for various systems on three aircraft types. It also supports complaints frequently voiced by base maintenance personnel during field surveys that the technical information on various systems or components is incomplete or not compatible with "real life." Innovative methods of presenting technical data material and making it readily available, such as those described in Section III 2f, are being studied by NSIA and need to be developed.

No attempt has been made here to measure cost reduction impact of improved technical publications; however, study results indicate that a potential saving does exist and will eventually be scoped as studies continue.

Support cost reductions pertaining to inspection and trouble-shooting manhours achieved through improvements in support and test equipment such as the built-in-test equipment or CITS are discussed in Section III 2a. As discussed in Section III, too often the test equipment required to fault isolate is unreliable or requires complicated procedures and excessive time to operate properly.

Frequently, new weapon systems with equipment reflecting the latest in current technology are introduced in the inventory, but are checked with government furnished test equipment which is obsolete and has been in the inventory for a considerable length of time. This concept has its advantages for such items as universal towbars and maintenance stands, but frequently does not provide adequate performance in testing new sophisticated equipment.

One approach to achieving support cost reductions is by achieving greater reliability in support and test equipment. This can be partially accomplished by use of the same or higher reliability level of piece parts in the test equipment as used for the aircraft subsystems being tested. The design, test and parts control disciplines would also have to be compatible. This would permit greater confidence and efficiency in system checkout and reduce maintenance requirements on test equipment.

3. COST REDUCTION IMPACT

This section correlates the improvements previously discussed in terms of a specific Air Force command environment (that of the Tactical Air Command fighter), so as to quantify improvements against a reasonable baseline. Operational factors were assumed and unclassified sources of data used in all cases to prevent classifying the report thereby allowing wider circulation. To keep the report unclassified, the normal versus improved total annual squadron costs are not calculated, as this would require use of classified data, such as squadron personnel strengths. In addition, cost of those elements which are not impacted by the scope of the report (POL, aircrews, etc.) are not included. Table VIII indicates the baseline factors used for each element. The factors were obtained from the sources as indicated:

Aircraft per Squadron	Assumed
Flying Hours per year	Assumed
Crew Ratio	Table 10 - AFM 173-10
Flyaway Cost	T.O. 00-25-30
Base Material Support Costs	Table 24, AFM 173-10
Replenishment Spares Cost	Table 24, AFM 173-10
Depot Maintenance Cost	Table 26, AFM 173-10
Vehicular and Other Base Maintenance	Page II-2, AFM 173-10
BOS (Base Operating Support)	Figure 1, AFM 173-10
Medical	Figure 2, AFM 173-10
PCS (Permanent Change of Station) Cost	Table 20, AFM 173-10

Miscellaneous Support Cost	Page II-1, AFM 173-10
Annual Pay of Civilian Employees	Table 22, AFM 173-10
Annual Pay of Military Personnel	Table 16, AFM 173-10
Attrition Rates F-4, A-7D	Table 13A, AFM 173-10
Attrition Rate F-111	Table 8a, AFM 172-3

TABLE VIII: BASELINE FACTORS

	F-111	F-4	A-7D
Aircraft per Squadron (assumed)	24	24	24
Flying Hours per year (assumed)	300	300	300
Crew Ratio	1.1	1.1	1.1
Flyaway Cost (millions)	$12.385	$1.682	$3.252
Base Material Support/FH	164	121	119
Replenishment Spares/FH	605	128	122
Depot Maintenance/FH	471	116	175
Vehicle/Other Base Maintenance	$225 per year per each military in PPE		
BOS (Base Operating Support)	17 percent of Primary Program Element (PPE)		
BOS Personnel Distribution	Officer - 2%, Airmen - 73%, Civilian - 25%		
Medical	Two percent of PPE and BOS military personnel and a personnel distribution of Officer - 25%, Airmen - 75%		
PCS Costs per Man-year	Officer - $575, Airmen - $225		
Miscellaneous Support Costs	$760 per Man-year		
Average Annual Pay	Officer - $18,334, Airmen - $8,202, Civilian - $11,267		
Average Aircraft Attrition Rate	Variable with flying hours; see data sources		

To facilitate comparison, cost reductions achieved on each of the three aircraft are shown for each cost category. The section concludes with a summary of squadron total annual reductions, and attrition rate savings.

a. Maintenance Manning

Primary Program Elements (PPE) is an aggregation of aircrews, aircraft and AGE maintenance; wing/base staff; munitions maintenance; and weapon system security. This study is directed primarily to that part of the PPE which is impacted by integrated logistics support; e.g., aircraft and AGE maintenance. Because of this, total PPE personnel will not be reduced proportionally to the manhour reductions in aircraft maintenance. Only that portion assigned to aircraft maintenance will be reduced. The reduction in maintenance manning as a function of MMH reductions is obtained thus:

$$\frac{(\text{Aircraft/Sqdn}) \times (\text{FH/month}) \times \underset{\text{Reduction}}{\text{MMH/FH}} \times \underset{(1.21\ \text{AGE Additive})}{\text{Chief of Maint. \&}}}{(\text{Productive manhours per month})}$$

		Maintenance Personnel Reduction
F-111	$\frac{24 \times 25 \times 12.17 \times 1.21}{85} =$	104
F-4	$\frac{24 \times 25 \times 11.41 \times 1.21}{85} =$	98
A-7D	$\frac{24 \times 25 \times 8.77 \times 1.21}{85} =$	75

On the basis of an assumed Tactical Air Command (TAC) mainte-anance personnel percentage of 98 percent airmen and 2 percent officers and Table 16, AFM 173-10, Military World-Wide Average Annual Pay and Allowances, annual dollar savings because of maintenance manhour reductions are as follows:

F-111	104 x 0.98 x $8,202/airman	=	$835,948
	104 x 0.02 x $18,334/officer	=	$ 38,135
	Total		$874,083
F-4	98 x 0.98 x $8,202/airmen	=	$787,720
	98 x 0.02 x $18,334/officer	=	$ 35,935
	Total		$823,655

A-7D	75 x 0.98 x $8,202/airmen =	$602,847
	75 x 0.02 x $18,334/officer =	$ 27,501
	Total	$630,348

b. Spares Replenishment

Annual replenishment spares costs are a function of aircraft component reliability. Decreases in failure frequencies of aircraft parts for high population systems are assumed to have a near proportional effect on this cost. As previously discussed, the estimated reduction in the failure frequencies for the three aircraft is F-111, 28 percent; F-4, 29.3 percent; and A-7D, 33.6 percent. On the basis of replenishment spares costs in Table 24, AFM 173-10, savings in replenishment spares are calculated as follows:

(Spares Cost/FH) x (Failure Rate Reduction) x (Aircraft/Sqdn) x (FH/year) = Annual Spares Cost Reduction

F-111	$605 x 0.28 x 24 x 300	= $1,219,680
F-4	$128 x 0.293 x 24 x 300	= $ 270,028
A-7D	$122 x 0.336 x 24 x 300	= $ 295,142

c. Depot

Total annual depot costs have typically been estimated as being divided equally between IRAN, engine overhaul, and special repair activity (SRA) or component repair. Using the 50 percent reduction in IRAN maintenance through improved techniques reduces total depot costs by 16.5 percent.

Depot costs per flight hour are obtained from AFM 173-10 Table 26, Aircraft Depot Maintenance Cost. Depot IRAN cost reduction is obtained through (Depot Cost/FH) x (Percent Reduction) x (Aircraft/Sqdn) x (FH/year)

F-111	$471 x .165 x 24 x 300	= $559,548
F-4	$116 x .165 x 24 x 300	= $137,808
A-7D	No IRAN savings were estimated: the aircraft was new and IRAN was not yet established.	

Additional depot cost reduction accrues through decreasing component failure frequency which lowers SRA/component repair; also one third of total depot costs. This reduction is determined through (Depot Cost/FH) x (Component Repair Percent) x (Failure Reduction) x (Aircraft/Sqdn) x (FH/year).

F-111	$471 x .33 x .28 x 24 x 300	= $313,347
F-4	$116 x .33 x .293 x 24 x 300	= $ 80,755
A-7D	$175 x .33 x .336 x 24 x 300	= $139,708

Total annual depot cost reductions are:

	F-111	F-4	A-7D
IRAN	$559,548	$137,808	--
Component Repair	$313,347	$ 80,755	$139,708
Total	$872,895	$218,563	$139,708

d. Supporting Elements

Vehicular and Base Maintenance

Vehicular and Other Base Maintenance costs are proportional to the number of PPE military personnel. These costs are 225 dollars per man-year, obtained from AFM 173-10, Page II-2, paragraph (14). Cost reductions are:

F-111	$225 x 104	= $23,400
F-4	$225 x 98	= $22,050
A-7D	$225 x 75	= $16,875

Base Material Support (BMS)

Base Material Support is consumable items (repair parts, such as gaskets, seals, small hardware), broken into two categories; system and general. The system category covers those items which are peculiar to the particular weapons system, the general category consists of those items which are common to several weapons systems, such as MIL-STD bolts, nuts, rivets, etc. Base material support costs are obtained from AFM 173-10, Table 24, Summary of Aircraft Flying-Hour-Cost Factors. The cost reduction is estimated to be proportional to the failure rate reduction and obtained through (BMS/FH) x (Aircraft/Sqdn) x (FH/year) x (Failure Reduction).

F-111	164 x 24 x 300 x 0.28	= $330,624
F-4	121 x 24 x 300 x 0.293	= $255,262
A-7D	119 x 24 x 300 x 0.336	= $287,885

Base Operating Support (BOS) Personnel

Base operating support are those elements required to support the primary program personnel such as base supply, dining halls, etc.; they are proportional to the number of PPE people assigned. AFM 173-10, Figure 1 shows the BOS for Program II (Tactical) as being 17 percent. On the basis of the average annual military pay, Table 16, AFM 173-10, and the personnel distribution shown in Figure 1, AFM 173-10, BOS cost reductions are obtained as follows:

(PPE personnel) x (0.17) = BOS Personnel

F-111	104 x 0.17	= 18
F-4	98 x 0.17	= 17
A-7D	75 x 0.17	= 13

BOS personnel makeup; officer, 2%; airmen, 73%; civilian, 25%

F-111	18 x 0.02 x $18,334	=	$ 6,600
	18 x 0.73 x $8,202	=	$107,774
	18 x 0.25 x $11,267	=	$ 50,701
	Total		$165,075
F-4	17 x 0.02 x $18,334	=	$ 6,234
	17 x 0.73 x $8,202	=	$101,787
	17 x 0.25 x $11,267	=	$ 47,885
	Total		$155,906
A-7D	13 x 0.02 x $18,334	=	$ 4,767
	13 x 0.73 x $8,202	=	$ 77,837
	13 x 0.25 x $11,267	=	$ 36,618
	Total	=	$119,222

Medical

Medical personnel are assigned in proportion to the population of PPE and BOS military personnel. The medical personnel factors are shown in AFM 173-10, Figure 2. Applying these factors and average military pay, the reduction in medical personnel costs is obtained:

Total PPE and BOS Military:	F-111	- 118
	F-4	- 111
	A-7D	- 85

A two percent manning factor yields the following number of medical personnel: F-111 - 3
F-4 - 3
A-7D - 2

F-111, F-4	3 x 0.25 x $18,334	=	$13,750
	3 x 0.75 x $8,202	=	$18,455
	Total	=	$32,205
A-7D	2 x 0.25 x $18,334	=	$ 9,167
	2 x 0.75 x $8,202	=	$12,303
	Total	=	$21,470

PCS (Permanent Change of Station)

AFM 173-10 shows permanent change of station costs per military manyear at $255 for airmen and $575 for officers. PCS cost savings are calculated as follows:

Total Military Personnel Reductions: F-111 - 121
F-4 - 114
A-7D - 87

F-111	121 x 0.98 x $255	=	$30,238
	121 x 0.02 x $575	=	$ 1,392
	Total	=	$31,630
F-4	114 x 0.98 x $255	=	$28,489
	114 x 0.02 x $575	=	$ 1,311
	Total	=	$29,800
A-7D	87 x 0.98 x $255	=	$21,741
	87 x 0.02 x $575	=	$ 1,000
	Total		$22,741

Miscellaneous Support

Miscellaneous support costs are calculated at 760 dollars per military and civilian man-year as indicated in AFM 173-10, Page II-1, subparagraph (5). Total personnel reductions are F-111, 125; F-4, 118; and A-7D, 90.

F-111	125 x $760	=	$95,000
F-4	118 x $760	=	$89,680
A-7D	90 x $760	=	$68,400

Other cost categories such as training costs (recruit, special, professional and flight training) have not been calculated here, as AFM 173-10 indicates these costs are not yet available to proportion back to operational squadrons. The trend should be similar to other cost areas, however, indicating that savings are possible. These costs should be considered in life cycle cost studies which have impact on these areas.

e. Operations

Table IX shows the total operations cost reductions for each of the three aircraft for an individual squadron. When numbers of active squadrons are considered the postulated cost savings become more significant.

f. Aircraft Attrition

Cost reductions for decreased aircraft attrition is not included in the squadrons operations cost. Loss of aircraft does have minor impact on the maintenance load, personnel and spares requirements, but the major impact is acquisition. Presently acquisition of fighter aircraft includes a 10 percent over-buy to account for this loss. A significant reduction in loss of aircraft could reduce this additional buy of aircraft and result in a substantial acquisition cost reduction.

The attrition improvement shown in Section IV 2 c. amounts to 14.15 F-111 aircraft; 7.90 F-4 aircraft and 6.06 A-7D aircraft.

Technical Order 00-25-30 shows the unit flyaway costs in millions of dollars of 12.384 for F-111 aircraft, 1.682 for the F-4D aircraft and 2.5 for the A-7D aircraft.

This results in a dollar value savings (in millions) of 175.25 for the F-111, 13.29 for the F-4 and 15.15 for the A-7D over the life of the fleet for each model aircraft.

The reduction applied to the entire F-4 fleet (all models) shows even more impressive savings:

Assumptions:	Fleet Size	1600 aircraft
	Utilization	300 hours/year/aircraft
	Average attrition rate flight hours	5.89/100,000

This produces 28.27 aircraft per year attrited, multiplied by 8-year life and 15 percent reduction which equals 33.9 fewer aircraft lost. Using an average cost for all F-4 models of 2.2 million dollars (the F-4D model was 1.68 million) this represents a total F-4 savings of 75.26 million dollars.

The analysis does not include saving that could also accrue to the government for their investment in aircraft crews. This investment in training alone could average 150,000 dollars per man.

TABLE IX: ANNUAL SQUADRON OPERATIONS COST REDUCTION

(Based on Unclassified Portions of AFM 173-10, 1 April 1973)

	F-111	F-4 (Cost Reduction Dollars)	A-7D
Direct Personnel (PPE)	874,803	823,655	630,348
Spares Replenishment	1,219,680	270,028	295,142
Depot			
Iran	559,548	137,808	---
Component Repair	313,347	80,755	139,708
Supporting Elements			
Vehicular & Other Base Maintenance	23,400	22,050	16,875
Base Material Support (Consumables)	330,624	255,262	287,885
BOS Personnel	165,075	155,906	119,222
Medical	32,205	32,205	21,470
PCS (Permanent Change of Station)	31,630	29,800	22,741
Miscellaneous Support	95,000	89,680	68,400
Squadron Total Annual Cost Reduction	3,645,312	1,897,149	1,601,791

GLOSSARY OF TERMS

Accessibility - A measure of the relative ease of admission to the various areas of an aircraft, subsystem, equipment or component.

Aircraft Utilization - The number of hours an aircraft is actively engaged in flying during a specified interval. Usually expressed as utilization per day, per month or year.

Base Material Support (Consumables) - The consumable type items (sealants, common hardware, etc.) used in maintaining the end item. Base Material Support is generally divided into two categories; System, and General. The System category refers to consumables that are peculiar to a specific airplane, and the General category to those items that are used on several airplanes.

Bench Check OK - The process of testing a removed component in the shop to determine the condition, and finding it serviceable.

BOS Personnel (Base Operating Support) - These are indirect personnel such as food service, ground communications maintenance, civil engineering, etc., required to support the primary program element. BOS personnel are calculated as a percentage of the total primary program element population.

Burn-In - The operation of an item to stabilize its characteristics.

Central Integrated Test System (CITS) - An integrated test system which provides independence from ground test AGE and flexible, timely airplane-system status for the aircrews, operational commander, and maintenance crews.

Debugging - A process to detect and remedy inadequacies preferably prior to operational use.

Depot Component Repair - Components that are returned to the depot for repair from the operating bases because of the item complexity, cost, or other considerations which make repair at base level impractical.

Depot IRAN (Inspect and Repair As Necessary) - Depot level modification/maintenance of aircraft normally scheduled on a calendar time cyclic basis, usually 24 or 36 months.

Derating - (a) Using an item in such a way that applied stresses are below rated values, or (b) The lowering of the rating of an item in one stress field to allow an increase in rating in another stress field.

Direct Personnel (PPE) - The primary program element (PPE) includes Chief of Maintenance, Organizational, Intermediate, Communications-Armament-Electronics, and munitions maintenance as determined through factors contained in AFM 26-3. It also includes aircrews, weapons system security, and Squadron and Wing/Staff personnel but which are not affected by or calculated in this study.

Fasteners - Those parts which are used to attach, connect or secure components in place, such as nuts, bolts, screws, rivets, and safetying devices.

Fault Isolation Time (Also called Troubleshooting) - That element of maintenance time during which testing and analysis is performed on an item to isolate a failure.

Fault Tree Analysis - The technique used to identify all hazardous potentials within a system (failures, malfunctions or human errors) and provide the designer with specific data that identify areas where redesign may be necessary, thus assuring the greatest possible degree of safety.

Item - The term item is used to denote any level of hardware assembly, i. e., system, subsystem, equipment, component, part, etc.

Life Cycle Cost - The total cost of an item or system over its full life (normally 10 years of operation). It includes the cost of development, acquisition, ownership (operation, maintenance, support, etc.) and where applicable, disposal.

Maintainability - A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

Maintenance - All actions necessary for retaining an item in or restoring it to a specified condition.

Maintenance Manhours per Flight Hour (MMH/FH) - For a particular interval, the maintenance manhours expended on the population of an item divided by the total flight hours accrued by the population during the measurement interval.

Mean-Time-Between Failures (MTBF) - For a particular interval, the total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for time, cycles, miles, events or other measures of life units.

Medical - Medical personnel requirements are determined as a percentage of total military personnel (PPE and BOS) population and the type medical facility (hospital or clinic).

Reliability - The probability that an item will perform its intended function for a specified interval under stated conditions.

Safety - The conservation of human life and its effectiveness, and the prevention of damage to items, consistent with mission requirements.

Scheduled Maintenance - Maintenance expended for the following:
- Look phase of all inspections (Preflight, Postflight, Phase)
- Fix phase of all inspections (Preflight, Postflight, Phase)
- Special Inspections
- Aircraft Washing and Cleaning
- Scheduled Shop Support
- Time Compliance Technical Orders (TCTO)

Spares Replenishment - The replenishment spares, components and repair parts that are identified as investment items and which are obtained as follow-on procurement primarily in support of the flying hour program.

Support General Maintenance - Repetitive type maintenance actions such as aircraft ground handling, servicing, look phase of scheduled inspections, aircraft washing/cleaning, ground safety, etc.

System Maintenance - Corrective maintenance performed on the functional systems or components of the equipment end item.

Technical Publication - A publication that gives specific technical directions and information with respect to the operation, inspection, storage, modification, and maintenance of a given equipment.

Total Aircraft Maintenance - All maintenance required to support the equipment end item, which includes both support general and system maintenance.

Unscheduled Maintenance - Maintenance expended between scheduled inspections on the repair of a malfunction in a system and/or item.

Vehicular and Other Base Maintenance - Includes an allocation of military and civilian labor costs associated with vehicle maintenance, repair, motor pool, and service station; and an allocation for material costs such as gasoline, tires, spark plugs and lubricants.

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This technical report addresses life cycle costs for fighter type aircraft, with emphasis on analysis performed during the early design phase. The engineer is provided a discussion of the factors and guidelines for estimating major elements of the life cycle costs for new or existing weapon systems using field experience data and cost planning factors from AFM 173-10. It does not include a computer model. Charts and curves are included

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which show how reliability and maintenance impact support costs during a program's operational phase.

Quantifiable support cost savings have been calculated on the F-4, F-111, and A-7D aircraft to demonstrate the analytical approach and rationale used in performing the analysis.