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TECHNOLOGY TRENDS AND MAINTENANCE WORKLOAD REQUIREMENTS FOR THE A-7, F-4, AND F-14 AIRCRAFT

Thomas A. Blanco

George Chernowitz
James Ciccotti
Alan Lee
American Power Jet Company

Reviewed by
Joe Silverman

Approved by
James J. Regan
Technical Director

Navy Personnel Research and Development Center
San Diego, California 92152

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Three major technology variables--system complexity, rate of technological change, and automation in diagnostics--were addressed to determine their significance in formulating a methodology for forecasting maintenance manpower requirements for new aircraft. These variables were analyzed separately for the A-7, F-4, and F-14 aircraft systems, as well as maintenance workload requirements. Conclusions are drawn from the effect of these variables on maintenance manhours per flying hour and distribution of workload among maintenance levels (organizational, intermediate, and depot) and work centers (skills).

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Results indicate that system complexity, measured in terms of component reliability and density of functions (number of parts per subsystem), and rate of technological change, measured by subsystem commonality, are important in forecasting the manpower requirements of a new aircraft system. Automation in diagnostics did not have a significant effect on manpower requirements. The F-14 aircraft had a significantly different maintenance distribution by levels than the A-7 and F-4 models, the biggest shift being from organizational level (down 20% from other aircraft) to depot level (up 71% from other aircraft). This was accompanied by a much greater use of commercial support (96% of total depot support) than for other aircraft.

FOREWORD

This research and development was performed in support of Navy Decision Coordinating Paper, Manpower Requirements Development System (NDCP-Z0109-PN) under the sponsorship of the Deputy Chief of Naval Operations (Manpower, Personnel, and Training) (OP-01). This is a preliminary report relating to subproject Z0109-PN.01, Technology-Based Manpower Requirements. The objective of this subproject is to determine the effect of technology on long-range military and civilian manpower requirements. The primary purpose of the advanced development presented here was to determine the significance of three major technological variables on maintenance workload requirements for three generations of fighter/strike aircraft, the A-7, F-4, and F-14. A better understanding of the influence of technology on maintenance workload requirements should eventually result in a methodology for forecasting maintenance manpower requirements for new aircraft.

Because it was less costly and entailed less risk, this initial investigation was confined to existing aircraft systems, and a limited data base was used. The results were encouraging enough to develop a methodology to forecast the manpower requirements of a new aircraft. The methodology is now being applied by the American Power Jet Company, under contract with NAVPERSRANDCEN, to forecast the life-cycle maintenance manpower requirements of the new F-18 aircraft.

The technical monitor was Thomas A. Blanco.

DONALD F. PARKER
Commanding Officer

SUMMARY

Problem

The Navy has had problems in assessing manpower and training requirements for new weapon systems due to uncertainties in advancing technology and the lack of quantitative methods for determining total manpower requirements. In fact, manpower shortages and lack of adequate skills for new systems have been attributed to an insufficient assessment of manpower and training requirements. This is especially true for support-maintenance manpower, both military and civilian, which is usually estimated as a percentage of operational manpower. Manpower shortages in critical skill areas and increased training costs due to shorter lead times have resulted.

Objective

The objective of the research was to investigate the degree to which technological factors influence aviation maintenance manpower requirements in three generations of fighter/strike aircraft--the A-7, F-4, and F-14. The results of this investigation will, if successful, prove useful in forecasting maintenance manpower requirements for new aircraft.

Approach

Three major technology variables--system complexity, rate of technological change, and automation diagnostics--were addressed to determine their significance in formulating a methodology for forecasting maintenance manpower requirements for new aircraft. These variables were analyzed separately for the A-7, F-4, and F-14 aircraft systems. Then, total aircraft maintenance workload requirements for the study aircraft were analyzed, and conclusions drawn as to the extent these variables impacted on maintenance manhours per flying hour, distribution of workload among maintenance levels (organizational, intermediate, and depot), and distribution of workload among work centers (skills).

Results

1. Technology trends show an increase in unit reliability but more dramatic increases in density of functions and capabilities onboard aircraft.

2. Average maintenance manhours per flight hour increase as technology levels increase from the A-7 to the F-4 to the F-14. There is no trend in the data, however, when looking at technological changes across series within an aircraft type.

3. The most significant result of the analysis of rate of technological change is the high commonality of avionics, mission, and support equipment among the study aircraft. Even the newest and most technologically advanced aircraft, the F-14A, was found to have at least 52 percent of its items incorporated from existing technology onboard the A-7 and F-4 aircraft.

4. The F-14A has a significantly different maintenance distribution by levels than the other aircraft models, the biggest shift being from organizational level (down 20% from the other aircraft) to depot level (up 71% from the other aircraft). This was accompanied by a much greater use of commercial support (96% of total depot support) than for other aircraft.

5. Significant differences in the distribution of maintenance manhours across work centers among all aircraft were found. For example, the A-7E had a high concentration of maintenance in Electronics/Avionics, but hardly any work done in Fire Control. Conversely, the F-4J had a high concentration of maintenance in Fire Control, but a much lower percentage of work done in Electronics/Avionics.

6. Built-in-test-equipment (BITE) in the A-7E and the automatic diagnostic system onboard the F-14A reduced maintenance manhours per maintenance action (MMH/MA) at the organizational level and increased MMH/MA at the intermediate level, shifting the troubleshooting function from the organizational to the intermediate level. From the data, however, it was not possible to determine if the automatic diagnostic capability reduced no-fault removals.

Conclusions

1. Although new technology has improved component reliability (failures per part per flight hour), it has also permitted an increase in density of functions and capabilities (numbers of parts per subsystem). This has resulted in overall decreases in system reliability and increases in maintenance manpower requirements.

2. The rate of technological change, as measured by subsystem commonality, was found to have a large influence on manpower requirements. The greater the rate of technological changes, the greater effect that can be expected on manpower requirements.

3. Automation in diagnostics in naval aviation seems to be in a transitional state with only measurable application directed at the troubleshooting function.

4. The increased complexity of new technology and the establishment of automated troubleshooting (both on and off aircraft) indicates a shift of workload away from the squadron to the depot level, and newer aircraft (F-14A) show much greater use of commercial depot support as compared to other aircraft.

Recommendations

1. In forecasting manpower requirements for new aircraft, attention must be paid to equipment similarities as well as differences from existing systems.

2. In forecasting manpower requirements for new aircraft, system complexity must be addressed. This can be done by relating physical characteristics, such as size, weight, and number of parts, to maintenance manhour expenditures, for aircraft equipments or subsystems with similar functions.

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INTRODUCTION

Problem

The Navy has had problems in assessing manpower and training requirements for new weapon systems due to uncertainties in advancing technology and the lack of quantitative methods to determine total manpower requirements. Manpower shortages and lack of adequate skills for new systems have been attributed to insufficient assessment of manpower and training requirements. This is especially true for support-maintenance manpower, both military and civilian, which is usually estimated as a percentage of operational manpower. Manpower shortages in critical skill areas and increased training costs due to shorter lead times have resulted.

The need to place greater emphasis on controlling and forecasting the effects of new weapon system acquisitions on manpower requirements is not unique to the Navy. The Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics), in a memorandum for the Secretaries of all the Military Departments, has stated the need to conduct earlier and more comprehensive tradeoffs among manpower, system characteristics, and support concepts for major systems in development.[1] Manpower requirements considerations are becoming an integral part of the Defense Acquisition Review Council (DSARC) process.

Objective

The objective of the research was to investigate the degree to which technological factors such as system complexity, degree of automation, and rate of technological change influence aviation maintenance manpower requirements in three generations of fighter/strike aircraft--the A-7, F-4, and F-14. It is expected that the results of this investigation will prove useful in forecasting maintenance manpower requirements for new aircraft.

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[1]John P. White, Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics), Memorandum for Secretaries of the Military Departments, dated 17 August 1978, Subj: Manpower Analysis Requirements for System Acquisition.

APPROACH

Technological factors, as well as the rate of weapon system replacement may influence the size and skill mix of the total manpower force. Thus, these factors should be evaluated during the conceptual and developmental stages of weapon system acquisition to determine their effect on manpower and training requirements. In this way, it may be possible to avoid underestimating life cycle costs and to provide adequate lead times to develop new skills. Moreover, the introduction of new technology in succeeding generations of weapon systems may reflect trends that, in the long run, imply excessive levels of manpower.

Three major technology variables--system complexity, rate of technological change, and automation in diagnostics--were addressed to determine their significance in formulating a methodology for forecasting maintenance manpower requirements for new aircraft. These variables were analyzed separately for the A-7, F-4, and F-14 aircraft systems. Then, total aircraft maintenance workload requirements for the study aircraft were analyzed, and conclusions drawn as to the extent these variables influenced maintenance manhours per flying hour, distribution of workload among maintenance levels (organizational, intermediate, and depot), and distribution of workload among work centers (skills).

As systems become more complex, they may be more difficult to maintain. Consequently, they may affect the quantity and quality of maintenance requirements, as well as the distribution of those requirements among military, civilian, and contractor resources. System complexity was defined and measured in two ways:

1. Developments in reliability and maintainability of individual components or parts. Reliability refers to the frequency of failure; and maintainability, to the amount of effort (manhours) involved in preventive and corrective maintenance.

2. Changes in density of functions. The number of functions required of an individual aircraft has increased from one generation of aircraft to the next. Performance of these increased functions requires an increased number of components or parts. Technological advances have led to the miniaturization of these components, allowing them to be installed in smaller and smaller spaces. Thus, the term density of functions is common in modern aviation terminology.

The rate of technological change from one generation of aircraft to another can be measured by analyzing subsystem commonality across different aircraft types, models, and series (T/M/S). This measurement indicates the system complexity of a new aircraft relative to the system complexity of other aircraft in the Fleet, and shows the proportion of subsystems designed for new aircraft that have been incorporated from existing technology.

Finally, consideration has been given to automating diagnostics of aircraft systems for some time. New aircraft systems, such as the F-14 and F-18, have sophisticated onboard diagnostic capabilities. Major subsystems in the aircraft have built-in sensors that are queried by onboard computers, which are integral parts of the aircraft mission equipment.

In principle, automatic diagnostics apparently have a far-reaching impact on maintenance manpower requirements for new systems, particularly with the high rate of no-fault removals that have been experienced in aircraft support in the past. Further, it would appear that the availability of automatic diagnostics on mechanical systems would permit more difficult repairs to be done at the Intermediate (I) level, rather than having to forward the unserviceable items to the Depot (D) level for repair.

RESULTS

System Complexity

Recent developments in construction materials, electronics, optics, and other technical elements have increased potential component reliability and maintainability (R&M). In most instances, however, technological improvement has been accompanied by an increase in density of functions and capabilities. This point is illustrated by Figure 1, which shows how both reliability and complexity of the radar subsystems of the F-4 and A-7 families of aircraft have increased. The increases in the number of components or parts associated with each radar subsystem (Figure 1b) is particularly dramatic. The F-4J and A-7E aircraft are much more technologically sophisticated and capable (can perform more functions) than their respective predecessors, the F-4B and A-7B.

Each new generation of aircraft, from the A-7 to the F-4 to the F-14, reflects enhanced performance capabilities, as well as increased system complexity. The additional complexity and parts count of weapon system electronics have resulted in decreasing system reliability in spite of increased reliability of each individual component. A recent Navy report[2] showed that reliability of a particular aircraft type is inversely proportional to its weight, and that the average weight of a Navy fighter or attack aircraft has increased an average of 1.7 percent per year since 1961. Figure 2 shows reliability prediction by weight for the F-18 aircraft. Using historical relationships between reliability and weight, the F-18 was projected to have a mean flight-hours between failure (MFHBF) of 1.25 hours, or about one-third of 3.63 hours MFHBF estimated by the manufacturer, McDonnell-Douglas. Figure 2 also shows that from the A-7 to the F-4 to the F-14 aircraft, system reliability (MFHBF) has decreased.

Rate of Technological Change

The Department of Defense (DoD) has increasingly emphasized the value of technological continuity; that is, the means whereby past and present successful technology is incorporated into future designs, thereby reducing cost, development time, and risk of failure. Indeed, of the 34 major manned fighter bomber weapon systems developed by the Air Force and the Navy since the Korean War, only three with simultaneous development of new engines, airframes, and avionics reached full production without major developmental problems. All other aircraft that reached production successfully had only one or two components developed at the same time.

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[2] A Prediction of Aviation Logistics Requirements for the Decade 1985-1995, Naval Weapons Engineering Support Activity, June 1978, p. 4.

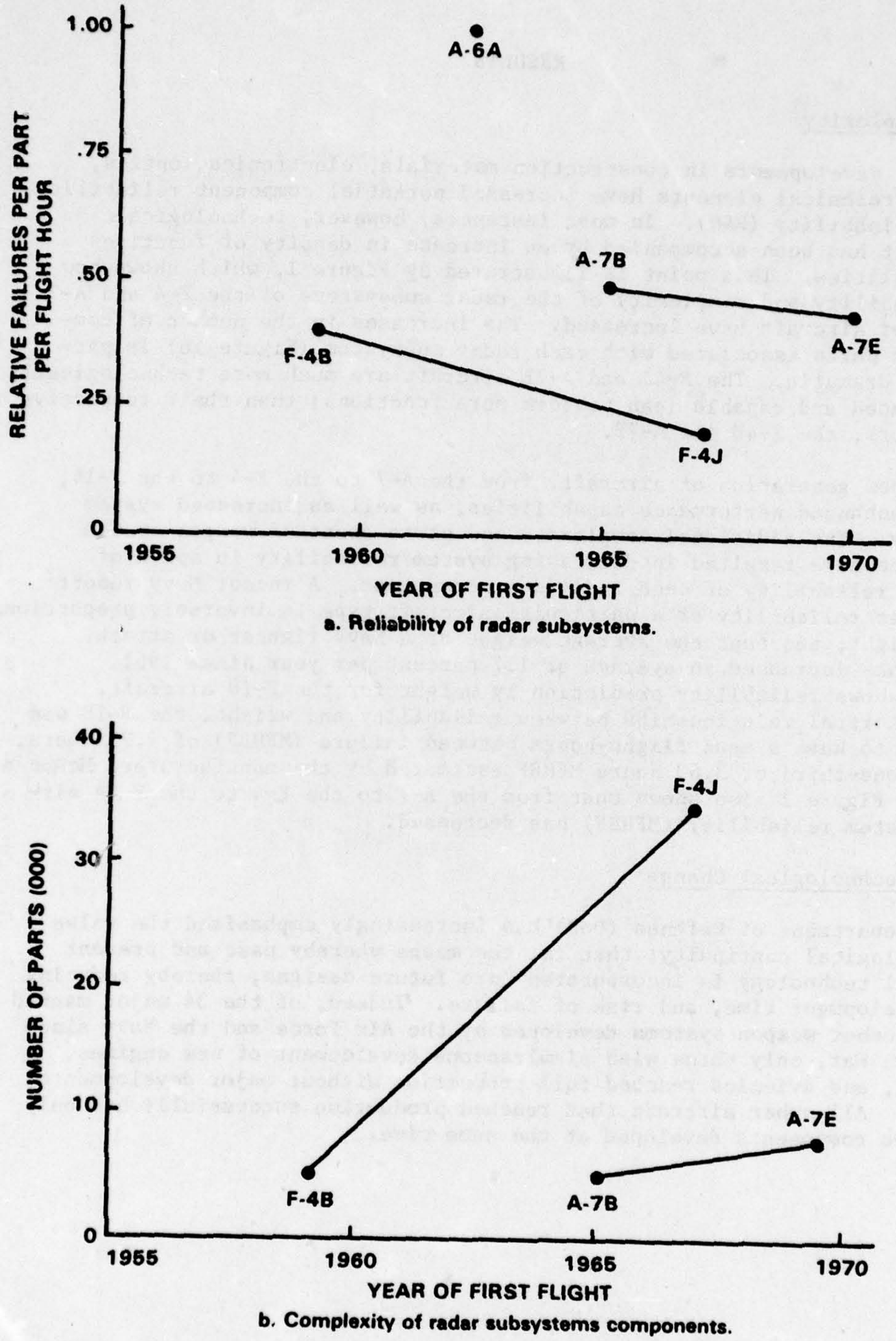

Figure 1. Changes in reliability and complexity of radar subsystems of F-4 and A-7 aircraft. Modified from Comptroller General of the United States report LCD-77-429. Operating and Support Costs of New Weapon Systems Compared with their Predecessors. Washington DC: October 1977.

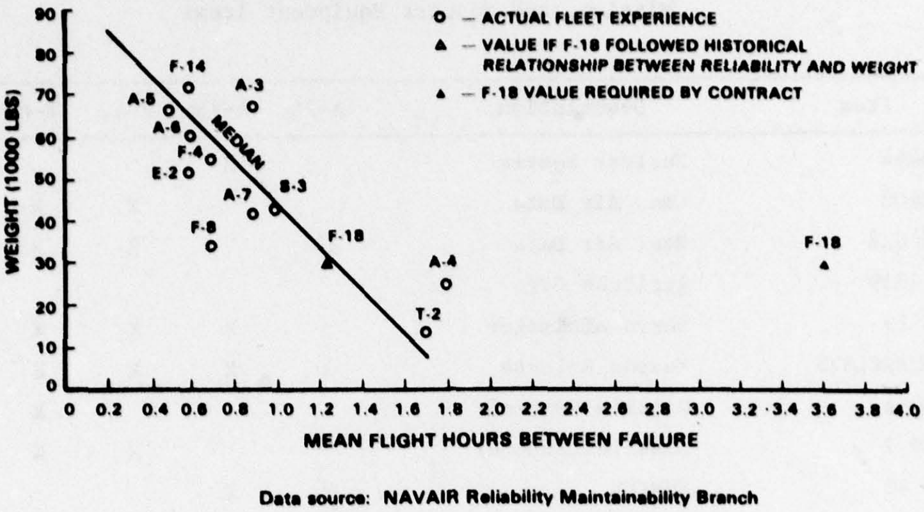

Figure 2. Reliability prediction by weight.
Source: A Prediction of Aviation Logistics Requirements for the Decade 1985-1995, Naval Weapons Engineering Support Activity, June 1978.

Subsystem Commonality

Because of the above, it is not surprising that the most striking characteristic of technology change is its essential continuity across generations of aircraft. To illustrate this fact, avionics, mission, and support equipment items were analyzed to determine commonality among the A-7B, A-7E, F-4J, F-4N, and F-14A aircraft. To be included in the analysis, items had to be sufficiently significant to merit an official identifying nomenclature and essential for weapon system support. The 165 items meeting these criteria, including 26 that are related to the Versatile Avionics Shop Test (VAST) system, are listed in Table 1. They range in function from major weapons (e.g., the AIM-54 Phoenix) to small gear (e.g., the PRC-63/90 survival radio). As shown, 71 of the 165 items are included in the A-7B, 80 in the A-7E, 69 in the F-45, 64 in the F-4N, and 91 in the F-14A. The table also shows that the VAST system introduced an element of discontinuity in avionic support, with the resultant required interface items being a source of additional support manpower requirements.

Table 1

Aircraft System Commonality--Avionics, Mission, and Support Equipment Items

Item	Description	A-7B	A-7E	F-4J	F-4N	F-14A
AA24B4	Nuclear System		X			
AA24G3	Cen. Air Data			X	X	
AA24G28	Cen. Air Data			X	X	
AA24G39	Attitude Gyro					X
AAU 19	Servo Altimeter		X	X	X	X
ACWPNRELSYS	Weapon Release	X	X	X	X	X
AERO 1	Missile Control	X			X	
AERO 7	Missile Launcher			X	X	
AGM 45	SHRIKE	X	X			
AGM 62	WALLEYE	X	X			
AIC 18	Intercomm.		X			
AIM 7	Sparrow Missile			X	X	X
AIM 9	Sidewinder Missile		X	X	X	X
AIM 54	Phoenix Missile					X
AITS	AV Integrated TX Sys.		X	X	X	X
AJB 3/7	Loft Bomb			X	X	
ALA 29	Countermeasures	X				
ALA 31	Countermeasures	X				
ALE 29	Chaff	X		X	X	X
ALE 39	CM Chaff		X			X
ALE 41	Chaff		X	X	X	
ALM 66	ECM Line Maint.	X	X	X	X	
ALM 69	GSE for GSE			X	X	
ALM 106	ECM ATE	X	X	X	X	
ALQ 126	ECM	X	X	X	X	X
ALR 45	ECM	X	X	X	X	X
ALR 50	Radar RX	X	X	X	X	X
AOA A7	Angle of Attack	X	X			
AOA F4	Angle of Attack			X	X	

No-Fault Removals vs. Automatic Diagnostic Capability

Table 1 (Continued)

Item	Description	A-7B	A-7E	F-4J	F-4N	F-14A
APM 378	Transponder Test		X			X
APN 141	Altimeter	X	X	X	X	
APN 153	Doppler	X				
APN 154	Radar Beacon	X	X	X	X	X
APN 190	Doppler		X			
APN 194	Radar Altimeter		X	X	X	X
APQ 116	Forward Radar	X				
APQ 126	Forward Radar		X			
APR 25	ECM Launch Alert	X	X	X		
APR 27	Launch Alert Sys.	X	X	X		X
APX 64	IFF	X				
APX 72	Transponder		X			X
APX 76	IFF			X	X	X
AR 150	MIARS	X	X	X	X	X
AR 151	MIARS	X	X	X	X	X
ARA 50	Direction Finder	X	X	X	X	X
ARA 63	Decode RX	X	X	X	X	X
ARC 51	UFF TRX	X	X			X
ARC 159	Radio	X	X	X	X	X
ARN 52	Tacan	X	X			
ARN 84	Tacan	X	X			X
ARN 105	Tacan	X				X
ARR 39	Forward Radar Pod		X			
ARR 69	Radio RX	X	X	X	X	X
ASA 32	Flight Control			X	X	
ASA 79	Display					X
ASCU	Armament Control		X			
ASN 39	Nav. Comp.			X	X	
ASN 41	Nav. Comp.	X				
ASN 50	Heading	X				
ASN 54	APP Power Comp.	X	X	X	X	

Table 1 (Continued)

Item	Description	A-7B	A-7E	F-4J	F-4N	F-14A
ASN 67	Display	X				
ASN 70	Vertical Ref.			X		
ASN 73	Heading Ref.	X				
ASN 90	Inertial Measure		X			
ASN 91	Weapon Delivery		X			
ASN 92	Inertial Guidance					X
ASN 99	Map Display	X	X			
ASN 105	APP Power Comp.					X
ASQ 19	Int. Elec. Ctl.			X	X	
ASW 25	Digital Comm.	X	X	X	X	
ASW 26	Auto. Flt. Cont.	X	X			
ASW 27	Digital Comp.					X
ASW 30	Auto. Flt. Cont.	X	X			
ASW 32	Auto. Flt. Cont.					X
ASW 37[a]	Wing Flap (VAST)					X
AVA 12	Vertical Display					X
AVG 8	Visual Target Sys.			X	X	
AVQ 7	Heads Up Display	X	X			
AWE 1	Weapon Release	X				
AWG 9	Weapon Control					X
AWG 10	Missile Control			X		
AWS 15	Fire Control					X
AWG 25	Harm Control		X			
AWW 1	Fuze Control	X	X	X	X	X
AWW 2	Fuze Control	X	X	X	X	X
AWW 4	Fuze Control	X	X	X	X	X
AXC 670-7	Air Data Compt.	X				
CATS	Comp. Auto. Test Sta.					X
CP 741A	Computer	X				

[a]Related to the Versatile Avionics Shop Test (VAST) system (N = 26).

Table 1 (Continued)

Item	Description	A-7B	A-7E	F-4J	F-4N	F-14A
CP953AJQ	Computer		X			
CP 1035A[a]	Dual Cont. Air Data					X
CP 1050	Signal Data Conv.					X
CP 8558A[a]	Environ. Cont.					X
CPU 82	Flt. Dir. Comp.			X	X	
CU 1466	Attitude Coupler	X	X			
DCU 179A[a]	Anti Skid Cont.					X
ECK 80A37JA	Fuel Flow					X
EMTC F-14	Elect. Mod. Test					X
FLQS	Fuel Lox Qty. Sys.	X	X	X	X	X
ID 1475	Digital Display			X	X	
ID 1481	Stand By Altitude					X
KD 26	Camera Scope			X	X	
KD 41	Camera Scope			X	X	
KIRIA KIT1A	Interro. TRX	X	X	X	X	X
KY28	Secure Voice	X	X	X	X	X
KY 74 KB 18	Photo Sys.		X			
LAU 7A	Missile Launcher	X	X	X	X	X
LAU 17A	Pylon Assem.			X	X	
LAU 92	Launcher					X
LAU 93	Phoenix Launcher					X
LS 460BAIC	Intercomm.					X
M 61	Gun System		X			
MCRS	Min. Comp. Repair Sta.	X	X	X	X	X
MER 7	Bomb Rack	X	X	X	X	X
MES A-7	Misc. Elect. Sys.	X	X			
MES F-4	Misc. Elect. Sys.			X	X	
MIES	Misc. Inst. Ele. Sys.					X

[a]Related to the Versatile Avionics Shop Test (VAST) system (N = 26).

Table 1 (Continued)

Item	Description	A-7B	A-7E	F-4J	F-4N	F-14A
MILA 22858	Attitude Ind. Sys.		X	X	X	
MK 4 Mod. 0	20mm Gun POD	X	X	X	X	
MMCRS	Micro MCRS	X	X	X	X	X
MMMCRS	Master MMCRS	X	X	X	X	X
MS 25447	Counting Accel. Gp.	X	X	X	X	X
MS 25448	Counting Accel. Gp.	X	X	X	X	X
MX 8278 ASQ	Destruct Igniter		X	X		
MX 8811 A[a]	Interface Blanker					
MX 9264 8253A	Interfer. Blanker		X	X		
OA 8794 USM	Electronic Equip.			X	X	X
OK 293 AWW	Guided Weap. Cont.		X			
PRC 49	Radio	X				
PRC 63/90 URT 33	Sur. Radio	X	X	X	X	X
R 1623 APN	RX Modulator	X	X			X
RMU 8	Tow Target Reel			X		
TER 7	Bomb Rack	X	X	X	X	X
TS 1843 APX	TRX Test Set	X	X			X
TTU 205	Press Temp. Test	X	X	X	X	X
USM 247[a]	VAST CGSE					X
USM 402	Swept Freq.	X	X	X	X	X
USM 406	Countermeas. Test		X	X	X	
WALLEYE Sys.	WALLEYE Weapon	X				
WCS A7	Weap. Cont. Sys.	X				
32-31000	Altitude Reporting			X	X	
32-87831	Interfer. Blanker				X	X
218 21136	Thermal Rad. Sys.		X	X		
220 09800	Video/Digital Sys.		X			
401 10083	Missile Sig.	X				
A51A9011[a]	Eng. Inst. Gp.					X
A51A9075-1[a]	Air Data Sngl. Comp.					X

[a]Related to the Versatile Avionics Shop Test (VAST) system (N = 26).

Table 1 (Continued)

Item	Description	A-7B	A-7E	F-4J	F-4N	F-14A
A51A9129[a]	Air Inlet Cont. Sys.					X
A51A10126-3[a]	Com. Nav. Comd. Panel					X
A51A20100[a]	Left Glove SW Assem.					X
A51A20101[a]	Right Glove SW Assem.					X
A51E9096-1[a]	Temp. Cont.					X
A51P9035-3[a]	Mach. Lever Trim					X
A51V Panels[a]	ID Panels					X
A51V Pallets[a]	ID Pallets					X
C 8571A[a]	Gun Control					X
C8612A[a]	Con. Pow. Windshield					X
C9128A[a]	Multi. Ch. Lt. Cont. A/C					X
CV 2441 ASW 27[a]	Conv. Data Link					X
ECK 80A 37J5[a]	Fuel Flow					X
Hydro/Mech[a]	Compnt. GSE					X
ID 1744AS[a]	Digital Data Ind.					X
ID 1758A[a]	Caution Advisor					X
ID 1759A[a]	Caution Advisor					X
MX 9467A[a]	Interfer. Blanker					X
Number		71	80	69	64	91

[a]Related to the Versatile Avionics Shop Test (VAST) system (N = 26).

The data were then analyzed to determine the commonality between pairs of aircraft. Results are provided in Table 2, which shows that the F-4J and the F-4N have the most items in common--63, which is 91 percent of those onboard the F-4J and 98 percent of those onboard the F-4N. The A-7B and the F-14A have the least items in common--34, but that still amounts to 48 percent of those onboard the A-7B and 37 percent of those onboard the F-14A. The F-14A has 44 items (48%) that are unique, and 47 (52%) that can be found on at least one of the other aircraft studied. Thus, the newest and most technologically advanced aircraft in the Fleet has over half of its items incorporated from existing technology. This significant finding should introduce an element of caution into claims for major manpower requirements changes in new generations of weapons systems through advanced technology. Thus, while any given element may change, the totality is heavily weighted in the direction of continuity.

Table 2

Commonality of Aircraft Pairs

Aircraft Pair[a]	Common Items	% Commonality
F-4J (69) vs. F-4N (64)	63	F-4J, 91%; F-4N, 98%
A-7B (71) vs. A-7E (80)	55	A-7B, 77%; A-7E, 69%
A-7E (80) vs. F-4J (69)	43	A-7E, 54%; F-4J, 62%
A-7E (80) vs. F-4N (64)	43	A-7E, 54%; F-4N, 67%
A-7E (80) vs. F-14A (91)	42	A-7E, 53%; F-14A, 46%
A-7B (71) vs. F-4J (69)	38	A-7B, 54%; F-4J, 55%
F-4J (69) vs. F-14A (91)	38	F-4J, 55%; F-14A, 42%
A-7B (71) vs. F-4N (64)	36	A-7B, 51%; F-4N, 56%
F-4N (64) vs. F-14A (91)	37	F-4N, 58%; F-14A, 42%
A-7B (71) vs. F-14A (91)	34	A-7B, 48%; F-14A, 37%
Range	34-63	37% - 98%

[a]Number of avionics and mission equipment items installed in each aircraft is shown in parentheses.

Model Continuity

To determine the commonality within a single type and model, a study was made of avionic items onboard the A-7 as it evolved from the B to the E series. Table 3 lists 93 avionic subsystems and major items, 53 of which are associated with the A-7B; and 76, with the A-7E. Of the A-7B items, 17 (32%) were deleted when the A-7E was introduced, and 36 (68%) were retained. Of the A-7E items, 40 (53%) are unique, and 36 (47%) are the same as those in the A-7B.

Table 3

A-7B to A-7E Avionic Subsystem Items

Item[a]	Deletions	Retentions	Additions
AA24B4			X
AAU19			X
ACWPNRELSYS			X
AGM45			X
AGM62			X
AIC18			X
AIM9			X
AITS			X
ALA29	X		
ALA31	X		
ALE29		X	
ALE39			X
ALE41			X
ALM66			X
ALM106			X
ALQ100		X	
ALQ126		X	
ALR45		X	
ALR50		X	
AOAA7			X
APM378			X
APN141		X	
APN153	X		
APN154		X	
APN190		X	
APN194		X	
APQ116	X		
APQ126		X	
APR25			X
APR27		X	
APX64	X		
APX72		X	
AR150			X
ARA50		X	
ARA63		X	
ARC51		X	
ARC159	X		
ARN52		X	
ARN84	X		
ARN105	X		
ARR69		X	
ARR154	X		
ASCU		X	
ASN41	X		
ASN50	X		
ASN54		X	

[a]These items are subsets of the avionics items presented in Table 1.

Table 3 (Continued)

Item[a]	Deletions	Retentions	Additions
ASN67	X		
ASN73	X		
ASN90		X	
ASN91		X	
ASN99		X	
ASW25		X	
ASW26		X	
ASW30		X	
AVQ7		X	
AWE1	X		
AWW1		X	
AWW2		X	
AWW4		X	
AXC670-7	X		
CP741A	X		
CP953AJQ		X	
CU14665835		X	
FLQS			X
KIRIA KIT1A			X
KY28		X	
KY741KB18			X
LAU7A			X
M61			X
MCRS			X
MER7			X
MESA-7		X	
MILA22858			X
MK4MODO			X
MMCRS			X
MMMCRS			X
MS25447			X
MS25448			X
MX8278AASQ			X
MX9264			X
OA8794VSM			X
OK293AWW			X
PRC63/90URT33			X
R1623APN		X	
TER7			X
TS1843APX		X	
TTU205			X
USM402			X
USM406		X	
WALLEYE SYS.			X
WCSA7	X		
218-21136			X
220-09800			X
Number	17	36	40

[a]These items are subsets of the avionics items presented in Table 1.

Figure 3 is a Venn diagram of the intersection between the A-7B and A-7E avionic suites. In point of fact, this continuity between series is considerably greater than 68 percent since the significant number of electromechanical subsystems and the airframe itself, which are continued unchanged between series, were not considered. Thus, in general, there is major technological continuity within any aviation system type and model.

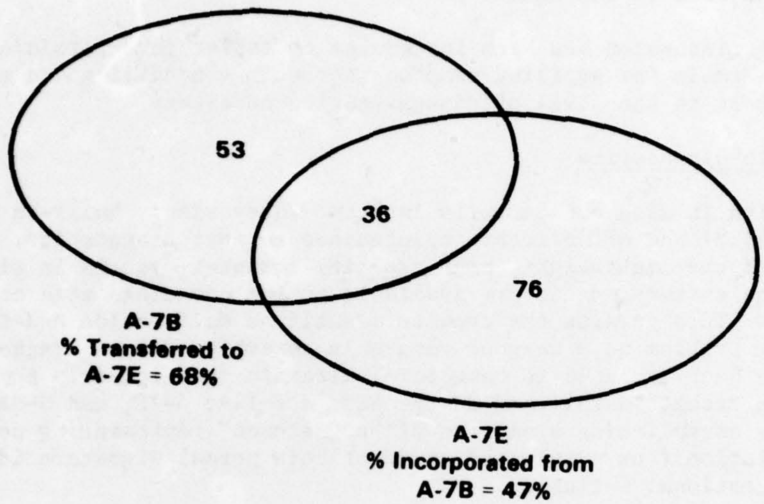

Figure 3. Venn diagram of the intersection of A-7B and A-7E avionic suites.

Table 3 presents the state of commonality at about the 1968-1971 time period, when the A-7E was introduced to the Fleet; and Table 1, in late 1977. Table 3 illustrates the significant technology transfer associated with a T/M/S introduction, and Table 1 demonstrates the greater degree of commonality achieved by progressively including changes in model types. For example, Table 1 shows that the A-7B was upgraded after the 1968-1971 time period to include items originally installed on the A-7E. Thus, the two tables do not (and should not) match up; rather, they jointly illustrate the flow of avionic technology and the stages in which it is introduced into naval aviation.

Block Number Differences

The emphasis placed on continuity across models and generations of aircraft should be tempered by a corresponding recognition of differences across individual aircraft. Although it is not surprising when there are major differences between airframes of different models, there are also differences--even though they are less obvious--within a single T/M/S. The practical significance of these differences is to limit the aggregation of airframe subsystems into a single fully controlled configuration.

Table 4 traces the evolution of the F-4 airframe over a period of about 10 years. The first column lists block numbers corresponding with a sequential series of aircraft bureau numbers. Thus, Block No. 6f comprises 24 F-4B aircraft that were not converted to F-4Ns; and Block No. 28ab, 18 F-4Bs that were converted to F-4Ns. Significant aircraft service changes (ASCs) or airframe changes (AFCs) were incorporated with, and as a part of the requirement for, block number change. Also, partial--as well as full--retrofit of changes--are associated with specific blocks. Therefore, at any point in time, aircraft of the same T/M/S will differ in various specific part numbers. Thus, individual block identification is pertinent and must be continued.

This discussion has been introduced to assist in determining the appropriate domain for applying manpower technology modelling and to provide insight as to the level of disaggregation necessary.

Automation in Diagnostics

Automation in diagnostics falls into two categories: built-in test equipment (BITE) and off-aircraft maintenance support diagnostics. With the advent of the lightweight, high capacity computer systems in airborne weapons systems, means are available to include diagnostic capability in aircraft. This permits the crew to identify a malfunction and to isolate the specific problem to a weapons removable assembly (WRA). Diagnostic systems have been included in commercial aircraft (particularly those introduced within recent years), and in the Navy's F-14A, A-7E, and S-3A aircraft. They work by establishing a pattern of "signatures" representing normal operations. Deviation from a selected range of this normal signature identifies a system operational failure.

The major avionic system currently in use for off-aircraft maintenance support diagnostics is the Versatile Avionics Shop Test (VAST) system (see Table 1). NAVAIR specifications require that all new procurement aircraft avionic subsystems be VAST compatible. This means that the major WRAs (principally, avionics and mission equipment) must include circuitry (or interfaces) that permits testing at a VAST station.

Manhours Per Maintenance Action vs. Automatic Diagnostic Capability

The initial investigation into this area attempted to relate support requirements to a given system across the aircraft under study, to determine if there were differences. Although the F-4 has essentially no significant diagnostic capability in the sense used here, the A-7E and F-14 have extensive on and off-aircraft diagnostics. Thus, the final investigation consisted of evaluating maintenance manhours per maintenance action (MMH/MA) for unscheduled maintenance by Work Unit Codes (WUCs) applicable to avionics and mission equipment at both organizational and intermediate levels. It was hypothesized that:

1. If diagnostics permitted fault isolation to the WRA, organizational level (ML_1) MMH/MA should be reduced because the troubleshooting phase would be reduced or even eliminated.

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Table 4

Evolution of F-4 Airframe through the B and N Series

Block Number	Corresponding Series of Aircraft Bureau Numbers		F-4B	F-4N	No. of Aircraft	Aircraft Service or Airframe Changes (ASC/AFC)
6f	148363f	148386f	X		24	
7g	148387g	148410g	X		24	AFC 86
8h	148411h	148434h	X		24	ASC 42
9i	149403i	149426i	X		24	(None)
10j	149427j	149450j	X		24	(None)
11k	149451k	149474k	X		24	(None)
12L	150406L	150435L	X	X	30	ASC 17/78 AFC 160
13m	150436m	150479m	X	X	44	ASC 92/115/133
14n	150480n	150651n	X	X	42	ASC 125
15o	150652o	150653o	X	X	2	ASC 69 AFC 151/305
	and					
	150993o	151021o	X	X	29	
16p	151397p	151426p	X	X	30	ASC 139
17q	151427q	151447q	X	X	21	(None)
18r	151448r	151472r	X	X	25	ASC 153 AFC 158/190
19s	151473s	151497s	X	X	25	ASC 186 AFC 176/216
20t	151498t	151519t	X	X	22	AFC 162/178/217
	and					
	152207t	152215t	X	X	9	
21u	152216	152243	X	X	28	AFC 262
22v	152244	152272	X	X	29	AFC 165/173/174/193
23w	152273	152304	X	X	32	AFC 202/213/241/267
24x	152305	152231	X	X	27	AFC 203
25y	152965	152994	X	X	30	AFC 172/220/273/317
26z	152995	153029	X	X	35	AFC 218/227/274
27aa	153030	153056	X	X	27	AFC 249/252/263
28ab	153057	153070	X	X	14	(None)
	and					
	153912	153915	X	X	4	

<u>Note</u>. Although there are over 550 AFCs, those after number 317 are not identified with blocks of aircraft bureau numbers.

2. If there were any significant reduction in no-fault removals because of the diagnostic capability, the MMH/MA at the intermediate level (ML_2) activity should be increased, since the data will reflect primarily the repair functions as opposed to an inspection and return to Ready for Issue (RFI).

The principal data source used in this investigation was the Naval Aviation Logistics Command Management Information System--Operations and Subsystem Report (NALCOMIS-O&S)/(VAMOSC/AIR) Maintenance Subsystem Report.

Table 5 shows the MMH/MAs at ML_1 and ML_2 for unscheduled maintenance by work unit code for the eight aircraft being studied, and the average MMH/MAs across those aircraft. Although a consistent time period was not available in the sample data, tests across time periods (where available) indicated no major divergence. This sample is thus considered representative for the intended purpose.

Table 5 also includes the ratios of aircraft subsystem ML_1 and ML_2 MMH/MAs to the group average MMH/MAs for the eight aircraft. To establish an index for each of the eight aircraft, the data associated with the individual WUCs were averaged across the 12 WUCs for both maintenance levels. This effort provides some interesting results.

Within the A-7 model, results for A-7A, B, and C are fairly consistent for both maintenance levels. For A-7E, however, the average ML_1 MMH/MA is somewhat lower than the average for the A, B, and C models, while ML_2 MMH/MA is much higher.

The three F-4 series had a large increase in organizational effort compared to the A-7s. Of even more interest are the results for the F-14A. The MMH/MA for this aircraft at ML_1 is the lowest, while that at ML_2 is next to the highest.

These results clearly show that automatic diagnostics onboard an aircraft have the effect of reducing MMH/MA at the organizational level (ML_1) and increasing it at the intermediate level (ML_2); that is, the troubleshooting function is shifted from ML_1 to ML_2. This infers that BITE in the A-7E, and the automatic diagnostic system onboard the F-14A, influence the manpower distribution requirements, as applied to an individual maintenance action. This does not consider, however, that F-14A is the most complex of the aircraft under investigation, and that the total number of systems and WRAs onboard this vehicle is considerably higher than that for the other aircraft. Thus, the direct influence of this manpower shift cannot be quantified in terms of specific personnel requirements unless it is related to the total support requirements.

Table 5

Maintenance Manhours Per Maintenance Action (MMH/MA) at Organizational (ML_1) and Intermediate (ML_2) Levels

(Unscheduled Maintenance)

Work Unit Code	A-7A (FY76)		A-7B (FY76)		A-7C (FY76)		A-7E (FY7T)		F-4B (FY7T)		F-4J (FY7T)		F-4N (FY7T)		F-14A (FY7T)		Group Average
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
Organizational Level (ML_1)																	
Avionics																	
63	2.4	1.06	2.3	1.02	2.1	.93	2.0	.89	1.5	.66	2.6	1.15	2.8	1.24	2.4	1.06	2.26
64	2.7	.92	2.3	.79	4.7	1.60	3.4	1.16	3.9	1.33	1.7	.58	2.4	.82	2.3	.79	2.93
65	2.0	.82	2.1	.86	2.0	.82	2.1	.86	3.8	1.56	2.4	.99	2.3	.95	2.7	1.11	2.43
66	1.3	1.00	1.1	.85	2.3	1.77	0.8	.61	2.3	1.77	1.1	.85	0.7	.54	0.8	.62	1.30
67	1.6	.78	2.0	.97	1.3	.63	1.6	.78	3.3	1.60	2.2	1.07	2.9	1.41	1.6	.78	2.06
Mission Equip.																	
71	2.6	1.00	2.8	1.08	2.9	1.12	2.4	.92	1.3	.50	2.7	1.04	3.4	1.31	2.7	1.04	2.60
72	2.8	.82	3.0	.88	2.7	.79	2.4	.70	8.4	2.45	2.7	.79	3.0	.88	2.4	.70	3.43
73	2.6	.72	2.8	.77	3.7	1.02	3.4	.94	4.6	1.27	3.5	.96	5.8	1.60	2.6	.72	3.63
74	4.9	1.21	3.7	.91	2.9	.72	2.8	.69	5.4	1.33	5.1	1.26	4.4	1.09	3.2	.79	4.05
75	3.2	1.06	3.1	1.03	2.8	.93	2.7	.90	3.8	1.26	2.8	.93	2.6	.86	3.1	1.02	3.01
76	4.3	1.25	4.1	1.19	2.1	.61	3.2	.93	2.0	.58	5.1	1.48	2.8	.81	4.0	1.16	3.45
77	1.7	.64	1.7	.64	2.2	.83	3.6	1.36	4.0	1.52	3.4	1.29	1.9	.72	0.0	—	2.64
Average ML_1 Ratio to Group Average		.94		.92		.98		.90		1.32		1.03		1.02		.89	
Intermediate Level (ML_2)																	
Avionics																	
63	5.4	.77	5.7	.81	5.5	.78	5.2	.74	19.7	2.79	5.9	.84	5.8	.82	3.2	.45	7.05
64	0.0	—	0.0	—	5.4	1.33	6.9	1.70	2.0	.49	4.4	1.09	3.0	.74	2.6	.64	4.05
65	5.4	1.30	4.9	1.18	3.4	.82	4.4	1.06	2.3	.56	4.8	1.16	3.7	.89	4.2	1.01	4.14
66	1.7	.77	3.2	1.45	2.0	.91	3.6	1.63	0.0	—	2.0	.91	1.5	.68	1.5	.68	2.21
67	1.8	.34	2.6	.49	11.0	2.05	4.7	.88	5.2	.97	6.0	1.12	5.8	1.08	5.8	1.08	5.36
Mission Equip.																	
71	6.8	1.75	4.7	1.21	5.0	1.29	4.2	1.08	2.0	.51	2.9	.75	2.8	.72	2.7	.69	3.89
72	6.2	1.25	4.7	.95	3.1	.63	3.5	.71	12.0	2.42	3.6	.73	5.0	1.01	1.6	.32	4.96
73	7.6	1.13	4.3	.64	7.4	1.11	8.9	1.33	3.1	.46	4.4	.66	4.3	.65	13.7	2.04	6.71
74	11.5	1.39	8.3	1.01	10.4	1.26	7.1	.86	7.9	.96	5.7	.69	6.5	.79	8.6	1.04	8.25
75	3.0	.82	5.3	1.45	2.8	.77	3.0	.84	1.1	.30	4.2	1.15	3.1	.85	6.8	1.86	3.66
76	9.3	.88	9.8	.92	10.3	.97	8.9	.84	0.0	—	8.2	.77	8.6	.81	19.3	1.82	10.63
77	1.5	.50	2.5	.83	1.0	.33	5.0	1.66	0.0	—	2.2	.73	5.9	1.95	0.0	—	3.02
Average ML_2 Ratio to Group Average		.99		.99		1.02		1.11		1.05		.88		.92		1.06	
Ratio of $\frac{ML_2}{ML_1}$		1.05		1.08		1.04		1.23		.78		.85		.90		1.19	
Level of Automatic Diagnostics	Very Limited		Very Limited		Very Limited		Limited		None		None		None		Extensive		

Note. Percent (%) refers to the ratio of aircraft subsystem MMH/MA at ML_1 and ML_2 levels to group average.

No-Fault Removals vs. Automatic Diagnostic Capability

Table 6, which summarizes the extent of no-fault removals (NFR) for the study aircraft, shows that the percentage of NFR for the A-7E is lower than that for the A and B models. Further, for the F-14A, which has substantial diagnostics systems, the percentage of NFR is exceptionally higher compared with the other study aircraft.

Table 6

Extent of No-Fault Removals (NFR)--Intermediate Level
(January-June 1977)

Aircraft	Total Items Processed	Items BCM[a]	Net Items	NFR Items	% of NFR Items
A-7A	6868	2008	4860	919	18.91
A-7B	9983	3581	6402	1123	17.54
A-7E	40729	13494	27235	3985	14.63
F-4B	869	334	535	103	19.25
F-4J	45381	15784	29597	5947	20.09
F-4N	20495	6554	13941	2621	18.80
F-14A	24664	8760	15904	4543	28.57

[a]Beyond capability of maintenance at the I level.

Since there is no way of evaluating the F-14 in "before and after" application of diagnostics, there is no apparent means of assessing the application of automation to this aircraft. Conceivably, the relative newness and density of sophisticated avionics and mission equipment in the F-14As are the major contributing factors to the high NFR rates: NFRs might have been significantly higher if diagnostics were not available. Validation tests or quantification of this conjecture, however, have not been performed. In general, diagnostic capability in the vehicle theoretically should reduce NFRs (with a resulting decrease in intermediate level requirements), as evidenced in the A-7E system.

Aircraft Maintenance Workload Requirements

The investigation of maintenance support requirements covers the operational inventory of the aircraft by T/M/S for FYs 75, 76, and 7T. Table 7 sets forth a summary of this inventory and the average flying hours per aircraft month during the three time periods. Although VAMOSC reports covering four time periods were not available during the course of this study, the data base is adequate for program objective.

Table 7

Aircraft Operations Data Base

	Number of Operational Aircraft			Flying Hours Per Aircraft Month		
Aircraft T/M/S	FY75	FY76	FY7T	FY75	FY76	FY7T
A-7B	91	92	81	45.5	31.2	34.3
A-7C	36	--[a]	28	20.8	--[a]	17.9
A-7E	--[a]	--[a]	287	--[a]	--[a]	32.8
F-4B	74	--[a]	20	19.9	--[a]	10.2
F-4J	259	231	293	27.6	28.4	20.8
F-4N	76	113	152	34.7	28.4	23.6
F-14A	77	126	178	21.2	20.7	18.3

[a]Compatible VAMOSC-AIR data not available.

Maintenance Level Distribution

Based on the total flying hours achieved over the time period studied, maintenance manhours per flying hour (MMH/FH) were determined for each T/M/S aircraft, separately identified by type of maintenance and summarized for the total level of maintenance. To reflect total maintenance support for a weapon system, commercial depot manhours were estimated and included in the results. Accordingly, Depot (D) level cost data for the component rework presented in the VAMOSC-AIR maintenance support reporting system were reviewed to determine the extent of commercial assistance in D level repair.

Table 8 presents a summary of the data base used in this study. The labor costs for the component rework program at the NARF and commercial rework facilities were abstracted for each T/M/S aircraft by the individual time period included in the sample data. These labor costs were then summed and the percent of labor consumed at the NARF was compared to that contracted to a commercial activity. Since the specific labor rates for commercial activities are not available in the data base, it was assumed that the commercial rates, which include direct labor, overhead, and profit margin, would be approximately equal to a NARF labor rate plus indirect and overhead charges. This assumption permits the extension of the data base to incorporate supplementary commercial labor required at the D level support.

It is interesting to note from Table 8 that 96 percent of the D level support of the F-14A component rework program has been contracted. Also, the amount of contract support for the A-7E--45 percent--is exceptionally high compared to the other aircraft in the samples.

Table 8

Depot Level Component Rework--NARF vs. Commercial Labor

Aircraft	Time Period (FY)	NARF $K	NARF Percent	Commercial $K	Commercial Percent	Total $K	Total Percent
A-7B	75	3128	88.16	420	11.84	3548	100.00
	76	2534	83.99	483	16.01	3017	100.00
	7T	414	82.47	88	17.53	502	100.00
Average			85.98		14.02		
A-7C	75	706	75.91	224	24.09	930	100.00
	76	--	--	--	--	--	--
	7T	114	77.03	34	22.97	148	100.00
Average			76.07		23.93		
A-7E	75	--	--	--	--	--	--
	76	--	--	--	--	--	--
	7T	1127	54.50	941	45.50	2068	100.00
Average			54.50		45.50		
F-4B	75	1801	96.52	65	3.48	1866	100.00
	76	--	--	--	--	--	--
	7T	86	97.73	2	2.27	88	100.00
Average			96.57		3.43		
F-4J	75	6685	64.80	3632	35.20	10317	100.00
	76	6841	72.97	2534	27.03	9375	100.00
	7T	1533	72.62	578	27.38	2111	100.00
Average			69.07		30.93		
F-4N	75	2158	84.79	387	15.21	2545	100.00
	76	3721	82.89	768	17.11	4489	100.00
	7T	862	88.59	111	11.41	973	100.00
Average			84.19		15.81		
F-14A	75	270	3.80	6843	96.20	7113	100.00
	76	373	3.47	10368	96.53	10741	100.00
	7T	124	4.28	2776	95.72	2900	100.00
Average			3.70		96.30		

Note. Source--VAMOSC Air MS Reports.

Table 9 presents, for the aircraft models studied, the total maintenance manhours per flying hour (MMH/FH) by the three maintenance levels. The data in this table are very interesting, particulary if we agree that the A-7 is the least technologically advanced; and the F-14, the most technologically advanced. The average MMH/FH is greater as technology increases from the A-7 to the F-4 to the F-14. This also holds for each maintenance level. These results are not surprising, since it was shown earlier that system reliability has decreased. There is no uniform trend in the data, however, when looking at technological changes within an aircraft type. For example, for the A-7 aircraft, the total MMH/FH increases as the plane evolves from the earlier B series to the E. For the F-4 aircraft, however, the total MMH/FH decreases with the newer series aircraft.

In regard to percentage distribution of MMH/FH, Table 9 shows that the F-14A, the newest and most sophisticated aircraft, requires a significantly different maintenance distribution than the six other aircraft models, particularly with regard to the organizational and depot maintenance levels. As shown, 53 percent of the F-14A's MMH/FH is performed at the organizational level; and 29 percent, at the depot level--compared to 66 and 17 percent for the other aircraft combined. These findings can be explained by the rapid pace of depot level technical changes during the F-14A's life cycle stage, and the lack of adequate skills and knowledge needed for the new system.

Work Center Distribution

To investigate the influence of technology on skill requirements, the percentage distribution of MMHs was determined for each aircraft model. Of all the types of maintenance performed, unscheduled maintenance is most reflective of skill requirements because of its troubleshooting and special correction requirements. Table 10 presents the percentage distribution of unscheduled organizational and intermediate MMHs across work centers by T/M/S.[3] As shown, at both levels, there were significant differences among aircraft in the distribution of maintenance manhours across work centers. For example, the A-7E had a high concentration of its maintenance done in work center 210, Electronics/Avionics, but hardly any work done in work center 211, Fire Control. On the other hand, the F-4J had a high concentration of its maintenance done in Fire Control, but a much lower percentage in Electronics/Avionics. The F-14A, because of its highly complicated engine, engine installations, and afterburner, had an extremely high concentration of maintenance done in work center 110, Power Plants, with the percentages of work done--at both levels--being nearly twice as high as those for the F-4B.

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[3]The percentage distribution of manhours across work centers at the depot level is not available because of the large amount of depot work done at commercial activities.

Table 9

Maintenance Manhours/Flying Hour (MH/FH) by Maintenance Level

Aircraft Type	Organizational Level		Intermediate Level		Depot (D) Level						Total	
					NARF		Commercial		D Total			
	N	%	N	%	N	%	N	%	N	%	N	%
A-7B	12.96	64.9	3.25	16.3	3.22	16.1	0.53	2.7	3.75	18.8	19.96	100.0
A-7C	16.50	66.2	3.20	12.9	3.96	15.9	1.25	5.0	5.21	20.9	24.91	100.0
A-7E	16.58	69.0	4.07	17.0	1.83	7.6	1.53	6.4	3.36	14.0	24.01	100.0
F-4B	27.67	64.3	8.88	20.7	6.25	14.5	0.22	0.5	6.47	15.0	43.02	100.0
F-4J	26.42	65.1	6.71	16.6	5.13	12.6	2.30	5.7	7.43	18.3	40.56	100.0
F-4N	23.79	67.0	5.68	16.0	5.09	14.3	0.96	2.7	6.05	17.0	35.52	100.0
F-14A	31.57	52.6	10.83	18.1	0.65	1.1	16.92	28.2	17.57	29.3	59.97	100.0

Table 10

Percentage Distribution of Unscheduled Organizational and Intermediate Maintenance Manhours Across Work Centers

Work Center	Principal Function	Aircraft T/M/S						
		A-7B	A-7C	A-7E	F-4B	F-4J	F-4N	F-14A
	Organizational Level (ML_1)							
110	Power Plants	9.3	9.8	13.2	9.1	7.6	7.6	18.0
120	Hydraulics and Structures	31.6	29.0	28.9	37.6	34.0	38.6	30.8
130	Aviators' Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
131	Safety Equipment	0.9	0.9	0.6	0.7	0.6	0.6	0.3
140	Planned Maintenance	0.0	0.0	0.0	0.0	0.0	0.0	0.0
210	Electronics/Avionics	18.2	29.2	29.2	11.5	10.2	11.6	9.1
211	Fire Control	9.0	1.2	1.8	12.6	21.2	14.5	11.7
212	Integrated Weapons Sys.	11.8	11.5	10.3	10.7	11.4	12.5	14.0
220	Electrical/Instrument	19.0	18.5	16.1	17.8	15.1	14.8	16.4
	Intermediate Level (ML_2)							
110	Power Plants	3.7	2.6	4.2	9.9	8.3	4.9	17.9
120	Hydraulics and Structures	17.4	16.1	14.2	17.6	13.8	15.7	12.4
130	Aviators' Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
131	Safety Equipment	0.7	1.3	0.4	1.8	1.3	1.3	0.5
140	Planned Maintenance	0.0	0.0	0.0	0.0	0.0	0.0	0.0
210	Electronics/Avionics	41.3	59.5	63.8	27.9	24.3	31.1	21.6
211	Fire Control	14.1	2.3	2.1	29.0	33.7	30.6	28.2
212	Integrated Weapons Sys.	6.4	7.7	5.0	2.7	4.1	3.9	3.6
220	Electrical/Instrument	16.4	10.6	10.3	11.2	14.5	12.6	15.9

CONCLUSIONS

1. Although new technology has improved component reliability (failures per part per flight hour), it has also permitted an increase in density of functions and capabilities (number of parts per subsystem). This has resulted in overall decreases in system reliability and increases in maintenance manpower requirements.

2. The rate of technological change, as measured by subsystem commonality, is significantly related to manpower requirements. The greater the rate of technological change, the greater the effect to be expected on manpower requirements.

3. Automation in diagnostics in naval aviation seems to be in a transitional state with only measurable application directed at the troubleshooting function. Since this involves about 5 percent of the total effort at organizational and intermediate levels of support, and since automation has been limited to mission and other avionic equipment, the maximum impact (on reduction of requirements) cannot exceed this value. Hence, no significant effect of automation in diagnostics on manpower requirements can be demonstrated.

4. The increased complexity of new technology and the establishment of automated troubleshooting (both on and off aircraft) indicates a shift of workload away from the squadron to the depot level, and newer aircraft (F-14A) show much greater use of commercial depot support as compared to other aircraft.

5. There are significant differences among aircraft T/M/S, not only in total maintenance manpower requirements but also in the distribution of maintenance manhours across work centers. Thus, forecasting and modelling of aircraft maintenance requirements should include a consideration of general skill area requirements (electrical/mechanical).

RECOMMENDATIONS

1. Several probes into the rate of technological change across types, models, and series (T/M/S) of aircraft show high commonality of mission and support equipments. Thus, in forecasting manpower requirements for new aircraft, attention must be paid to equipment similarities as well as differences from existing systems.

2. In forecasting manpower requirements for new aircraft, system complexity can be addressed by relating physical characteristics, such as size, weight, and number of parts, to maintenance manhour expenditures for aircraft equipments or subsystems with similar functions.

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