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INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS): USER FIELD DEMONSTRATION AND TEST

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13. ABSTRACT *(Maximum 200 words)*

This report presents the results of a field test and demonstration of the Integrated Maintenance Information System (IMIS). The IMIS project was an advanced development demonstration project which developed and field tested the technology to provide the maintenance technician with the capability to access all of the technical information (interactive electronic technical manuals, interactive diagnostics instructions, work orders, supply availability and ordering, historical data, training material, etc.) required to maintain aircraft via a single, integrated system, regardless of the source of that information. In the final phase of the project, an IMIS Demonstration System was developed and tested. In the field test, the performance of technicians on troubleshooting tasks when using the IMIS Demonstration System was compared with their performance on comparable tasks when using the paper technical orders. Test results indicated that technicians were able to perform the tasks significantly faster, used fewer parts, and made fewer serious errors when using the IMIS. In addition, the test indicated that, when using the IMIS, non-specialist (crew chief) technicians could perform the tasks as effectively as the specialists.

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PREFACE

Since the late 1970s, the Logistics Research Division of the Armstrong Laboratory has conducted research to develop and evaluate the technology for an Integrated Maintenance Information System (IMIS). An IMIS will provide maintenance technicians and managers with the capability to access all technical information required to perform their jobs via a single, integrated system. The final phase of the IMIS program was to develop a demonstration system incorporating the technologies and illustrating the capabilities of an IMIS. This report summarizes the results of a user field test and demonstration conducted to evaluate the IMIS and demonstrate its capabilities to operational maintenance personnel. The user field test and demonstration was conducted at Luke AFB, AZ, during the summer of 1994.

The IMIS is the product of the creativity, talents, and efforts of many people, including Armstrong Laboratory personnel and a number of contractors. The IMIS program was initiated and directed by Mr. Robert C. Johnson, Operational Logistics Branch, Armstrong Laboratory's Logistic Research Division (AL/HRGO). The program was accomplished by a dedicated staff of scientists and engineers, with the strong support of three Division Chiefs: Mr. Bertram W. Cream, Col. James C. Clark, and Col. Donald C. Tetmeyer.

The prime contractor for the development of the IMIS Demonstration System was GDE Systems, with its subcontractors Applied Science Associates, Inc., Softech, and Systems Control Technology. In addition, technical support was provided to the Laboratory by NCI Information Systems, the University of Dayton Research Institute, Computer Sciences Corporation, RJO Enterprises, and Robins-Gioia, Inc. Additional support was received from the Lockheed Corporation, under the sponsorship of the F-16 System Program Office.

The user demonstration and field test could not have been accomplished without the generous support of the host unit, the 310th Fighter Squadron. The efforts of Capts. Tribble and Ramero, CMSgt Rios, and the technicians and supervisors under their command were a major factor in the success of the field test.

INTEGRATED MAINTENANCE INFORMATION SYSTEM: DEMONSTRATION AND FIELD TEST

SUMMARY

This report summarizes the results of the final phase of a program to develop and evaluate the concept of an Integrated Maintenance Information System (IMIS). IMIS will provide maintenance technicians and managers with the capability to access all the technical information required to perform their jobs via a single, integrated system. The project developed and field tested the technologies to implement the concept. The technologies were then implemented in a demonstration system for evaluation. Technological developments include advances in the areas of interactive electronic technical manuals (IETMs); interactive, computer-generated diagnostics; human/computer interface; special purpose portable computers; and integration of divergent data bases. An IMIS demonstration system, applying these technologies, was developed and evaluated.

The IMIS program was established to evaluate the IMIS concept and to develop and test the technology required for an operational IMIS. Major activities under the program included:

a. Comprehensive analysis of maintenance information requirements to serve as the baseline for developing IMIS;

b. Research to develop an advanced, interactive, diagnostic-aiding capability;

c. Research to develop effective human/computer interface and technical information presentation techniques to make IMIS easy to use and an effective means of communicating technical information;

d. Development of a methodology for authoring and coding IETMs (technical orders [TOs]) in an efficient and cost effective manner, which provides flexibility and reduces redundancy;

e. Development of demonstration portable maintenance aids (PMAs) using off-the-shelf components; and

f. Development of an IMIS demonstration system which incorporates the major features and functions of IMIS for use in evaluating IMIS technology and validating requirements.

The IMIS Demonstration System was evaluated in a three-phase field test at Luke Air Force Base (AFB), AZ, in the spring and summer of 1994. This report summarizes the findings of the third phase of the evaluation, a test to evaluate the ability of the system to support on-aircraft fault isolation and repair tasks. In the test, an experiment was conducted to evaluate the impact of IMIS on the performance of maintenance technicians. In the experiment, 12 avionics

specialists and 12 non-specialists (airplane general [APG] technicians) performed 12 fault isolation problems on three F-16 subsystems: the fire control radar (FCR), heads-up display (HUD), and inertial navigation system (INS). Half the problems were performed using the current paper-based TOs and part-ordering and documentation procedures, and half were performed using the IMIS. The APG technicians were included in the study to determine if the use of IMIS would enable non-specialist technicians, with little or no training on a specific aircraft subsystem, to isolate and repair faults in that system at least as effectively as specialists, with specific experience and training on the system, using paper TOs.

Analysis of the technicians' performance on the 12 test problems suggests the following benefits from IMIS.

a. The rate for successful problem completion was improved by approximately 22 percent for specialists and 42 percent for APG technicians.

b. The frequency of serious errors (errors which could lead to failure to correct the problem) were reduced by 58 percent for specialists and 83 percent for APG technicians.

c. Overall problem times (i.e., troubleshoot, order parts, repair, and document) were reduced by approximately 17 percent for specialists and 29 percent for APG technicians. Analysis indicates that the reductions in times were due primarily to time saved by the automated part-ordering and work order close-out features of IMIS.

d. Overall parts consumption for the 12 problems was reduced by 26 percent for specialists and 37 percent for APG technicians. In-depth analysis indicates that IMIS diagnostics are much more beneficial for the more complex problems (e.g., most of the part savings were from the INS system).

e. Part ordering times were reduced by 94 percent for both specialists and APG technicians.

f. For all measures, the performance of the APG technicians when using IMIS was approximately equal to the performance of the specialists when using paper TOs.

A key finding is that the use of IMIS in effect "leveled the playing field" for the APG technicians. With IMIS, the APG technicians were able to perform the fault isolation problems as effectively as specialists using IMIS and more effectively than the specialists using paper TOs. This finding suggests that the use of IMIS will enable the crew chief to perform a much wider range of tasks, thus reducing reliance on specialists.

The responses to questionnaires administered to the technicians after completing the test problems indicate a high rate of acceptance of IMIS and a desire to see it implemented in the Air Force. IMIS features which were rated highly include the integration of technical data, automated parts-ordering by radio frequency (RF) link, automated work order close-out, and automated diagnostic advice.

INTRODUCTION

This report presents the results of the final phase of a program to develop and evaluate the concept of an IMIS. An IMIS will provide the maintenance technician with the capability to access all technical information (IETMs, interactive diagnostics instructions, work orders, supply availability and ordering, historical data, training material, etc.) required to maintain aircraft, via a single, integrated system, regardless of the source of that information. This capability will help maintain the new technology found in advanced weapon systems and will also support the current trend toward fewer maintenance specialties. In the future, portable computers will deliver the electronic data at the flight line work site, and a network of work stations will interact with existing maintenance computer systems in shops and work centers. The IMIS is designed to be totally integrated with other maintenance information systems during peacetime at main operating bases, but the basic portable diagnostic and TO automation is fully deployable to remote dispersed locations during war (Johnson, 1994). The project developed and field tested the technology to implement the concept. The technologies were then implemented in a demonstration system for evaluation.

BACKGROUND

The IMIS program was an advanced development demonstration project conducted by the AL/HRGO. The program was established to evaluate the IMIS concept and to develop and test the technology required for an operational IMIS. Major activities under the program included:

a. A comprehensive analysis of maintenance information requirements to serve as the baseline for developing an IMIS;

b. Research to develop an advanced, interactive, diagnostic-aiding capability;

c. Research to develop effective human/computer interface and technical information presentation techniques to make the IMIS easy to use and an effective means of communicating technical information;

d. Development of a methodology for authoring and coding, interactive electronic maintenance technical data (TOs) in an efficient and cost-effective manner that provides flexibility and reduces redundancy;

e. Development of demonstration PMAs using off-the-shelf components; and

f. Development of a demonstration system which incorporates the major features and functions of an IMIS for use in evaluating the technology and for validating requirements.

Reports and publications documenting the research conducted under the IMIS program are listed in a comprehensive bibliography at the end of this report.

A full implementation of the IMIS concept will have the following features and capabilities (Johnson, 1994):

- IETMs — TOs in digital form, presented on a PMA.

- Interactive diagnostic-aiding via a PMA, supported by an interface with the aircraft data bus to operate built-in-tests (BITs) and download subsystem performance data for use by the IMIS maintenance diagnostic algorithm.

- Interface with maintenance data collection systems such as the Core Automated Maintenance System (CAMS), Standard Base Supply System (SBSS), and other information systems and data bases which support maintenance operations.

- Automated maintenance data collection and reporting, via the CAMS interface.

- Training materials integrated with the IETM and automated diagnostics data base to support on-the-job and upgrade training.

- IMIS local area network (LAN), connects IMIS workstations, RF modems, printers, data storage devices, and interfaces with external data bases.

- Communication capability via RF link between PMAs and the IMIS LAN.

A fully implemented IMIS would include the following basic hardware and software:

- PMAs — special purpose computers, four to six pounds, fully ruggedized, multiple power sources, removable hard disk drive, screen readable under all conditions, self-contained batteries, interface to aircraft maintenance bus, usable with chemical and cold weather gloves, easy to operate without training, keypad, does not require typing skills.

- Maintenance Information Workstations (MIWs) — desktop computers to support maintenance management activities, maintain the IMIS data base, and interface with external data bases. Located in maintenance management and support offices.

- Mobile Workstation Computers — RF capability, mounted in maintenance supervisory vehicles for use in managing and controlling flightline maintenance activities.

- Technical Data Presentation Software — presents IETM data and diagnostic procedures.

- Interactive Diagnostics Software — generates most efficient diagnostic strategy based upon technical data, system design information, component failure rates, and current system status (e.g., symptoms and test results).

- IMIS Data Base — maintains data required to support the IMIS and maintains a backup copy of the relevant CAMS information to prevent interruption of operations if CAMS is down.

- External Data Base Interface Software — controls interface with CAMS, SBSS, and other external data bases.

IMIS REQUIREMENTS ANALYSIS AND DEMONSTRATION SYSTEM DEVELOPMENT

The final phase of the IMIS program was a large contract effort to define requirements and specifications for an operational IMIS, develop a demonstration system incorporating the major functions and capabilities of an IMIS, evaluate the IMIS concept using the demonstration system, and update the specifications based upon lessons learned in the demonstration system evaluation. The major activities under this effort are summarized below.

A comprehensive analysis was conducted to define information requirements to support maintenance of tactical fighter aircraft. The analysis was accomplished by interviewing maintenance technicians and supervisors, and by observing maintenance operations at nine Tactical Air Command and United States Air Forces - Europe bases, interviewing personnel responsible for developing and maintaining existing maintenance data systems (e.g., CAMS) at the Air Force Systems Design Center, interviewing senior Air Force maintenance managers, and reviewing Air Force regulations. Integrated Computer-Aided Manufacturing (ICAM) Definition (IDEF) modeling techniques were then used to develop "AS IS" and "TO BE" models of the information flow in a fighter squadron (FS) maintenance organization.

The TO BE model defined the sources, processing, transmission, and uses of information within a maintenance organization when supported by IMIS. The model was based upon the AS IS model, the IMIS operational concept document, a review of applicable hardware and software technology, and the inputs and recommendations of maintenance analysts, software engineers, computer engineers, and information management specialists. The AS IS and TO BE models are defined and described in the IMIS Architecture Document (General Dynamics Electronics Division, 1990).

The IMIS Architecture provided the basis for the development of the IMIS System Segment Specification (SSS). The SSS established system design, performance requirements, design goals, and test requirements for use in developing an operational IMIS. In addition to basic design requirements, the SSS provided a comprehensive listing of the functions the IMIS must perform and the performance criteria that must be met. A high-level representation of the IMIS architecture is presented in Figure 1.

The functional requirements for an IMIS specified in the SSS were prioritized to develop a set of essential functions for evaluation. The IMIS Demonstration System was then designed and developed to provide these functions for evaluation of the IMIS concept and to provide data on the impact of the IMIS on the performance of maintenance technicians and the overall operation of the maintenance organization. The IMIS Demonstration System implemented the basic architecture specified in the SSS, except that all functions were not provided. A PMA was designed and fabricated, and an off-the-shelf workstation was selected to serve as the MIW. A mockup of the aircraft interface panel (AIP) was developed in place of developing an actual AIP for the F-16 aircraft (due to cost considerations). The Demonstration System PMA is presented in Figure 2.

IMIS FIELD TEST

The IMIS Demonstration System was evaluated in a three-phase field test at Luke AFB, AZ in the Spring and Summer of 1994. In Phase I, the IMIS debriefing function was evaluated. The results of this evaluation indicated that the IMIS provides an effective debriefing capability. Use of the system resulted in faster debriefs for Code 1 aircraft. In addition, it has the capability to provide the technician with more extensive information on reported system failures than provided by current debriefing procedures.[1] Debriefers who used the system found it effective and easy to use (Ward, Weimer, and Kruzick 1995b).

The Phase II evaluation was an "End-to-End" Demonstration designed to evaluate the capability of the IMIS to support flightline management functions, especially those performed by the Production Superintendent and Expediters. To avoid interfering with ongoing maintenance operations, the evaluation was conducted in a classroom environment. Expediters and Production Superintendents used the IMIS to perform typical scenarios incorporating the tasks they normally perform in their day-to-day activities. These included performing actions such as assigning a work order to a technician, creating and closing work orders, approving part orders, retrieving aircraft status information, changing aircraft status, and sending messages. The participants were asked to evaluate the system as an aid for performing their jobs. The evaluations were very positive. See Ward, Kruzick, and Weimer (1995c) for details of the end-to-end demonstration.

[1] This benefit was not fully evaluated because the test was conducted under operational conditions and the current paper-based system has no mechanism available to provide this information to the technician. In a full implementation of the IMIS, this information would be automatically entered into the IMIS data base, loaded onto the technician's PMA, and used by the diagnostic routine to isolate the fault.

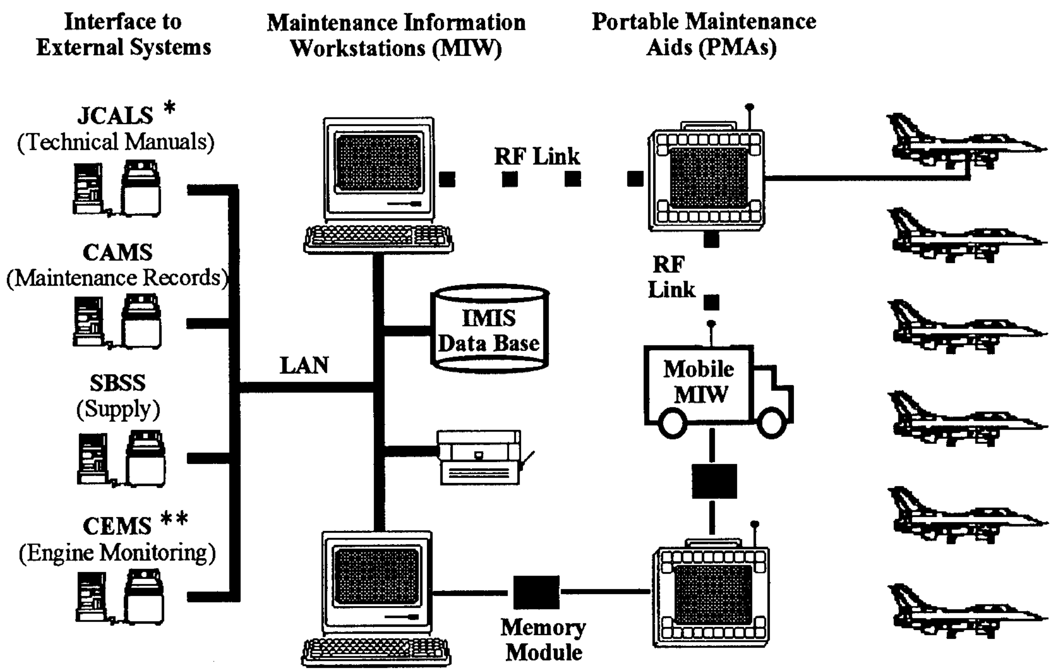

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Figure 1. High-Level IMIS Architecture

Figure 2. Demonstration System Portable Maintenance Aid

Finally, the Phase III evaluation (Field Test) was designed to evaluate the capability of the IMIS to support on-aircraft maintenance, especially diagnostics. The results of this test are described in the remainder of this report.

Objectives

The IMIS Field Test was conducted to evaluate the ability of the IMIS to support on-aircraft maintenance — especially diagnostic tasks — and to provide additional data for use in evaluating the overall effectiveness of the IMIS. The Field Test had the following the objectives:

- Demonstrate that use of the IMIS can significantly improve the troubleshooting performance of technicians by reducing the time required to return an aircraft to service and reducing the number of errors made by technicians.

- Demonstrate that use of the IMIS can reduce the consumption of spare parts by reducing the number of good parts unnecessarily replaced during the diagnostic process (i.e., reduce the retest OK rate).

- Demonstrate that technicians without extensive, specialized training on a given system (e.g., airplane general [APG] technicians) can effectively perform troubleshooting tasks on the system when using the IMIS.

- Demonstrate that use of the IMIS will reduce the time required to document maintenance actions taken and close-out work orders.

- Demonstrate that use of the IMIS will provide more accurate information on maintenance actions taken for input to the Maintenance Data Collection system.

- Develop data to demonstrate the technical and cost advantages of the IMIS over the current paper-based system.

- Identify the strengths and weaknesses of the IMIS, identify changes to the IMIS which would make it more effective, and identify changes to the IMIS specifications required for an operational implementation of the IMIS.

Hypotheses

The Field Test was designed to test the following hypotheses.

1. Avionics specialist technicians will successfully complete significantly more diagnostic problems when using the IMIS as the source of technical information than when using the paper TO.

2. APG technicians using the IMIS as the source of technical information will successfully complete significantly more diagnostic problems than will avionics specialists using paper TOs as their source of technical information.

3. Avionics specialist technicians using the IMIS to perform troubleshooting tasks will replace significantly fewer parts when using the IMIS than when using paper TOs.

4. APG technicians using the IMIS to perform troubleshooting tasks will replace significantly fewer parts than will avionics specialists using paper TOs.

5. Avionics specialist technicians will make significantly fewer maintenance errors while performing the troubleshooting problems when using the IMIS than when using paper TOs.

6. APG technicians will make significantly fewer maintenance errors while performing the troubleshooting problems when using the IMIS than will avionics specialists using the paper TOs.

7. Avionics specialist technicians will require significantly less total time to complete troubleshooting problems when using the IMIS than when using paper TOs.

8. APG technicians will require significantly less total time to complete the troubleshooting problems when using the IMIS than will avionics specialists using the paper TO.

9. Avionics specialist technicians will require significantly less time to prepare for a troubleshooting task when using the IMIS as the source of technical information than when using the paper TO.

10. APG technicians using the IMIS will require significantly less time to prepare for a troubleshooting task than will avionics specialists using paper TOs.

11. Avionics specialist technicians will require significantly less time to verify faults in the test-bed subsystems when using the IMIS than when using paper TOs.

12. APG technicians using the IMIS will require significantly less time to verify faults in the test-bed subsystems than will avionics specialists using paper TOs.

13. Avionics specialist technicians will require significantly less time to isolate faults in the test-bed subsystems when using the IMIS than when using paper TOs.

14. APG technicians using the IMIS will require significantly less time to isolate faults in the test-bed subsystems than will avionics specialists using paper TOs.

15. Avionics specialist technicians will require significantly less time to order each part when using the IMIS than when using current part ordering procedures.

16. APG technicians using the IMIS will require significantly less time to order each part than required by avionics specialists using current part ordering procedures.

17. Avionics specialist technicians will require significantly less time to complete required documentation when using the IMIS than when using current documentation and close-out procedures.

18. APG technicians using the IMIS will require significantly less time to complete required documentation than will avionics specialists using current documentation and close-out procedures.

19. Avionics specialist technicians will make significantly fewer documentation errors when using the IMIS than when using current documentation procedures.

20. APG technicians using the IMIS will make significantly fewer documentation errors than will avionics specialist technicians using current documentation procedures.

METHOD

The objective of this effort was to compare the performance of technicians using the IMIS with their performance using paper TOs and to compare the performance of APG technicians using the IMIS with the performance of specialists; therefore, it was essential that performance of the technicians be measured under comparable conditions. Consequently, it was necessary to measure the performance of technicians engaged in very similar tasks under very similar conditions, preferably doing the same tasks under identical conditions. To ensure the required symmetry of tasks and data collection conditions, an experimental approach was adopted.

An experiment was conducted in which specialist and APG technicians performed 12 troubleshooting tasks, six using the IMIS and six using paper TOs. The order of task presentation was counterbalanced so that half the technicians performed their IMIS tasks first and half performed their paper-based TO tasks first. Twelve troubleshooting tasks for three F-16 subsystems were used as test problems for the study. The test-bed subsystems were the F-16 FCR, HUD, and INS. The tasks were selected in pairs so that paired tasks were approximately equal in difficulty and required skills. The tasks were representative of the troubleshooting tasks normally encountered in maintaining the test-bed subsystems.

Experimental Design

A two-factor experiment with repeated measure measures was used for the study (after Winer, Brown, & Michels, 1991) for all performance measures except parts used. The factors were specialty (avionics specialist vs. APG technician) and media (IMIS vs. paper TO). Repeated measures were made on the media factor, with each subject performing half the tasks with IMIS and half with paper TOs. Specialty was measured between groups. Problem order within the blocks of tasks was systematically varied to avoid order effects and to ensure that each task was performed an equal number of times with IMIS and with paper TOs. The experimental design and problem administration sequence are presented in Appendix A.

Subjects

Twelve avionics technicians (specialists) and 12 APG technicians served as subjects for the study. Eight of the avionics technicians were from the 310 FS, three from the 63 FS, and one from the 308 FS. Eight were Skill Level 5 and four were Skill Level 3. Their experience levels ranged from 16 months to 108 months. The 12 APG technicians were all from the 310 FS. Two were Skill Level 5 and ten were Skill Level 3. Their experience levels in F-16 maintenance ranged from two months to 70 months. All subjects were male and were assigned to the project by their supervisors.

Test Facilities

The field test was conducted using the facilities of the 310 FS, Luke AFB, AZ. The squadron provided an aircraft, hangar space for the aircraft, office/training room, required test equipment, ground support equipment, and tools. The office was located in a hangar. For most of the test period, the aircraft was parked in the same hangar, approximately 50 feet from the office door. The remainder of the time, it was parked in one of two adjacent hangars, one approximately 150 feet from the office and the other approximately 200 feet from the office. The assigned aircraft was dedicated to the test. No maintenance or other actions were performed on the aircraft during the assigned period. The aircraft was changed periodically to meet squadron mission requirements. Normally, an aircraft was assigned for a one-week period. An intercom system was used for communications between the technician and data collectors during periods of high noise (e.g., when the ground power and air conditioning units were operating).

In addition to administrative functions, the IMIS office was used for technician orientation, training, as technician break room, and as a staging area for problem initiation. Also, a file of TOs required for the test problems was maintained in the office.

IMIS Demonstration System

The IMIS Demonstration System, as installed at Luke AFB, served as the test system for the Field Test. The demonstration system installed at Luke AFB included the following equipment:

1 MIW installed in the 310 FS Debriefing Room
1 MIW installed in the Combat Oriented Support Organization (COSO)
1 MIW installed in the IMIS Project Office
1 memory module loading station installed in the IMIS Project Office
6 PMAs maintained in the IMIS Project Office
2 Laptop computers which served as mobile MIWs for the Expediters and Production Superintendent
1 RF modem installed on the 310 FS hangar
1 RF modem installed above the IMIS Project Office

The MIWs were connected via a fiber optic cable to form the IMIS LAN and were interfaced with the CAMS network. The following capabilities of the IMIS Demonstration System were used, to some extent, during the Field Test.

PMA removable hard disk drive loading
Presentation of work orders
Presentation of TOs
Diagnostics module
1553 interface
Parts ordering/part approval process (via RF link)
Work order close-out/documentation

The PMA removable disk drive loading capability was used to load data onto the disk drives with the proper work orders and technical data for presentation on the PMA. The removable disk drive loader was used by the data collection staff only.

Job Performance Tests

Job performance tests were used to measure technician performance. Each job performance test measured the technician's performance on one diagnostic problem — identifying and correcting the cause of an observed fault in the system. Job performance tests were developed for 12 diagnostics problems. The test problems were based on 12 faults judged to be typical of those occurring in the FCR, HUD, and INS systems. Four tests were developed for each subsystem; these tests were developed as "matched pairs." The two tests which compose a pair were designed to be as nearly equal as possible in terms of difficulty, time to perform, and number of subtasks (e.g., diagnostic tests performed) as possible. Comparability of test problems was accomplished by selecting two different fault codes (returned by the aircraft BIT) or malfunction symptoms that led to similar maintenance actions (e.g., replace the same component or repair different wires in the same wire bundle). Troubleshooting the two fault codes followed almost identical troubleshooting procedures, typically deviating only at the last step or two.[2]

Test problems were selected based upon several criteria. These selection criteria were:

a. It must be possible to simulate the problem without damaging the aircraft or causing a safety hazard.

b. The test problem must be representative of faults normally encountered in the day-to-day maintenance of the subsystem.

c. The problem must be sufficiently difficult to test the capabilities of the IMIS and paper-based TO troubleshooting aids.

d. The problem must not require more than approximately one hour to complete (under test conditions).

e. It must be possible to develop a companion problem of approximately equal difficulty.

A large number of subsystem faults were evaluated in selecting the test problems. It was found that very few problems could satisfy all the above criteria. The faults used were the best of those. The twelve faults used and their associated maintenance fault list (MFL) codes are listed in Table 1.

Breakout boxes were used to simulate faults used for the test problems. The breakout boxes were installed between line replaceable units (LRUs) of the test subsystem. The breakout boxes provide a means of interrupting communication between the LRUs by breaking the continuity of selected wire or wires. Thus, it is possible to simulate a malfunction in an LRU by interrupting its output to another component of the subsystem. This produces the same symptoms as if the LRU were actually defective.

None of the available tests could be performed in their "entirety" within the time constraint, primarily because of the time required to perform several repetitive tasks. For example, several problems require alignment of the INS, either to verify system health or as part of the troubleshooting process. This is a lengthy automated process with little input from the technician. The time required to perform the alignment is the same when using the IMIS as when using the paper TO. Thus, it consumes time without providing any meaningful information for test purposes. Similar situations exist for the FCR and HUD. To conserve testing time, standard times were used for these subtasks. This was done by the observer telling the technician to assume that the task had already been done.

[2] The similarity of the problems was not readily apparent to the technicians because they were working with different technical data (one with IMIS the other with the TO).

Table 1. Faults Used for Job Performance Tests

Problem Number	Subsystem	Fault Code	Symptom/MFL	Fault
F1	FCR	AD	MFL 001	Wiring
F2	FCR	AE	MFL 002	Wiring
F3	FCR	AN	MFL 004	PSP
F4	FCR	AU	MFL 084	PSP
H5	HUD	AD	MFL 001	EU
H6	HUD	AE	MFL 002	EU
H7	HUD	BM	Depr. Ret. Sw.	Wiring
H8	HUD	BR	Test Sw.	Wiring
I9	INS	AG	MFL 011	Wiring
I10	INS	AG	MFL 011	Wiring
I11	INS	AG	MFL 011	HSI
I12	INS	AG	MFL 011	HSI

(Note: Although problems 9 through 12 all have the same fault code (AG) and MFL (011), they are in fact different problems. Problems 9 and 10 both lead to wiring repairs, but different wires are bad. Problems 11 and 12 both lead to replacement of the HSI, due to different malfunctions within the HSI.)

Standard times were used in four situations: (1) for tasks that were too time consuming and yielded no new information on technician performance (e.g., FCR pressurization test required following antenna replacement); (2) for tasks which risked damage to the aircraft (e.g., removal of the HUD pilot's display unit); (3) for rectifications, since it was not practical to make actual repairs (to avoid damage to the aircraft due to repeated repairs); and (4) for the final system health checks to verify that the subsystem is fully operational. The technicians had already performed the system health checks as part of the problem verification, demonstrating the capability to do those checks using the IMIS or paper TO. Thus, little new information would be gained by repeating the checks to establish system health. Standard times (based upon observation of the task being performed or estimates from technicians experienced in performing the task) were used in calculating test times. When standard times were used, the technician was required to tell the technical observer what task he would perform and show the required technical data (in the TO or on the IMIS).

In addition, standard times were used to account for times required to perform two processes under the paper-based condition which could not be accomplished during the test without interfering with the host unit's operations. These processes were parts ordering and entering work order close-out information into the CAMS. It was not necessary to use standard times for the IMIS condition because these processes were automatically performed by the IMIS.

Several actions involved in ordering a part in actual maintenance operations were not considered in this test. These include the time to obtain authorization to order the part, the time to travel to the COSO to place the part order, the time for the COSO to order the part, and the time for the supply system to process and deliver the part. There was no realistic way to simulate this process; therefore, standard times were used. An additional 15 minutes per part order was added for each time a part was ordered under the paper-based condition. This estimate was based on estimates given by technicians, supervisors, and supply personnel. The 15 minutes includes 10 minutes to secure the aircraft and travel to the COSO and five minutes to process the order at the COSO. The estimates used are conservative. Times are frequently much longer due to unpredictable factors, such as the supply clerk being out of the office and delays in getting transportation from the aircraft to the COSO.

There was no practical way to simulate the process of entering the work order close-out information into CAMS. The host unit CAMS terminals could have been used but would have resulted in putting test data into the active CAMS data base, which was unacceptable to the CAMS data base manager. Thus, a standard time was used. An additional ten minutes was added to the close-out time to adjust for the time to input the data to CAMS. This adjustment was made for the paper condition only. The estimate includes five minutes to travel to the maintenance office and five minutes to input the data. Time spent waiting for access to a CAMS terminal was not considered. This is believed to be a very conservative estimate.

The test problems yielded the following performance measures.

a. Preparation Time. Preparation time is the time from problem assignment until start of fault verification. For the paper TO condition, preparation time includes the time to identify and sign out required TOs, time to move to the aircraft, time to locate required instructions, and questions for the pilot. For the IMIS condition, preparation time includes the time to move to the aircraft and set up to start fault verification (including questions for the pilot and connecting PMA to 1553 interface) and prepare to start fault verification.

b. Fault Verification Time. Fault verification time is the time to conduct the necessary checks to verify that reported malfunction symptoms are present in the subsystem.

c. Fault Isolation Time. Fault isolation time is the time required to identify the cause of the observed subsystem malfunction, rectify the fault, and verify that the subsystem is fully operational. This time is composed of the elapsed time from the start of the troubleshooting checks until the completion of the system health checks to verify repair, in addition to standard times for replacing any parts or making any repairs, ordering parts, and completing the final system health checks.[3]

[3] In some cases, the diagnostic procedures required replacement of a nondefective part as a means of eliminating that component from the set of possible faults. In these cases, the system health checks required to determine if the fault had been corrected were actually performed and times were recorded. Standard times were not used.

d. Close-Out Time. Close-out time is the time necessary for the technician to complete the close-out documentation. For the IMIS condition, close-out time is the time to enter the information into the IMIS using the PMA. For the paper condition, it is the time to complete a paper form by entering the required information in addition to a standard time for entering the information into CAMS.

e. Problem Performance Time. Problem performance time is the total time required to complete the test, adjusted for any necessary time outs (due to external interruptions such as an unexpected problem with the aircraft).

f. Total Problem Time. Total problem time is the problem performance time and the standard times for performing rectifications, conducting system health checks, and completing documentation.

g. Successful Fault Isolation. Successful fault isolation indicates whether the technician successfully identified the fault and verified that the subsystem was fully operational.[4]

h. Number of Parts Used. The "number of parts used" measure indicates the number of parts the technician used to rectify the problem (including both necessary and unnecessary replacements).

i. Parts Ordering Time. Parts ordering time is the time required to order parts. For the IMIS condition, it is the time required for the technician to enter the parts order request into the PMA. For the paper condition, it is the time to locate the required parts ordering information and fill out the parts order form plus a standard time of 15 minutes for submitting and processing the order.

j. Errors Made. The "errors made" measure refers to the number of errors due to incorrect use of IMIS or the paper TO, the number of maintenance errors (e.g., a technician taking a continuity reading from wrong connector pin), and the number of documentation errors.

k. Helps Given. "Helps given" indicates the number of assists provided on the use of IMIS or paper TOs and the number of system knowledge assists (help in locating a component).[5]

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[4] Since the final system health was simulated, the critical task for system health was to identify and locate the necessary technical data for all system tests required to establish that it is fully operational.

[5] Helps were given in some instances when requested by the technician. Helps provided included use of the IMIS or paper TO, component location, interpretation of technical data, and use of the multimeter. Helps were intended primarily for the APG technicians to compensate for their lack of familiarity with the test-bed subsystems. Helps were also provided to the specialists

Data collection forms were developed for each test problem. Different versions were provided for the problems performed with the paper TO and for problems performed with the IMIS. The data collection forms identify the steps required to perform the task in the order specified by the paper TO or IMIS. Places to record times at specified check points and ample space were provided on the form for the data collector to record times, pertinent information, and observations. In addition, a supplemental data collection sheet was provided for use when the technician deviated from the expected path. Sample data collection sheets are provided in Appendix B.

Other Measures

In addition to the performance measures listed above, three other measures were used in this effort: the National Aeronautics and Space Agency Task Load Index (NASA TLX), an IMIS characteristics questionnaire, and an end of test questionnaire

a. NASA TLX. The NASA TLX provides a measure of the work load imposed by a given set of work conditions. After completing a task under specified working conditions, the subject rates the workload imposed by the conditions on several factors (mental load, physical demands, etc.). The ratings are then combined to provide an index of the work load. Collecting NASA TLX ratings under different working conditions provides a means of comparing the relative workloads imposed by the work conditions (NASA, 1986). For the Field Test, the technicians completed the NASA TLX after each test problem. The NASA TLX ratings were used to evaluate the relative impact of the IMIS on the technicians perceived workload. The NASA TLX was administered using a notebook computer.

b. IMIS Characteristics Questionnaire. After completion of all assigned tasks using the IMIS, the technicians completed a questionnaire designed to evaluate various features or qualities of the IMIS (e.g., readability of the display). The questions were presented in the Likert format using a notebook computer..

c. End of Test Questionnaire. After completing their last problem, the technicians completed a short exit questionnaire which asked them to describe what they liked and disliked about the IMIS, and what should be done to make it better.

Training

Two primary types of training were provided to all technicians participating in the study: (1) how to use the IMIS, and (2) how to use the paper TOs required to perform the test problems. In addition, a brief lesson was given on the use of the multimeter and how to identify

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in selected situations. These helps were in situations where the technician normally would have sought help from another technician or supervisor.

pins on multi-pin connectors (e.g., multi-pin plugs/jacks). This training was given the day before the technicians were scheduled to begin the performance tests.

IMIS Training

The IMIS training was provided to develop the skills needed to use the IMIS to perform the fault isolation tasks required for the study. Training included an overview of the IMIS system, a review of IMIS capabilities, log-on/off procedures, work order creation/close-out, parts ordering procedures, accessing job assignments, accessing and using TOs, and using the IMIS diagnostic-aiding capability. The training included a practice exercise which took the technician through the process of selecting a work order from the list of assigned tasks, accessing the appropriate fault verification procedures, going through the diagnostic process, ordering parts, and closing out the work order. This practice exercise demonstrated all the processes required to perform the test problems. In addition to the formal training, the technicians were provided an opportunity to "play" with the system and exercise its various features on their own. This hands-on experience gave them an opportunity to become comfortable with the system. This training required approximately four to five hours.

Paper TO Training

Paper TO training was provided to ensure the technicians were fully proficient in the use of the TOs required to perform the test problems. For the specialist technicians, this training was a refresher because they are required to use these TOs in their day-to-day duties. However, the training provided new material to the APG technicians because they had no prior training or experience with the avionics fault isolation manuals. This training included a review of the TO numbering system, how to locate and use job guide manuals, fault isolation manuals, wiring diagrams, and the illustrated parts breakdown TO. An emphasis was placed on how the different TOs relate to each other and how to "navigate" through the TO system to find the needed information. As part of the training, the technician completed the same exercise used in the IMIS training to illustrate the procedures required for the test. This training required approximately one hour.

Multimeter Training

Multimeter training was provided to ensure that all technicians knew how to properly use the multimeter to make voltage and continuity checks. This training included an introduction to the Fluke multimeter and instruction on making voltage and ohms readings and performing continuity checks. Emphasis was placed on avoiding commonly made errors while conducting multimeter readings and performing checks. In addition, training was given on how to identify pins and jacks on multi-pin connectors. The various schemes used to identify and code pins on cannon plugs were explained, and the technicians were given an opportunity to practice locating pins on typical multi-pin connectors.

IMIS/TO Refresher Training

Following the completion of the first six test problems using either IMIS or TOs, the technicians were given a quick refresher on the type of data to be used for the next block of tests. This training was provided to ensure the technicians were proficient in the use of the media required for the remaining tasks.

Technical Data

Paper Technical Orders

The standard Air Force TOs in effect at the time of the test were used in the data collection. TOs were checked out from the Squadron COSO.

IMIS Technical Data

Technical data for the three subsystems was developed for the IMIS by converting the existing TO data to the IMIS format. This was accomplished by converting the digital data base from which the paper TOs were printed into the IETM format required for the IMIS (as specified by Military Standard MIL-D-87269). The conversion process left the technical content the same but added the codes or tags required to present the data on a computer system. The technical content of the IMIS data was nearly identical to the TOs. Some questions were restated to meet electronic presentation requirements, and some data was reformatted. For example, when the TO referred the user to a table in another part of the TO, the IMIS presented the relevant data rather than the table. The IMIS technical data was developed by the F-16 prime contractor, Lockheed Aircraft Corporation, Fort Worth Division.

Test and Data Collection Procedures

The field test was conducted in three sessions. The first two-week session was a pretest in which all data collection procedures were tested, refined, and practiced. This was followed by two three-week sessions in which the actual testing and data collection was accomplished. Approximately one week separated the two sessions. Testing and data collection activities were conducted on a two-shift-per-day basis, 0800 to 1700 and 1700 to 0100 hours. Two technicians were tested per shift. Approximately four days were required to test each pair of technicians, in addition to one day for training and orientation.

Two data collection teams, one per shift, administered the performance tests and collected the data. Each team consisted of a team leader, technical observer, and data collectors.

a. Team Leader. The team leader is responsible for technician orientation and training as well as scheduling. Additionally, the team leader must ensure data collection activities are conducted according to the established rules and must resolve any problems encountered.

b. Technical Observer. The technical observer is responsible for installation of faults for test problems; close (step-by-step) monitoring of the technician's performance, determining when each required process is completed, and determining when the technician has successfully completed (or failed) the task; providing guidance to the technician on test procedures to be followed; and, where appropriate, answering questions and providing helps. Additionally, the technical observer keeps the data collector informed of progress. This is accomplished by informing the data collector when the technician starts or completes each subtask, when checkpoints have been reached, and when problems are encountered. The technical observers in this effort were former Air Force avionics technicians who were thoroughly familiar with F-16 maintenance procedures, the test-bed subsystems, and associated technical data.

c. Data Collector. The data collector is responsible for monitoring an assigned technician's performance, recording the data collected for each problem (including start/stop times at each checkpoint, any errors made by the technician, and any helps given by the technical observer), checking close-out information entered by the technician into IMIS or the work order form, debriefing the technician at the end of each problem, and ensuring that any required questionnaires were completed. Two data collectors were assigned to each team. Each data collector was assigned to a technician and monitored that technician's performance throughout the test period. Data collectors were selected from the IMIS project development team. The personnel assigned were thoroughly familiar with the IMIS and maintenance operations.

The data collection team was supported by a software specialist who prepared PMA removable disk drives and resolved any hardware or software problems encountered.

Data Collection Process

Prior to the start of the test session, the aircraft was prepared. Preparations included opening all panels covering areas to be accessed during any of the tests, installing the breakout boxes used to simulate the faults, and connecting external air conditioning and power to the aircraft. In addition, two PMA removable disk drives (one primary, one backup) were prepared for each problem to be performed that day.

Upon arrival the first day, the technicians were given an introduction to the IMIS project, the goals of the field test were described, and the technicians' role in accomplishing those goals was explained. In addition, they were asked to complete a short biographical questionnaire and to sign an agreement indicating their willingness to participate in the study. This brief orientation was followed by training on the IMIS, TOs, and multimeter. After completing the training and demonstrating an adequate understanding of the materials, each technician was assigned to one of the data collectors to prepare for the first test. In some cases, data collection started that afternoon; in others it was necessary to wait until the next day (due to inadequate time or the aircraft being in use by another test subject).

Technicians completed six tasks using the first assigned information presentation media (IMIS or paper TO), followed by a refresher on the use of the other media, followed by the six tasks using that media. Each task performance was followed by a break period. Since only one technician could work at the aircraft at one time, the technicians alternated task performance and break times, so that when one technician was working a task, the other technician was on break. This process made maximum use of the aircraft, while providing ample time for the technicians to take breaks.

Immediately prior to the first task, the technicians were given an orientation briefing in which the data collection procedures and rules were explained. The briefing emphasized that the technical data and delivery system were being evaluated *not* the technicians. The roles of the observer and data collector were explained, and the technicians were reminded that they were free to ask questions, but that the observer may or may not answer the question depending on the question and the situation. The technician was instructed to always use the IMIS or TO.[6]

After the briefing, the technicians were given their assigned problem. For the paper TO condition, the technicians were given a paper work order with a write-up typical of those described on work orders created during the pilot debrief and were told to work the problem. The technicians then selected the required TOs, signed them out from the "mini-TO library" in the IMIS office, and reported to the aircraft. For the IMIS condition, the technicians were given a PMA (already booted and ready for the technician to sign-on) and were told that the assigned work order was on the PMA. Since the IMIS PMA contained the required technical data, the technician and data collector proceeded to the aircraft to start the problem. The technician started the task by accessing the work order. The work order provided the information as it would have been recorded in a pilot debrief conducted using the IMIS. The IMIS-based debriefing process prompts the debriefer to ask questions not normally asked during the standard paper-based debrief. These questions are those a technician assigned to work the write-up would like to ask the pilot. The questions help to define the problem and eliminate possible causes, thereby speeding up the diagnostic process. This information is presented on the IMIS work order for the technician to review and is used by the IMIS in developing the diagnostic process to be followed.

After receiving the task assignment, the technicians reported to the aircraft to start the diagnostic process. Upon arrival, they were given the opportunity to ask the technical observer (acting as the pilot) questions on system performance at the time of the failure. Although the basic steps for performing the tasks (verify fault, isolate cause of fault, order any parts, rectify fault, verify repair, and document results) are the same for the IMIS and paper TO conditions,

[6] This requirement was not strictly enforced. Technicians were required to have the correct paper TOs available, but absolute adherence to the TOs was not required. Technicians were allowed to proceed without interference unless they were about to make a serious error that could cause a safety hazard or damage the aircraft.

the actions required to accomplish each step were significantly different. The processes for accomplishing the steps with IMIS and paper TOs are compared in Table 2. The data collection process is illustrated in Figure 3.

After each problem the technician completed the NASA TLX ratings. After completing the block of IMIS tasks, the technicians completed the IMIS characteristics questionnaire which measured their reactions to using the IMIS also. After all testing, the technicians completed an end-of-test questionnaire giving their evaluation of IMIS (what they liked or disliked) and provided any suggestions for improving the IMIS.

Data Analysis

Analysis of variance was used to analyze the data collected for each performance measure. A two factor, with repeated measures on one factor, design was used. Between group comparisons were made for Factor A (specialty — avionics specialist vs. APG technician) and within group comparisons for Factor B (media — paper TO or IMIS). The Scheffe method of comparisons was used to evaluate differences between means for variables identified in the analysis of variance as having significant differences. All computations were performed using the MANOVA module of the STATISTICA software package (Statsoft, 1994).

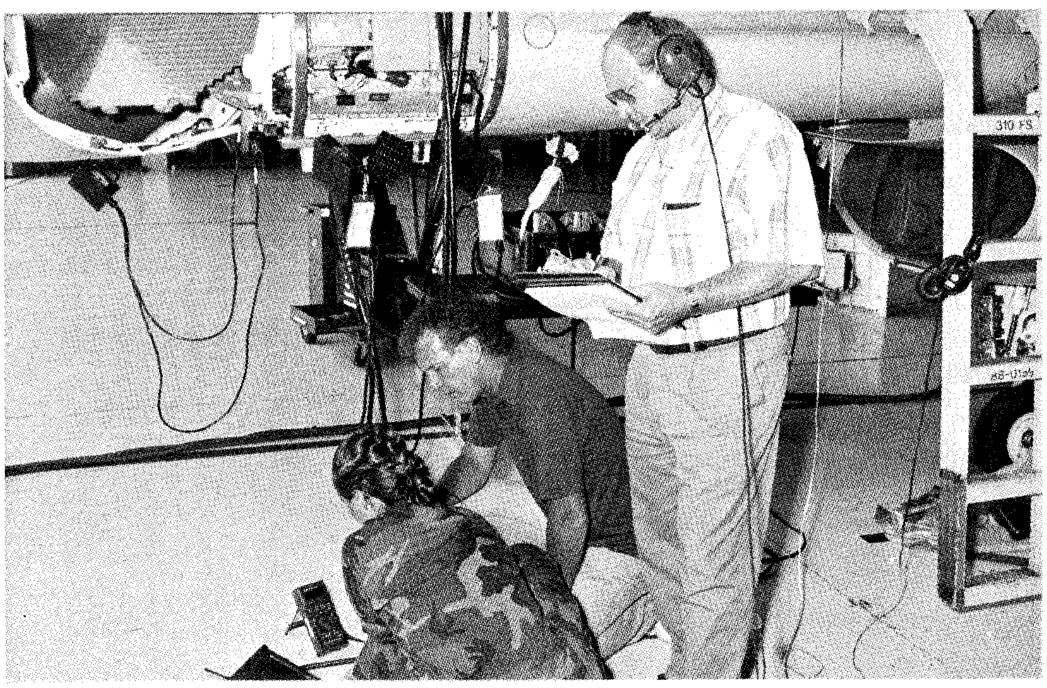

Figure 3. Technician Performing Diagnostic Task While being Observed by the Technical Observer and Data Collector

Table 2. Comparison of Fault Isolation Process Using IMIS vs. Using Standard Paper-Based TOs as Implemented for Fault Isolation Test

Action	Current Paper-Based Procedures	IMIS Based Procedures
Preparation	Identify required TOs, gather TOs, sign TOs out, go to aircraft.	Go to aircraft. Connect to 1553 interface.
Verify Fault	Verify fault using operator-initiated BIT procedures.	Verify fault with IMIS-controlled BIT (via 1553 interface).
Isolate Fault	Logic tree diagnostic procedures.	Dynamic troubleshooting procedures.
Order Part	Return to COSO (IMIS Office), look up part number in the illustrated parts breakdown (IPB), get pro-super approval (data collector acting as pro-super), return to aircraft and proceed with rectification.	Select "order part" from dialog box; part order forwarded to pro-super. Proceed with rectification.
Rectify Fault	Locate and show observer proper job guide for remove and replace rectification. Locate and show observer wires to be repaired in wiring diagram and connector and wiring to be repaired. If correct, observer declares rectification complete. If incorrect, observer tells technician repair has been made and to continue. Technician uses TO to identify required system health checks. Performs (actual) system health to verify repair. System health fails; fault isolation continued until correct solution found.	Select "Replace Component" or "Repair Wiring" from dialog box. PMA presents required instructions. Show to observer. If correct rectification, observer declares rectification complete. Technician presses continue to initiate system health. If not the correct rectification, the technician performs system health using 1553 interface. System health fails; fault isolation continued until correct solution found.
System Health	Technician uses TO to determine checks required to establish system health. Shows observer job guides required to perform system health.	Technician continues to initiate system health.
Document Repair Action	Technician returns to IMIS office and completes simulated Air Force Technical Order (AFTO) Form 349. Accuracy verified by data collector.	Technician uses PMA to complete close-out form. Accuracy verified by data collector.

Limitations of the Study

Test Environment Limitations

The test situation imposed the following limitations:

a. The test could not interfere with normal maintenance operations of the host squadron (310 FS).

b. No activities could be performed which risked damage to the aircraft or injury to the technicians participating in the study.

c. The "live" CAMS data base could not be used.

d. Time constraints required some short cuts which added a degree of artificiality to the test environment. For example, aircraft panels were opened before the start of the test and standard times were used to simulate some processes (e.g., removal and replacement of parts).

Demonstration System Limitations

The IMIS system used for the study was built as a proof-of-concept demonstrator. As a result, it did not have all the functionality that would be available in a system developed for operational use, nor did it fully satisfy the performance requirements of an operational system. Consequently, performance benefits of the IMIS are not fully demonstrated in this test. The IMIS Demonstration System had the following limitations.

a. System Performance. The times required for the system to process information requests and present technical information were relatively long.

b. System Reliability. The system was prone to "freezing up," requiring a delay (i.e., time out) in the testing process while the problem was resolved.

TEST RESULTS

The test results are presented in three parts. The first section presents the results of the performance tests. The second section presents an analysis of the IMIS diagnostics capability to reduce parts consumption. Finally, the third section presents the results of the NASA-TLX ratings, questionnaire data, and an analysis of the impact of the IMIS Demonstration System speed limitations.

Performance Test Findings

The performance test results are presented according to the performance measures discussed in the previous section and the relevant hypotheses. The results for successful problem completion, parts used, maintenance errors, and the overall time to complete each problem are presented first, followed by an analysis which examines various components of the observed times to determine which factors contribute most to the differences observed. Finally, an analysis is made of the factors contributing to observed differences in parts use. Only the basic analysis results (means and levels of significance) are presented in this section. The complete analysis of variance tables for each analysis are presented in Appendix B.

Performance Measure: Successful Problem Completion

Hypotheses:

1. Avionics specialist technicians will successfully complete significantly more diagnostic problems when using the IMIS as the source of technical information than when using the paper TO.

2. APG technicians using the IMIS as the source of technical information will successfully complete significantly more diagnostic problems than will avionics specialists using paper TOs as their source of technical information.

Findings:

Successful completion of a problem was defined as "satisfactorily completing all subtasks required to return the aircraft to fully operational status." Thus, to complete the problem, the technician was required to verify the existence of the reported fault, isolate the cause of the fault, specify the required rectification, order any necessary parts, rectify the fault (actual repair simulated), verify that the system was fully operational (system health checks simulated), and complete the required documentation.[7] The findings for this variable are presented in Tables 3 and 4. Errors in completing the documentation were recorded, but not considered in determining the passing or failing of a problem.

[7] Actual rectifications were not made. The technician was required to tell the technical observer what actions he would take to make the rectification and show the specific technical data required. The system health checks were actually made on the aircraft, if the rectification just made would not fix the problem. If the correct rectification had been made, the system health checks were simulated. When the system health checks were simulated, the technician was required to tell the observer which checks he would make and to show the instructions for making the check to the observer.

The specialist and APG technicians successfully completed nearly all the problems when using the IMIS. Only one problem was failed when using the IMIS, compared to 26 (of 144) problems failed using the paper TO as the source of technical data.

Table 3. Percent of Problems Successfully Completed by Avionics Specialists and APG Technicians

Subject Category	TO	IMIS
Avionics Specialist	81.94	100.00
APG Technician	69.44	98.61
Total	75.69	99.31

Table 4. Comparisons of Interest for Percentage of Problems Successfully Completed

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	75.69	99.31	-23.61	Yes***
Spec. TO vs. IMIS	81.94	100.00	-18.06	Yes**
APG TO vs. IMIS	69.44	98.61	-29.17	Yes***
Spec. TO vs. APG IMIS	81.94	98.61	-16.67	Yes*
Spec. TO vs. APG TO	81.94	69.44	12.50	No
Spec. IMIS vs. APG IMIS	100.00	98.61	1.39	No

* $p < .05$
** $p < .01$
*** $p < .001$

The success rate for both specialists and APG technicians was much lower when the paper TO was the source of technical data. Close examination of the data reveals that most of the failures with the paper TO were due to a failure to complete all required system healthchecks. These differences in performance can be explained by the fact one or more BITs or operational checks are required to verify that the system has been returned to operationally ready status. System health tests and checkout requirements are presented in the follow-on maintenance requirements section of the paper TO. The manner in which the follow-on maintenance requirements are presented in the paper TOs for some systems makes it easy to overlook required checks. Several technicians failed to complete all the required checks and failed the problems for this reason. With the IMIS, it is impossible to overlook the required checks. When a technician completes a task, IMIS immediately presents the instructions for the follow-on task. He either has to follow the instructions or consciously choose not to do the task.

Statistical analysis of the data indicates that the observed differences in the rate of successful problem completion, when using IMIS vs. paper TO, are statistically significant for both the avionics specialists and APG technicians ($p < .01$ and $p < .001$, respectively). Further, the analysis indicates that APG technicians using the IMIS were able to successfully return significantly more systems to operational status than specialists using paper TOs as their source of technical data. This difference is statistically significant ($p < .05$). Thus, the data supports both Hypothesis 1 and Hypothesis 2. Also, it should be noted that, on this measure, the APG technicians using the IMIS were as proficient as the avionics specialists using the IMIS (i.e., no significant differences were found) and more proficient than the specialists when they used the paper TO.

Performance Measure: Parts Used.

Hypotheses:

3. Avionics specialist technicians using IMIS to perform troubleshooting tasks will replace significantly fewer parts when using the IMIS than when using paper TOs.

4. APG technicians using IMIS to perform troubleshooting tasks will replace significantly fewer parts than will avionics specialists using paper TOs.

Findings:

Frequently in the troubleshooting process, "good" parts are unnecessarily replaced. Good parts are sometimes replaced as part of the diagnostic strategy. This occurs when there is no way to determine if a part is good or bad, other than to replace it, and see if a known good part fixes the problem. Also, good parts may be replaced as the result of technician error. The IMIS diagnostics seek to reduce the number of good parts unnecessarily replaced by providing a strategy which reduces the frequency of instances where the diagnostic data requires replacing a part to determine if it is good, and by presenting diagnostic information in a manner which will reduce the frequency of technician errors which can cause a good part to be replaced. For each set of six problems (two FCR, two HUD, two INS) used in this test, correctly following the diagnostic procedures in the paper TOs required the replacement of eight parts — five good parts and three defective parts. The corresponding set of six problems performed with the IMIS required replacing five parts — two good parts and three defective parts. The good parts saved were all for the INS. The paper TO and IMIS required the same number of parts for the FCR and HUD problems. The INS problems required replacing five parts with the paper TO and two parts with the IMIS.

The mean number of parts used by technicians to complete the six problems under each condition are shown in Tables 5 and 6. The specialists required an average of 8.67 parts to complete the six problems using the paper TO, compared to 6.42 parts when using the IMIS. The APG technicians required 8.30 parts for the problems when using the paper TO, compared to 5.30 parts when using the IMIS. The difference in the mean number of parts used with IMIS vs. the paper TO were statistically significant at the .001 level of confidence for both the specialists and APG technicians. Thus, Hypothesis 3 is supported by the data. When the mean number of parts used by APG technicians is compared with the mean for specialists, the difference is statistically significant ($p < .001$) also. Thus, Hypothesis 4 is supported by the data.

Table 5. Mean Number of Parts Used for Six Problems Under Each Condition

Subject Category	TO	IMIS
Avionics Specialist	8.67	6.42
APG Technician	8.30	5.30
Total	8.50	5.91

Table 6. Comparisons of Interest for Mean Number of Parts Used for Six Problems Under Each Condition

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	8.48	5.90	2.69	Yes***
TO vs. IMIS	8.67	6.42	2.25	Yes**
APG TO vs. IMIS	8.28	5.30	3.13	Yes***
Spec. TO vs. APG IMIS	8.67	5.30	3.51	Yes***
Spec. TO vs. APG TO	8.67	8.28	0.38	No
Spec. IMIS vs. APG IMIS	6.42	5.30	1.26	No

** $p < .01$
*** $p < .001$

Analysis of the data revealed that both the specialists and APG technicians replaced significantly more good parts when using paper TOs than when using IMIS ($p < .01$ and $p < .001$, respectively). Thus, Hypothesis 3 is accepted. In addition, specialists using the paper TO replaced significantly more parts than APG technicians using the IMIS ($p < .001$), supporting Hypothesis 4. Five of the good parts replaced when using the paper TO were directed by the paper TO as part of its troubleshooting strategy. The additional good parts (0.67 for specialists and 0.30 for APG technicians) replaced when using the paper TO were due to technician error. Two of the good parts replaced using the IMIS were directed as part of its troubleshooting strategy. The additional good parts (1.42 for specialists and 0.30 for APG technicians) replaced when using the IMIS were due to technician error.

Detailed analysis of parts usage revealed that the part savings for the IMIS were from one subsystem, the INS. This appears to be due to the differences in the complexity of the troubleshooting tasks for the systems. The INS troubleshooting procedures are much more complex than procedures for the FCR and HUD. A detailed analysis of the ability of the IMIS to reduce parts requirements is presented later in this section.

Performance Measure: Maintenance Errors

Hypotheses:

5. Avionics specialist technicians will make significantly fewer maintenance errors while performing the troubleshooting problems when using the IMIS than when using paper TOs.

6. APG technicians will make significantly fewer maintenance errors while performing the troubleshooting problems when using the IMIS than will avionics specialists using the paper TOs.

Findings:

As indicated above, one goal of the IMIS diagnostics was to reduce the frequency of errors which could result in the unnecessary replacement of good parts. The degree to which this goal was met by the IMIS Demonstration System is reflected in Tables 7 and 8.

Table 7. Mean Number of Serious Errors Under Each Condition

Subject Category	TO	IMIS
Avionics Specialist	0.69	0.29
APG Technician	1.06	0.18
Total	0.87	0.23

Table 8. Comparisons of Interest for Mean Number of Errors per Problem Under Each Condition

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	0.87	0.23	0.64	Yes***
Spec. TO vs. IMIS	0.69	0.29	0.40	No
APG TO vs. IMIS	1.06	0.18	0.88	Yes***
Spec. TO vs. APG IMIS	0.69	0.18	0.51	Yes*
Spec. TO vs. APG TO	0.69	1.06	-0.37	No
Spec. IMIS vs. APG IMIS	0.29	0.18	0.11	No

* $p < .05$

*** $p < .001$

Maintenance errors made while performing the test problems were recorded by the data collector.[8] Analysis of the error data reveals that errors made by avionics specialists were reduced by 58 percent and errors by the APG technicians were reduced by 83 percent. The observed difference for the APG technicians is statistically significant ($p < .001$). However, the observed difference for the specialists was not statistically significant. Thus, Hypothesis 5 is rejected. Comparison of the errors made by specialists using the paper TO with the number of errors made by the APG technicians using the IMIS revealed that the APG technicians made significantly fewer errors, supporting Hypothesis 6. The IMIS had a greater impact for reducing errors for the APG technicians than for the specialists. This difference is reflected in a significant statistical interaction ($p < .05$). This difference in impact appears to be due, in part, to their lack of familiarity with some of the tasks required to perform the problems (e.g., taking resistance readings from multi-pin connectors).

The most frequent errors for the paper TO condition were omitting a required BIT or operational check, use of the wrong operational check, misuse of the paper TO (followed wrong path, used wrong procedure, misread data, etc.), and errors in making readings with the multimeter. The most common errors for the IMIS condition were errors in using the multimeter (read wrong pin, read from jack instead of plug, etc.), and omission of a required step (e.g., failure to reconnect cannon plug, skipping step, etc.).

Performance Measure: Total Time

Hypotheses:

7. Avionics specialist technicians will require significantly less total time to complete troubleshooting problems when using the IMIS than when using paper TOs.

8. APG technicians will require significantly less total time to complete the troubleshooting problems when using the IMIS than will avionics specialists using the paper TO.

Findings:

The mean times[9] to complete the troubleshooting tasks and results of the statistical analysis are shown in Tables 9 and 10.

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[8] For the study, an error was defined as an incorrect action which could result in a failure to diagnose the fault, result in unnecessary replacement of a good part, significantly increase the troubleshooting time (by sending the technician down the wrong path), or cause an injury to the technician or serious damage to the aircraft.

[9] The times in Tables 9 and 10 are adjusted to include the time required to submit and process part orders and the time required to input close-out data into CAMS. This adjustment was made by adding 15 minutes to the observed time for each part ordered and 10 minutes to the observed time to adjust for the time to enter the close-out information into CAMS.

Table 9. Mean Problem Performance Times (in Minutes) for Each Problem

Subject Category	TO	IMIS
Avionics Specialist	149.29	123.64
APG Technician	175.82	124.04
Total	161.46	123.83

Table 10. Comparisons of Interest for Performance Times

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	161.46	123.83	37.63	Yes***
Spec. TO vs. IMIS	149.29	123.64	25.64	Yes**
APG TO vs. IMIS	175.82	124.04	51.78	Yes***
Spec. TO vs. APG IMIS	149.29	124.04	25.25	Yes**
Spec. TO vs. APG TO	149.29	175.82	-26.53	Yes**
Spec. IMIS vs. APG IMIS	123.64	124.04	-0.40	No

** $p < .01$
*** $p < .001$

Both the avionics specialists and APG technicians required more time to complete the fault isolation problems when using the paper TO. Use of the IMIS reduced problem performance times of the specialists by approximately 17 percent and the times of the APG technicians by approximately 29 percent. The performance times of the specialists and APG technicians were essentially the same (i.e., no statistically significant differences were found).

The statistical analysis indicates that when using the IMIS, the specialists were able to perform the troubleshooting problems in significantly less time than when using the paper TO ($p < .001$), supporting Hypothesis 7. In addition, the APG technicians using the IMIS were able to perform the problems in significantly less time than the specialists using the paper TOs ($p < .01$). Thus, Hypothesis 8 is supported, also. In addition, the data indicates that the use of the IMIS had a greater relative benefit for the APG technicians than the specialists (i.e., APG technicians improved more with IMIS). The IMIS had the impact of improving the performance times of the APG technicians from being much slower than the specialists, to being on a par with the specialists. This finding is reflected in a significant statistical interaction ($p < .001$) between the media (IMIS vs. paper TO) and job classification (specialist vs. APG).

Performance Measure: Preparation Time

Hypotheses:

9. Avionics specialist technicians will require significantly less time to prepare for a troubleshooting task when using the IMIS as the source of technical information than when using the paper TO.

10. APG technicians using the IMIS will require significantly less time to prepare for a troubleshooting task than will avionics specialists using paper TOs.

Findings:

The mean preparation times and results of the statistical analysis of the observed preparation times are presented in Tables 11 and 12. As may be observed from the tables, only a small difference in preparation times was observed for problems performed with the paper TO versus problems performed with the IMIS. Also, only small differences in preparation times were observed for specialists and APG technicians. Hypotheses 9 and 10 are not supported by the data. Specialists were not able to prepare for the troubleshooting task significantly faster when using IMIS than when using the paper TO, and APG technicians using the IMIS were not able to prepare for the task significantly faster than the specialists using the paper TO.

Table 11. Mean Preparation Time (in Minutes) for Each Problem

Subject Category	TO	IMIS
Avionics Specialist	5.00	5.18
APG Technician	5.10	4.56
Total	5.05	4.87

Table 12. Comparisons of Interest for Preparation Times

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	5.05	4.87	0.18	No
Spec. TO vs. IMIS	5.00	5.18	-0.18	No
APG TO vs. IMIS	5.10	4.56	0.54	No
Spec. TO vs. APG IMIS	5.00	4.56	0.44	No
Spec. TO vs. APG TO	5.00	5.10	-0.10	No
Spec. IMIS vs. APG IMIS	5.18	4.56	0.63	No

Performance Measure: Fault Verification Time

Hypotheses:

11. Avionics specialist technicians will require significantly less time to verify faults in the test-bed subsystems when using the IMIS than when using paper TOs.

12. APG technicians using IMIS will require significantly less time to verify faults in the test-bed subsystems than will avionics specialists using paper TOs.

Findings:

Tables 13 and 14 present the mean fault verification times. Examination of the tables reveals that using the IMIS to verify the fault did not have a significant benefit for the specialists. They required slightly longer to verify the fault when the IMIS was used. This difference is not statistically significant; thus, Hypothesis 11 is rejected. However, the IMIS did make a significant difference for the APG technicians when verifying the fault. Use of the IMIS reduced the time required to verify the fault by 40 percent. The analysis also indicates that the APG technicians using IMIS were not able to verify the fault significantly faster than the specialists using the paper TO. Thus, Hypothesis 12 is rejected also.

Table 13. Mean Fault Verification Times

Subject Category	TO	IMIS
Avionics Specialist	9.65	10.57
APG Technician	18.31	11.07
Total	13.98	10.82

Table 14. Comparisons of Interest for Fault Verification Times

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	13.98	10.82	3.16	Yes***
Spec. TO vs. IMIS	9.65	10.57	-0.92	No
APG TO vs. IMIS	18.31	11.07	7.24	Yes***
Spec. TO vs. APG IMIS	9.65	11.07	-1.42	No
Spec. TO vs. APG TO	9.65	18.31	-8.65	Yes***
Spec. IMIS vs. APG IMIS	10.57	11.07	-0.50	No

***$p < .001$

The IMIS had a much greater effect for the APG technicians performing the fault verification task than for the specialists. Their times improved from being significantly slower than the specialist times to being approximately equal. This difference in the effect of the diagnostic-aiding methodology is reflected in a significant statistical interaction ($p < .001$). The interaction shows that when using paper TOs there was a significant difference between specialties; however, when using the IMIS, significant differences were not found.

Performance Measure: Fault Isolation Time

Hypotheses:

13. Avionics specialist technicians will require significantly less time to isolate faults in the test-bed subsystems when using the IMIS than when using paper TOs.

14. APG technicians using IMIS will require significantly less time to isolate faults in the test-bed subsystems than will avionics specialists using paper TOs.

Findings:

The mean fault isolation times are given in Tables 15 and 16. For this measure, fault isolation time was defined as the performance time (starting when the technical observer told the technician to isolate the fault [after fault verification] and ending when the technician

Table 15. Mean Fault Isolation Times (in Minutes) for Each Problem

Subject Category	TO	IMIS
Avionics Specialist	116.22	95.92
APG Technician	132.72	96.86
Total	123.79	96.35

Table 16. Comparisons of Interest for Fault Isolation Times

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	123.79	96.35	27.44	Yes***
Spec. TO vs. IMIS	116.22	95.92	20.31	Yes**
APG TO vs. IMIS	132.72	96.86	35.86	Yes***
Spec. TO vs. APG IMIS	116.22	96.86	19.36	Yes**
Spec. TO vs. APG TO	116.22	132.72	-16.50	No
Spec. IMIS vs. APG IMIS	95.92	96.86	-0.94	No

**$p < .01$
*** $< .001$

declared the rectification complete and the subsystem returned to full operational status) in addition to standard times for rectifications made, part ordering, and the final system health.

Both the specialists and APG technicians were able to isolate the faults significantly faster ($p < .05$ and $p < .001$ respectively) when using the IMIS than when using the paper TO. Thus, Hypothesis 13 is supported. In addition, the APG technicians using the IMIS required significantly less time than the specialists to isolate the faults ($p < .05$), thereby supporting Hypothesis 14. Although there was a relatively large (but not statistically significant) difference between the times for specialists and APG technicians when both used the paper TOs, the use of the IMIS brought the performance of the APG technicians to a level approximately equal to the specialists. Thus, the IMIS had a greater benefit for the APG technicians. This observation is reflected in a significant statistical interaction ($p < .001$) for the specialty and media (IMIS vs. paper TO) variables.

Performance Measure: Part Ordering Time

Hypotheses:

15. Avionics specialist technicians will require significantly less time to order each part when using the IMIS than when using current part ordering procedures.

16. APG technicians using IMIS will require significantly less time to order each part than required by avionics specialists using current part ordering procedures.

Findings:

The mean times to order each part are shown in Tables 17 and 18. Since there was no way to simulate the part ordering process for the current procedures without interfering with squadron operations, a standard time estimate was used for this measure. The estimate used for each part order was the observed time for the technician to locate the necessary part ordering information (part number, figure number, etc.) plus a standard time for traveling to the COSO, getting supervisor approval, and processing the order. A standard time of 15 minutes was used for each part order. The estimate was based on estimates by experienced technicians, supervisors, and COSO personnel, and is considered to be conservative. Analysis of the data indicates that both the specialists and APG technicians were able to order parts significantly faster ($p < .001$) when using the IMIS to order parts than when they use the current part

Table 17. Mean Part Ordering Time

Subject Category	Current	IMIS
Avionics Specialist	19.42	1.16
APG Technician	25.28	1.47
Total	22.29	1.30

Table 18. Comparisons of Interest for Mean Part Ordering Time

Comparison	Mean	Mean	Difference	Significant
Total Current vs. IMIS	22.29	1.30	-5.86	Yes***
Spec. Current vs. IMIS	19.42	1.16	18.26	Yes***
APG Current vs. IMIS	25.28	1.47	23.81	Yes***
Spec. Current vs. APG IMIS	19.42	1.47	17.95	Yes***
Spec. Current vs. APG TO	19.42	25.28	-5.86	Yes***
Spec. IMIS vs. APG IMIS	1.16	1.47	-0.31	No

*** $p < .001$

ordering process. In addition, the analysis indicates that the APG technicians using the IMIS required significantly less time to order parts ($p < .001$) than did specialists using the paper TO. Consequently, Hypotheses 15 and 16 are both supported by the data. The analysis also revealed a significant statistical interaction ($p < .001$) between specialty and media, indicating that the IMIS had more effect on part ordering time for the APG technicians than for the specialists.

The greatly reduced part ordering times when the IMIS is used are primarily due to the use of the RF link. The IMIS transmits the part order request directly to the Production Superintendent for approval. After approval, the order is directly transmitted to the CAMS and SBSS to be filled. The current procedure requires the technician to go to the COSO, look up the part number, fill out the part order, locate the Production Superintendent, get his or her approval, and take the order to the supply clerk for entry to the SBSS.

Performance Measure: Close-Out Time

Hypotheses:

17. Avionics specialist technicians will require significantly less time to complete required documentation when using the IMIS than when using current documentation and close-out procedures.

18. APG technicians using IMIS will require significantly less time to complete required documentation than will avionics specialists using current documentation and close-out procedures.

Findings:

Test constraints did not permit a direct comparison of the current close-out procedures and the IMIS-based close-out procedures because the current procedures require the technician to locate a CAMS terminal and enter the data to the CAMS system. Since there was no way to do this in a test situation without inputting the test data into the CAMS (and thus contaminating the CAMS data base), it was necessary to simulate the CAMS input for the current process condition. This simulation was accomplished by having the technicians enter the necessary information on a paper form. The time required to complete the form was recorded and a standard time for entering the data to the CAMS was added to the observed time to provide an estimated close-out time. The standard time was developed from estimates provided by experienced technicians. The technicians estimated that the process of going to the maintenance office, obtaining access to a CAMS terminal, and entering the data requires approximately 15 minutes. A conservative estimate of 10 minutes per problem was used as the standard time for this measure.

The work order close-out procedure implemented in the IMIS Demonstration System required the technician to enter the required information on a form displayed on the screen. To complete the form, the technician selected the desired entries from lists of possible entries. The completed information was then transmitted via the RF link to the CAMS. This process saved the time required for the technician to locate a CAMS terminal and enter the data. The IMIS work order close-out was a slow process, given the slow response times of the IMIS Demonstration System. It also provided an opportunity for error.[10]

The mean close-out times are given in Tables 19 and 20. The analysis indicates that the IMIS significantly reduces the time required to complete close-out documentation. The total close-out times are reduced by approximately 46 percent. All comparisons of paper TO-based close-out with IMIS-based close-out are statistically significant ($p < .001$). Specialists were able to complete the close-out significantly faster when using the IMIS than when using paper TOs. Thus, Hypothesis 17 is supported. Also, APG technicians using the IMIS were able to perform the close-out task significantly faster than specialists using paper TOs. Therefore, Hypothesis 18 is accepted.

Table 19. Mean Close-Out Times
(in Minutes)

Subject Category	TO	IMIS
Avionics Specialist	14.67	8.17
APG Technician	17.31	8.82
Total	15.98	8.49

[10] The IMIS Demonstration System did not fully implement the IMIS requirements for documenting maintenance actions. Most of the information required for completion of the work order close-out (work unit code, part numbers, etc.) can be automatically collected during the diagnostic session and automatically inserted into the close-out record at the end of the session. The technician would not be required to do more than verify the information before it is submitted. The IMIS Demonstration System did not automatically insert this information. An operational implementation of the IMIS will provide this automated data collection and recording function.

Table 20. Comparisons of Interest for Close-Out Time

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	15.98	8.49	7.49	Yes***
Spec. TO vs. IMIS	14.67	8.17	6.50	Yes***
APG TO vs. IMIS	17.31	8.82	8.49	Yes***
Spec. TO vs. APG IMIS	14.67	8.82	5.85	Yes***
Spec. TO vs. APG TO	14.67	17.31	-2.64	Yes**
Spec. IMIS vs. APG IMIS	8.17	8.82	-0.65	No

** $p < .01$
*** $p < .001$

Performance Measure: Documentation Errors

Hypotheses

19. Avionics specialist technicians will make significantly fewer documentation errors when using the IMIS than when using current documentation procedures.

20. APG technicians using IMIS will make significantly fewer documentation errors than will avionics specialist technicians using current documentation procedures.

Findings:

Documentation errors are summarized in Tables 21 and 22. Examination of the tables reveals that relatively few errors were made per problem. No significant differences were found in the number of documentation errors made by specialists and APG technicians. In addition, there were no significant differences in the number of errors made when using the IMIS vs. using current documentation procedures. However, there was a significant statistical interaction ($p < .05$) for media vs. specialty. The interaction indicates that the IMIS was more successful in reducing documentation errors for APG technicians than for specialists. In the paper TO condition, APG technicians made more documentation errors than the specialists. In the IMIS condition, specialists made more documentation errors than the APG technicians. It should be noted that the number of documentation errors made was relatively small and not of much operational significance. As noted earlier, a full implementation of the IMIS concept will automatically complete the documentation, eliminating almost all errors.

Relative Impact of IMIS for Specialists and APG Technicians

When the mean times for the various measures are examined as a whole, a major benefit of the IMIS is obvious. The use of IMIS essentially "evens out the playing field" for specialists and APG technicians. When the APG technician uses the IMIS, the performance advantages of the specialist disappear. This effect is clearly illustrated in Figure 4. When the APG technicians used the IMIS, their performance was essentially equal to the specialists using the IMIS and

Table 21. Mean Number of Documentation Errors per Problem

Subject Category	TO	IMIS
Avionics Specialist	0.01	0.11
APG Technician	0.08	0.04
Total	0.05	0.08

Table 22. Comparisons of Interest for Documentation Errors

Comparison	Mean	Mean	Difference	Significant
Total TO vs. IMIS	0.05	0.08	-0.03	No
Spec. TO vs. IMIS	0.01	0.11	-0.10	No
APG TO vs. IMIS	0.08	0.04	0.04	No
Spec. TO vs. APG IMIS	0.01	0.04	-0.03	No
Spec. TO vs. APG TO	0.01	0.08	-0.07	No
Spec. IMIS vs. APG IMIS	0.11	0.04	0.07	No

better than the specialists using the paper TO. With the exception of fault verification, there were no significant differences in the mean times observed for any of the measures used in this test when both the specialists and APG technicians used the IMIS. However, with the exception of preparation times, there was a significant difference for all measures in the performance of specialists and APG technicians when both used the paper TO. The graphs in Figure 4 also illustrate the statistically significant interactions observed for several of the measures. Statistically significant interactions were found for total time ($p < .01$), fault verification ($p < .001$), close-out time ($p < .05$), maintenance errors ($p < .05$), part order time ($p < .001$), and documentation errors ($p < .05$). The interaction indicates that the benefits of the IMIS are greater for the APG technicians than for the specialists.

Analysis of IMIS Diagnostics Capability

The IMIS Diagnostics Module is expected to produce significant reductions in the consumption of spare parts, therefore it is essential that these capabilities be fully understood. To this end, a thorough analysis was made of the IMIS diagnostic capability to minimize unnecessary part replacements. The analysis was conducted in three parts: a more thorough examination of the field test parts consumption data, a table-top comparison of the diagnostic strategies developed by IMIS versus diagnostic strategies used in the paper TO, and a comparison of projected parts usage based upon subsystem failure data. These analyses are based upon the FCR, HUD, and INS paper TOs, and the diagnostic strategies developed by the IMIS from the IMIS data base for those subsystems. The results of the analyses are presented in the following paragraphs.

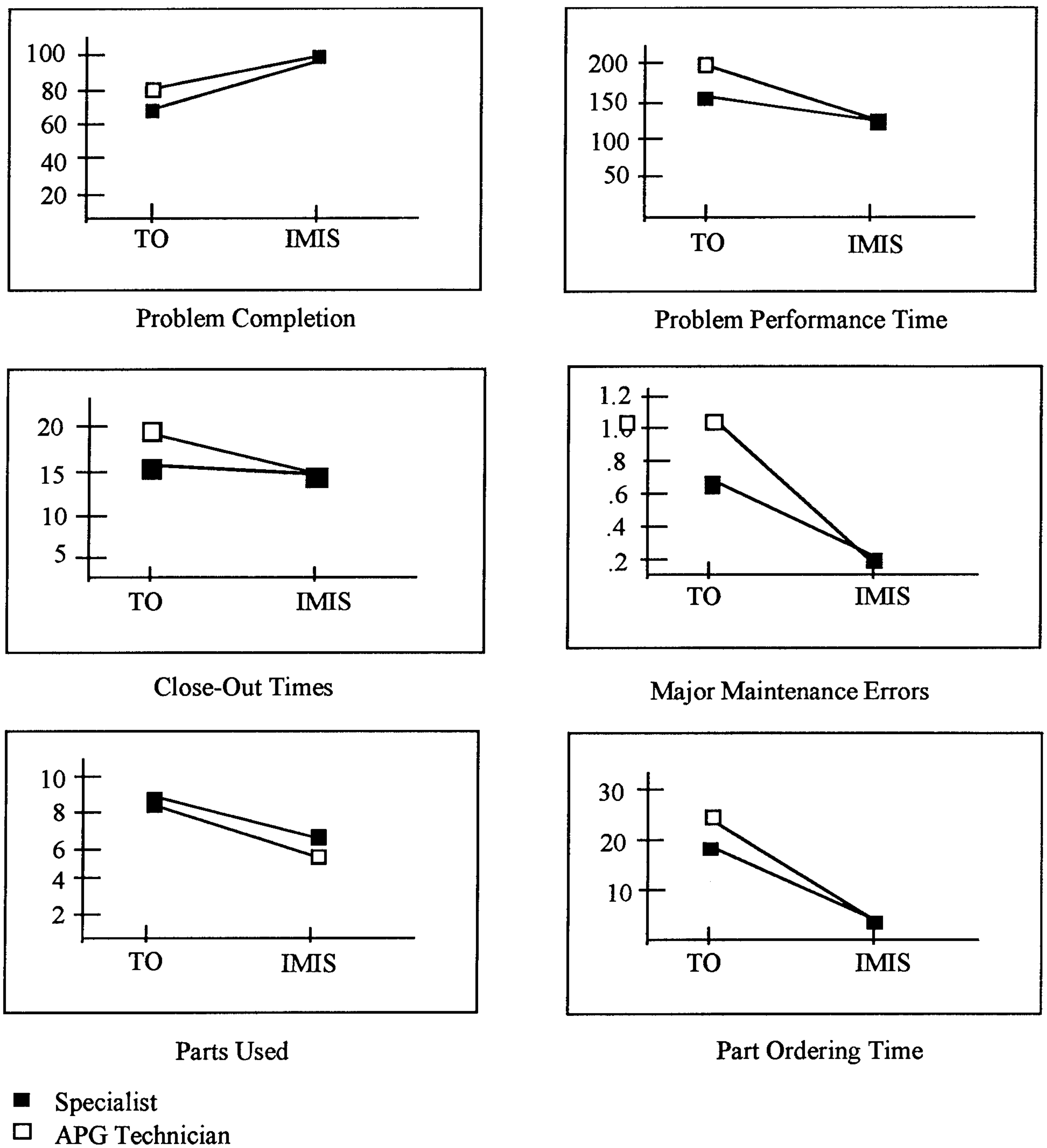


Figure 4. Plots of Means Demonstrating Impact of IMIS for Avionics Specialists and APG Technicians

Further Analysis of Field Test Parts Data

Parts use by the technicians for all problems are summarized in Table 23. The table presents information on the following elements.

a. Expected Part Use. The "expected part use" indicates the total number of parts all subjects were expected to use for all problems under each condition when the IMIS or paper TO are followed without deviation or error.[11]

b. Actual Part Use. The "actual part use" represents the number of parts actually used by all subjects under each condition.

c. Unnecessary Removals. "Unnecessary removals" are the number of parts used in excess of the number of parts required to complete the test problems by following the diagnostic procedures without deviation or error (actual part use minus expected part use).

d. Parts Not Used. The "parts not used" indicates the number of parts "saved" by deviating from the diagnostic procedure (due to technicians choice based upon subsystem knowledge or a lucky error which led to a quicker solution of the problem).

Table 23 reveals that the technicians replaced many more parts than required to actually fix the problems. A total of 72 parts were required under each condition to solve the problems; yet, 202 parts were used with the paper TO and 138 were used with the IMIS. Thus, 130 good parts were replaced with the paper TO and 66 good parts were replaced with the IMIS. The paper TO directed 118 of the good part removals as part of the diagnostic strategy. The IMIS led to replacing 46 parts as part of the diagnostic strategy. An additional 12 good parts were replaced with the paper TO due to technician error or a conscious decision to deviate from the paper TO procedure. Twenty good parts were replaced with the IMIS because of technician error or intentional deviation. In addition, there were three instances where the technician used one less part than required by correctly following the diagnostic procedures. These instances all occurred when the paper TO was used.

The data clearly illustrate one of the major problems encountered in avionics diagnostics — ambiguity groups. An ambiguity group is two or more components in a system which could be the cause of the fault under consideration for which there is no way to eliminate a component from consideration without replacing it or another component. The IMIS was successful

[11] There were two instances in which the technician was not able to correctly identify the faulty part. Data for these problems is not included in this analysis.

Table 23. Summary of Parts Used by All Technicians for All Problems

	Expected Part Use		Actual Part Use		Unnecessary Parts		Parts Not Used	
	TO	IMIS	TO	IMIS	TO	IMIS	TO	IMIS
Specialist								
FCR	24	24	27	31	3	7	1	0
HUD	12	12	16	21	4	9	0	0
INS	60	24	61	25	1	1	0	0
Total Specialist	96	60	104	77	8	17	1	0
APG								
FCR	24	24	24	24	0	0	1	0
HUD	12	12	15	15	3	3	0	0
INS	58	22	59	22	1	0	1	0
Total APG	94	58	98	61	7	3	2	0
Total All Subjects	190	118	202	138	12	20	3	0

in breaking the ambiguity groups for two of the INS problems (by recommending a quick test before making a rectification), resulting in saving three good parts per problem. However, the IMIS was not able to break the ambiguity groups in the other problems and used the same number of parts as the paper TO. Dealing with ambiguity groups is a complex issue which is examined in more detail in the discussion section of this report.

For several problems, technicians replaced more than the expected number of parts for both the IMIS and paper TO conditions. These additional parts were replaced either due to an error made by the technician or due to a decision by the technician to deviate from the prescribed procedure. Those instances where extra parts were used were examined to identify the reasons for the use of extra parts. The apparent reasons for each use of an extra part are summarized in Table 24.

Table 24 presents several items worth noting. The major cause of unnecessary part use for both the paper TO and IMIS was errors made in taking multimeter readings. The errors were due to the technician taking measurements from the wrong pin or from the jack instead of the plug (or vice versa). This type of error appears to occur because of inadequate guidance in the technical data (both paper TO and IMIS) and because it is easy to miscount pins on the plug or jack. Earlier test versions of IMIS diagnostics have provided improved illustrations to help technicians locate the correct pins. Results from those tests suggest that the use of similar

Table 24. Reasons for Unnecessary (Unexpected) Parts Use

Paper TO Problems	Number Errors	Number Parts*
Use of Technical Data	5	6
Incorrect Measurements	4	6
Technicians Choice	1	2
IMIS Problems		
Use of Technical Data	3	3
Incorrect Measurements	6	11
Tech. Choice (best actions list)	5	6

* Some errors led to replacing more than one part unnecessarily (i.e., continuing down the wrong path).

illustrations in the IMIS technical data may have reduced the number of errors and unnecessary component replacements.[12]

Parts were unnecessarily replaced as a result of incorrect use of both the paper TO and the IMIS. Errors made using the paper TO were due to misreading or misinterpreting the data, incorrectly following the procedure (e.g., taking the wrong path in a troubleshooting tree or using the wrong table), or the technician losing his place (e.g., wind turning the page without the technician noticing). The errors with the IMIS were due to the technician not correctly following the procedures or misinterpreting them.

Several parts were replaced because the technician consciously chose to replace a part instead of following the procedure. This occurred when the technician thought he knew the cause of the fault and chose to take a short cut. Proper use of the paper TO (as required in this study) does not permit deviation from the technical data. However, some technicians chose to deviate and replace a part based upon their system knowledge. One of those instances resulted in the unnecessary replacement of two parts. There were three instances when the technicians deviated from the recommended sequence, one less part was used than would have been required by adhering to the data.

The IMIS permits technicians to take advantage of their system knowledge and deviate from the step-by-step diagnostic procedures. This option is provided by the best actions list which the technician can call up during the diagnostic process. The list gives ranked lists of the tests and rectifications available at that time and the probability of the test passing or the listed rectification correcting the problem. The first item in the list is always the recommended action; however, the technician can choose other lower-ranked options. When the technician selects from the list, the system presents the technical data required to accomplish that action. Several technicians chose to take advantage of the best actions option (i.e., they did not choose the

[12] The illustrations used in the IMIS were taken from the paper TO with little modification other than to remove some unnecessary detail and clutter.

recommended action) and used it to replace parts at their discretion. In five instances where the technician chose to use the best actions option, six extra parts were used. There were no instances where use of the best actions option resulted in using fewer than the expected number of parts.

Four of the unnecessary part replacements with the paper TO and six of the replacements with the IMIS can be classified as continuations. These were parts replaced as the result of an error that had already led to the replacement of one or more good parts. This type of part use occurred when the technician made an error which led him down the wrong path, or made a part replacement based upon his system knowledge which led to further replacements when the fault was not corrected.

The data presented in Table 23 also provides an explanation for the finding that the parts savings were all for the INS. Comparison of the expected parts use for the paper TO versus the expected parts use for the IMIS reveals that error-free performance of the FCR and HUD tasks using the paper TO would require the same number of parts as error-free performance using the IMIS. However, error-free performance using the paper TO for the two INS problems requires five parts per subject, while error-free performance using the IMIS requires only two parts per subject. It was expected that the use of the IMIS diagnostics also would have required fewer parts for the FCR and HUD problems. There are two explanations: (1) the evaluation team chose FCR and HUD faults that IMIS cannot improve upon the existing paper TOs (the paper TO is as efficient as possible given the available subsystem performance information for that fault), and (2) the IMIS diagnostics do not yield the expected benefits for all subsystems.

Examination of the FCR and HUD fault trees used in the test suggest that the problem was basically the "luck of the draw." Other faults could have been selected from the trees as the test faults which would have required fewer parts when using IMIS diagnostics than when using the paper TO diagnostics. Although, this finding explains why better results were not achieved for the test faults, it does raise the question of how often the IMIS diagnostics require fewer parts. In other words, what is the real potential of the IMIS diagnostics for reducing parts consumption on the F-16 INS, FCR, and HUD? An additional analysis was made to answer this question. The results are provided in the following sections.

Comparison of Paper TO and IMIS Fault Trees

The 12 faults used as the basis for the problems for the IMIS field test represent only a small portion of the possible faults in the three test-bed subsystems. Although, they were selected to be representative of the faults occurring in the subsystems, it is not known how representative the paper TO fault trees used actually are. Nor, is it known if the diagnostic procedures generated by the IMIS for the 12 faults are representative of the fault trees that would be generated to isolate all faults in the subsystem. To answer this question and to obtain a better understanding of the relative efficiency of the IMIS and paper TO fault trees, a table-top analysis was accomplished to compare the efficiency (in terms of part use) of the paper TO fault trees with the fault trees generated by the IMIS.

The analysis was accomplished by selecting a representative sample of fault trees for each of the three subsystems. Eight fault trees were selected for the FCR (of 26 trees), eight for the HUD (of 20 trees), and four plus two partial[13] trees for the INS (of six trees). Trees were selected to be representative in terms of length and complexity. Six of the FCR fault trees were of average complexity, and two were above average in complexity; five of the HUD fault trees were average, two were complex, and one was simple; and four of the INS fault trees were average and two were complex. The partial fault trees were of average complexity. Each tree was analyzed by identifying all faults covered by the tree, then identifying the maintenance actions (tests and rectifications) performed to isolate each fault. The number of maintenance actions and parts used to isolate each fault was recorded. A similar process was followed for the IMIS. An analyst entered the IMIS with the appropriate symptom for each fault. He then entered the appropriate information until he reached the rectification for each fault. The number of maintenance actions and rectifications were recorded. The results of this analysis are presented in Table 25.

The table presents the number of *unnecessary* rectifications (part replacement or wire repairs) made in the process of isolating each fault. Examination of the table indicates large differences in the effectiveness of the paper TO fault trees and the IMIS diagnostics (in terms of unnecessary rectifications made) for the three subsystems. The IMIS appears to have the most benefit for the INS subsystem where unnecessary replacements were reduced by 87.5 percent and for the FCR with a reduction of 51.6 percent. The IMIS also reduces unnecessary rectifications for the HUD, however only by 9.5 percent.

The analysis identifies the number of unnecessary part removals for locating each fault covered by the trees one time. However, faults occur with different frequencies. Thus, this information does not provide a complete picture of the capability of the IMIS to reduce the number of unnecessary rectifications. A second analysis was undertaken to provide an estimate based upon the expected frequency of occurrence of each fault. A comparison was made by estimating the number of unnecessary part rectifications which would occur in 100 repetitions of each of the fault trees listed in Table 25 using the paper TO and 100 repetitions using IMIS.[14]

The unnecessary replacement estimates were based upon the probabilities of the occurrence of each fault and the probabilities of each test passing or failing. The probabilities used were from the IMIS data base. They were generated by engineers at Lockheed Corporation, Fort Worth Division, prime contractor for the F-16 and authors of the F-16 TOs. The probabilities were based on estimates and computations provided by engineers who designed the test-bed subsystems, inputs from experienced FCR, HUD, and INS technicians, and component failure data from the Air Force Maintenance Data Collection System. The rectification estimates were made by following the fault trees and applying the appropriate probabilities at each point. An example is presented in Figure 5.

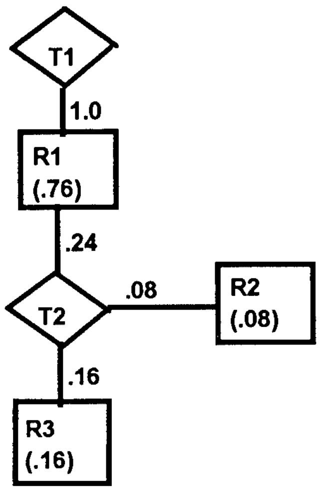
[13] The partial fault trees were "off shoots" of a larger more complex fault tree provided to evaluate the results of the inspection of the contents of a memory location on the inertial navigation unit (INU). They accounted for only a portion of the possible causes of the main tree.
[14] For the memory inspect trees, this is 100 repetitions of the parent tree.

Table 25. Number of Unnecessary Parts Replaced to Isolate Each Fault One Time for Representative FCR, HUD, and INS Fault Trees

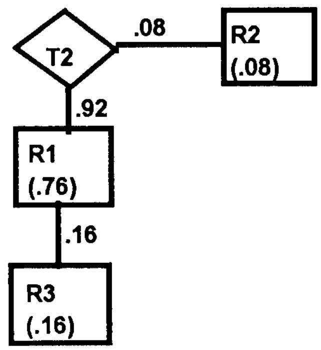
Fault Tree	Rectifications	Unnecessary Parts TO	IMIS	Difference
FCR				
XD	11	4	4	0
AL	19	18	6	12
AD	4	0	0	0
AE	4	0	0	0
XS	4	3	2	1
XM 01	6	2	1	1
AN	3	2	1	1
AU	3	2	1	1
Total FCR	54	31	15	16
Percent Change				51.6
HUD				
AL	6	9	5	4
BH 01	5	3	3	0
XD	6	0	2	-2
AK	3	3	3	0
AD	4	0	0	0
AE	4	0	0	0
BM	5	3	3	0
BR	5	3	3	0
Total HUD	38	21	19	2
Percent Change				9.5
INS				
AF	11	19	1	18
XD	8	12	2	10
XG	6	9	1	8
AG XD	11	29	2	27
AG 144/200	5	20	3	17
AG 145/100	4	15	4	11
Total INS	45	104	13	91
Percent Change				87.5

Figure 5 illustrates how the rectification estimates were made. The fault tree provided in the paper TO (FCR fault tree AN) starts with running the subsystem BIT to verify the fault and obtain the MFL. If there is a fault, Test 1 always "fails" ($p = 1.0$). The fault tree then prescribes Rectification 1 (replace antenna). Thus, the antenna is always replaced, requiring 100 antennas

Paper TO Fault Tree AN
for Fire Control Radar



IMIS Fault Tree AN
for Fire Control Radar
(Electronic Equivilent



	Probability	MTTR
Test 1	1.00	14
Test 2	.08	5
Rectectification 1	.76	75
Rectectification 2	.08	90
Rectectification 3	.16	46

MTTR 100 Repetitions

TO	104.76 Minutes
IMIS	88.56 Minutes

Rectifications Required for 100 Repetitions of Fault Tree AN

Paper TO

Rec 1	100	1.00 x 100
Rec 2	8	.08 x 100
Rec 3	16	.16 x 100

IMIS

Rec 1	92	(.76+.16) x 100
Rec 2	8	.08 x 100
Rec 3	16	.16 x 100

Parts Required for 100 Repetitions:

Paper TO	124
IMIS	116

MTTR = Mean Time to Repair
R = Rectification
T = Test

Figure 5. Example Paper TO and IMIS Fault Trees with Calculations of Estimated Rectifications for 100 Repetitions of Each Fault Tree

in 100 repetitions. Replacing the antenna rectifies the fault 76 percent of the time. If replacing the antenna does not fix the problem, Test 2 is required. The answer to Test 2 is yes 8 percent of the time, leading to Rectification 2 (wiring repair), requiring 8 repairs in 100 replications. If the Test 2 answer is no, Rectification 3 (replace PSP) is made, requiring 16 more parts. Thus, 100 repetitions of paper TO Fault Tree AN require 124 rectifications: 100 to fix the problem and 24 unnecessary rectifications.

The IMIS provides a different strategy. Test 1 is omitted (this information is obtained from the pilot during the debrief using IMIS or during fault verification by the technician). IMIS requires performing Test 2 first. If the answer to Test 2 is yes, Rectification 2 (repair wiring) is required, and the antenna and PSP are eliminated from consideration. If the Test 2 answer is no, the antenna and PSP are both suspect. Since, there is no test which will eliminate either the antenna or PSP from consideration (an ambiguity group), the only option remaining is to replace the antenna or PSP and verify whether the fault still exists in the subsystem. The IMIS recommends replacing the antenna because it has the highest probability of failure. If the fault is still present, it is in the PSP. IMIS requires eight wiring repairs, 92 antenna replacements (76 times when it is bad and 16 times en route to the PSP), and 16 PSPs for a total of 116 rectifications. Thus, IMIS requires eight fewer rectifications than the paper TO for 100 repetitions.

The same analysis procedure can be used to estimate the times for completing the rectifications using the paper TO and IMIS. The Air Force has established mean time to repair (MTTR) estimates for every task required for the test-bed subsystems. The estimated MTTR for 100 repetitions equals the sum of the frequency of each test and rectification times the associated MTTR. The MTTRs were based on use of the paper TO to make the repairs. These same MTTRs were used to estimate the rectification times for the IMIS. Thus, the estimates do not consider any differences in performance times for each repair which would result from using the IMIS. The actual repair times are not expected to be very different, whether the IMIS or paper TO is used. Thus, the MTTRs provide a reasonable estimate of performance times with IMIS. However, the MTTR based estimates do not reflect the time advantages of the use of the IMIS to order parts. A second set of time estimates was made for the IMIS condition to incorporate the advantages of IMIS part ordering.

The estimated unnecessary rectifications for each of the fault trees analyzed are presented in Table 26. The table provides the total number of rectifications for the fault trees studied broken down by type. Three types of rectifications are shown: major, minor, and repair.

Major — Replace a primary LRU such as the PDP or INU.
Minor — Replace a minor (inexpensive) component such as a relay.
Repair — A minor on-equipment repair such as a wiring repair.

The data provided in Table 26 provides further support for the observation that the benefits of the IMIS diagnostics vary with the subsystem. The IMIS yields a substantial savings

Table 26. Total Number of Unnecessary Rectification by Subsystem for 100 Repetitions of Each Fault Tree and the Percent Reduction in Parts Requirements

Subsystem	Unnecessary Rectifications TO	IMIS	Rectifications Saved	Percent Improvement
FCR				
Major	127.0	79.0	48.0	38.2
Minor	45.5	36.0	9.5	20.9
Repair	2.4	21.0	-18.6	-779.0
HUD				
Major	97.0	94.0	3.0	3.09
Minor	0.0	0.0	0.0	0.0
Repair	0.0	0.0	0.0	0.0
INS				
Major	289.0	74.0	215.0	74.4
Minor	0.0	0.0	0.0	0.0
Repair	433.0	47.0	386.0	89.1
Total				
Major	513.0	247.0	266.0	51.9
Minor	46.0	36.0	10.0	20.9
Repair	435.0	68.1	366.9	84.4

in parts for the INS and FCR subsystems. However, the IMIS diagnostics do not appear to have much benefit for the HUD. Further study is needed to determine what characteristics influence the ability of the IMIS to reduce the number of unnecessary removals

The MTTR Estimates are presented in Table 27. The estimates represent an estimate of the average time to complete each of the fault trees studied 100 times. This data supports the observation that the IMIS diagnostics have the greatest benefit for the INS.

Table 27. Mean Times to Repair (in Minutes) for Each of 100 Repetitions of Each Fault Tree (Adjusted for Part Ordering Time)

Subsystem	TO	IMIS
FCR	108.1	100.7
HUD	78.3	72.6
INS	127.8	98.9

To further evaluate the benefits of the IMIS diagnostics, the analysis was extended to estimate the potential cost savings. Cost savings were estimated by multiplying the number of units of each LRU saved by the cost to process the good unit through the depot checkout and repair process. The cost estimates are summarized in Table 28.

The cost data presented in Table 28 indicates that major cost savings can be achieved with the implementation of the IMIS. Cost savings result from both a reduction in expenditures

Table 28. Estimated Savings in Cost of Unnecessary Rectifications Resulting from the Use of IMIS in Place of Paper TOs (for 100 Repetitions of Each Fault Tree Evaluated)

Subsystem	Rectification	Number of Units Saved	Unit Cost in $	Unit Hours Saved	Projected $ Cost Savings	Hours Saved (Lost)
FCR	Replace Antenna	8	18,380	95	147,040	13
	Replace DMT	-1.1	39,580	74	-43,538	(1)
	Replace MLPRF	30.8	47,075	68	1,449,910	35
	Replace Power Relay K2	8	500*	60	4,000	8
	Replace PSP	1.4	79,840	66	111,776	2
	Replace RDR Power Relay K1	10.5	500	60	5,250	11
	Repair AC Compression	3.5	0	90	0	5
	Repair Wiring	-7.5	0	90	0	(11)
	Total FCR Savings - Parts	57.6			1,674,438	66
	Total FCR Savings - Repairs	(4)			0	(6)
HUD	Replace EU	11.5	14,445	45	166,118	9
	Replace GAC	-4.5	16,960	44	(76,320)	(3)
	Replace PDU	-4.8	20,925	58	(100,440)	(5)
	Total HUD Savings (Loss) - Parts	2			(10,643)	1
INS	Replace ADI	4	5,000*	72	20,000	5
	Replace HSI	1	5,000*	72	5,000	1
	Replace INU (3)	183	24,270	74	4,441,410	226
	Replace PSP	4	79,840	76	319,360	5
	Replace Avionics Power Panel	54	5,000*	72	270,000	65
	Repair MUX Address Jumpers	82		110	0	150
	Align INU	100		15	0	25
	Total INS Savings Parts	246			5,055,770	302
	Total INS Repairs/Alignments	182				175
Totals	Part Savings	306			6,719,566	369
	Repair/Alignment Savings	178			0	169

* Estimated cost

for components and a reduction in man-hours required to make unnecessary rectifications. From the data, it is clear that the cost benefits vary greatly from subsystem to subsystem. Implementation of the IMIS for the INS would result in substantial savings (over five million dollars for 100 occurrences of the fault codes associated with the six fault trees studied). The data also indicates significant savings can be achieved by implementing IMIS diagnostics for the FCR. However, the data indicates that the IMIS diagnostics would not significantly reduce costs for the HUD. For the eight fault trees studied, the use of IMIS would have resulted in a slight cost penalty.

Other Findings

Helps Provided

Although helps given were not used as a formal measure for the study, the number of helps required by the technicians provides a good indicator of the ease of use of the IMIS versus the paper TO and of the relative ability of the IMIS and paper TO to meet the technicians' information needs.

For analysis, helps were categorized by impact and by type of help given. The impact categories were: none, minor, and major.

None — help was informative and had no impact on outcome of session.

Minor — help was given as a positive reinforcement or to boost confidence where the technician was demonstrating apparent confusion or frustration.

Major — help was given in response to a direct question after the technician had reached a dead end, or was confused or frustrated beyond independent recovery. The help had a definite impact on the session outcome.

Four types of helps were given. These types are: system knowledge or background, problem solving, clarify/supplement technical data, and technical data use.

System Knowledge or Background — provided primarily for APG technicians to compensate for a lack of experience with the systems (e.g., system function and interaction).

Problem Solving — provided to help technicians interpret information such as cockpit displays, aircraft response, or MFLs.

Clarify/Supplement Technical Data — provided where the technical data omitted necessary information such as configuration data or marking of connector pins.

Technical Data Use — provided to help technicians find and use the required information in the paper TO or IMIS.

The total helps provided are summarized in Table 29.

Examination of Table 29 reveals the expected pattern. The great majority of helps were provided to the APG technicians, and most of those helps were required when the technicians used the paper TO. The APG technicians required 84 percent of the total helps, and 65 percent of the helps occurred when using the paper TO. Most of the helps given to APG technicians were provided during their first few problems. The specialists required very few helps; slightly more of those helps occurred when using the TO.

The system knowledge helps appear to have had little impact on the outcome. All of these helps were judged as having no impact or only a minor impact. Most of the system knowledge helps were given to the APG technicians. Many of these helps were system orientation information, provided to satisfy the technicians' curiosity about how the subsystems work. They indirectly influenced performance because they gave the technicians a better knowledge base from which to attack the problems assigned.

Table 29. Total Number of Helps by Category for Specialists and APG Technicians by Degree of Impact on Problem Outcome

	System Knowledge		Problem Solving		Clarify/ Supplement		Tech Data Use		Total Helps	
Impact	TO	IMIS	TO	IMIS	TO	IMIS	TO	IMIS	TO	IMIS
Specialist										
No Impact	1	6	0	0	0	0	0	0	1	6
Minor	0	1	0	0	2	6	15	3	17	10
Major	0	0	0	0	0	0	7	5	7	5
Total	1	7	0	0	2	6	22	8	25	21
APG Technician										
No Impact	24	28	1	3	0	0	0	0	25	31
Minor	6	0	10	9	18	22	72	13	106	44
Major	0	0	1	0	1	0	31	5	33	5
Total	30	28	12	12	19	22	103	18	164	80
Totals										
No Impact	25	34	1	3	0	0	0	0	26	37
Minor	6	1	10	9	20	28	87	16	123	54
Major	0	0	1	0	2	0	38	10	40	10
Total	31	35	12	12	21	28	121	26	189	101

Problem solving helps appeared to have only a moderate impact on the test outcome. Most of the helps were in the minor category and were largely coaching in nature (e.g., "where would be a good place to find that kind of information" or "remember what you learned in training"). Most of the helps were given to the APG technicians who were unaccustomed to performing troubleshooting tasks and were not comfortable with this type of problem solving. Specialists had little problem in this area because troubleshooting tasks are a major component of their day-to-day work requirements.

Use of the technical data was the primary problem encountered by both specialists and APG technicians. Problems encountered in using the TO accounted for most of these helps. Of the 151 helps for technical data use, 125 (83 percent) were for using the TO. As would be expected, most of the technical data use helps were for the APG technicians, and 85 percent of these were for help in using the TO. Thirty-one of these were classified as major; most were for navigating through the paper TOs and using the wiring diagrams. The specialists also encountered some difficulties in using both types of technical data. The primary problem encountered in using the TO was using the wiring diagrams; the primary problem encountered with the IMIS was failure to read and follow instructions.

Impact of IMIS Demonstration System Speed

As indicated earlier in this report, one limitation of the IMIS Demonstration System is the time for the system to process and present technical data. System response time ranges from one or two seconds (e.g., to present the next step in a sequence) to more than one minute (e.g., to recalculate the set of probable faults). The slow response times slowed technician performance noticeably for some subtasks. An IMIS system for operational implementation is not expected to have these speed limitations. Consequently, it is likely that the time estimates developed for IMIS in this field test are significantly greater than will be experienced with an operational system. Thus, performance estimates based upon the IMIS Demonstration System will underestimate the benefits of an IMIS, unless the data is adjusted to allow for improved system performance. To provide an indication of how much technician performance was slowed by the IMIS Demonstration System, an informal comparison was made with a "second generation" IMIS under development by the AL/HRGO in an in-house project.

The "second generation" IMIS — the IETM Presentation System (IPS) — is a package of DOS/Windows-based software capable of performing most of the functions performed on the IMIS Demonstration System. IPS is designed to run on the IMIS Demonstration System PMA. In addition, it will operate on most PCs with at least eight megabytes of RAM and operating Microsoft Windows 3.1. The IPS uses a simpler and more efficient software design. The times required for the IPS to present information are a small fraction of the times required for the IMIS Demonstration System used in the field test. The IPS is capable of responding to most information requests in less than one second, with no information request requiring more than 15 seconds (to recalculate the set of probable faults).

Rough estimates of the potential benefit of the speed improvements provided by the IPS were developed by recording the times required for "paging through" the problems, requesting information and responding to prompts in the same way that technicians did when actually performing the problems. As soon as the computer presented a screen of information, the experimenter immediately pressed next or other appropriate response so that almost all time recorded was due to computer processing time. It was assumed that experimenter response times would be the same for both computer systems. Times were recorded for eight problems using the IMIS Demonstration System and six problems using IPS. It was not possible to directly estimate IPS times for the INS problems because the IPS memory inspect capability was not available. The mean times for the FCR and HUD problems were used to estimate the times for those subsystems, respectively. The mean times for the FCR and HUD problems combined were use to estimate the INS problem times. A conservative adjustment time was then estimated and used to adjust the data collected in the test for the total problem time. The time estimates developed are presented in Table 30.

Table 30. Comparative Speeds of IMIS Demonstration System (IMIS DS) and IPS

Test-Bed Subsystem	IMIS DS	IPS	Percent Improvement
Fire Control Radar	13:26	1:39	88
Heads-Up Display	10:21	1:39	84
Inertial Navigation Sys.	16.34	2.29	85

The estimates developed suggest that, if IPS had been used for the test, performance times would have been reduced by from eight to 14 minutes. The IPS processing speeds are believed to be representative of the speed of a system fielded for operational use.[15]

NASA TLX Workload Ratings

The NASA TLX ratings are presented in Table 31. The workload ratings made by the technicians after each problem were significantly higher following performance of a task with the TO than ratings given following performance of a task with the IMIS ($p < .001$). APG technicians rated workload higher than specialists ($p < .001$). This finding is consistent with expectations because the tasks were new to the APG technicians and represented more of a challenge to them than to the specialists. APG technicians tended to rate the paper TO-based tasks much higher than did the specialists, while there was only a small difference in the ratings

[15] The IPS is not a fully developed system. Work on the system was halted when it was determined that the IMIS Demonstration System would be used for the field test. However, for the IPS, most of the capabilities required to support the field test are operational and suitable for use as a comparison system. The only capabilities required for the field test that are not complete are the 1553 interface and the RF Link.

Table 31. Mean NTLX Ratings

	TO	IMIS
Avionics Specialists	35.36	23.56
APG Technician	48.90	28.41
Total	42.13	25.98

by the specialists and APG technicians following tasks using the IMIS. In addition, there was an interaction of media and specialty ($p < .015$). For paper tasks, the APG technicians rated workload significantly higher than the specialists ($p < .001$). For IMIS tasks, there was no significant difference in workload ratings by specialists and APG technicians. Thus, the IMIS had a greater impact on the workload of the APG technician, as reflected in a significant interaction ($p < .001$) between media and specialty.

IMIS Characteristics Questionnaire

After completing all assigned tasks with the IMIS, the technicians completed a 69-item questionnaire. The questionnaire was designed to measure technician reactions to various characteristics of the IMIS Demonstration System. Technicians responded on a seven-point scale to questions about the IMIS. The questions, the descriptors which the technicians based their answers upon, and the mean ratings given each question are presented in Table 32. The ratings were evaluated on a seven-point scale: a rating of one generally indicated a response very favorable to IMIS, a rating of seven generally indicated a response very unfavorable to IMIS. The questions are presented in rank order, with the most positively rated questions listed first. In interpreting the results, note that the technicians were responding with the IMIS Demonstration System as the point of reference, not the IMIS concept itself.

The technicians gave an average rating of 2.78 on the 69 questions. The ratings ranged from 1.39 (indicating part ordering is easy with IMIS) to 5.48 (indicating that the response time after a key press was too slow). The most positively rated features of IMIS were its automated parts ordering, work order close-out, and ability to use the IMIS and the 1553 interface to operate the aircraft BITs. The most negatively related items appear to be related to the slow speed of the IMIS Demonstration System and a perceived need for a full keyboard. The system's slow response time was the most frequent complaint cited on the exit questionnaire; this complaint was also mentioned during informal discussions with the technicians during and after their participation in the test.

Exit Questionnaire

Review of the written comments provided by the technicians at the end of the test revealed that the technicians had a very positive attitude toward the IMIS. The exit questionnaire statements clearly indicate that the technicians like the concept of the IMIS and believe it has great potential. This observation is based upon statements such as:

Table 32. IMIS Characteristics Questionnaire Items with Mean Ratings for Each Item

Question	Descriptors		Mean Rating
The process of ordering a part from the IMIS system was?	Clear	Unclear	1.39
Attaching cables to the PMA was?	Easy	Difficult	1.50
Ordering parts through IMIS is a?	Good idea	Bad idea	1.64
Closing a Work Order on the PMA was?	Easy	Difficult	1.70
Time permitted to become familiar with the PMA and its functions was?	Adequate	Inadequate	1.77
The BIT process and procedure was?	Effective	Ineffective	1.88
Self-tests on the PMA were?	Effective	Ineffective	1.89
The size of the PMA screen for displaying text was?	Adequate	Not adequate	1.92
Use of MFLs in the Fault Isolation process was?	Helpful	Not helpful	1.96
The training you received was?	Thorough	Not thorough	2.00
The back light was?	Helpful	Not helpful	2.00
Function keys (F1 through F8) were?	Useful	Not useful	2.04
Filling out forms while using IMIS was?	Easy	Difficult	2.09
Connection and disconnection to the 1553 bus was?	Easy	Difficult	2.16
Mapping the MFLs to the fault codes was?	Easy	Difficult	2.22
The ruggedness of the keys on the keypad appeared to be?	Acceptable	Not acceptable	2.23
Highlighting information on the screen made tasks?	Easier	Harder	2.25

Table 32. (Continued)

Question	Descriptors		Mean Rating
In comparison with paper Tech Orders, the IMIS fault isolation process seemed?	Better	Worse	2.25
The size of the PMA screen for displaying graphical information was?	Adequate	Not adequate	2.26
Spacing between keys on the keypad was?	Acceptable	Unacceptable	2.30
In troubleshooting, the diagnostic aid was?	Helpful	Not helpful	2.33
Ability to override the IMIS-DM recommended action was?	Easy	Difficult	2.38
Failure probabilities associated with recommended actions were?	Helpful	Not helpful	2.38
Handling of CND's on the PMA was?	Satisfactory	Unsatisfactory	2.43
The weight of the PMA was?	Light	Heavy	2.43
Instructions, procedures, and guidance about 1553 connections were?	Effective	Ineffective	2.44
In troubleshooting, the diagnostic block diagrams were?	Helpful	Not helpful	2.45
The prop or handle was?	Effective	Not effective	2.45
Determining how to proceed through the PMA screens in order to support your task was?	Difficult	Easy	2.48
The width and length (the general shape) of the PMA was?	Acceptable	Not acceptable	2.52
The weight of the PMA was?	Heavy	Light	5.57
Message lines (informing you how to proceed on to the next piece of information) were?	Effective	Ineffective	2.59

Table 32. (Continued)

Question	Descriptors		Mean Rating
The PMA screen made information?	Easy to see	Hard to see	2.59
Use of icons was?	Easy	Hard	2.60
The brightness of the back light was?	Good	Bad	2.61
When performing maintenance, the size of the text was?	Easy to read	Hard to read	2.63
On-line help on the PMA would be?	Useful	Not useful	2.65
Scrolling in order to see additional procedural information was?	Good	Bad	2.68
The cursor moved where you thought it should?	Always	Never	2.70
Using the PMA while cables were attached, affected PMA use?	Not at all	Very negatively	2.71
The IMIS automatic status updating would reduce the chatter on "bricks?"	A great deal	Not at all	2.72
Keeping track of where you were in the procedure was?	Easy	Difficult	2.75
When viewing Tech Order data, location and labels on function keys were?	Appropriate	Not appropriate	2.77
In comparison with paper Tech Orders, the IMIS failure data seemed?	More accurate	Less accurate	2.83
Accessing screens required to perform the task was?	Easy	Difficult	2.83
Zoom capability on graphics would have been?	Helpful	Not helpful	2.86
Moving the cursor around the screen using the PMA arrow keys was?	Easy	Hard	2.91
Use of fault codes in the Fault Isolation process was?	Helpful	Not helpful	2.96

Table 32. (Continued)

Question	Descriptors		Mean Rating
Symbols chosen for icon pictures were?	Effective	Not Effective	3.00
Moving the pointer around the screen using the PMA thumb knob was?	Easy	Hard	3.04
The recommended "best action" seemed to be an effective choice for the troubleshooting task?	Always	Sometimes	3.09
The keyboard arrangement used on the PMA screen was?	Easy to use	Hard to use	3.17
Reliability of the IMIS machine that you worked with was?	Very reliable	Unreliable	3.30
Limited descriptions in the Discrepancy field of the work order form had?	No impact	Limited impact	3.39
Limited descriptions in the Discrepancy field of the Work Order form had?	No impact	Negative impact	3.39
The size of keys on the keypad were?	Too big	Too small	3.55
Handling of RTOK's on the PMA was?	Satisfactory	Unsatisfactory	3.71
Glare on the screen affected performance on the task?	Not at all	A great deal	3.79
Limiting the presentation of steps to one step per screen was?	Necessary	Not necessary	3.88
The limited ability to describe a discrepancy impacted the FI process?	Not at all	Negatively	3.90
Ability to see and read the screen contents from various angles was?	Easy	Hard	3.96
Pressing and activating keys on the keypad was?	Easy	Hard	4.00
The screen was readable at?	Many angles	Limited angles	4.23

Table 32. (Concluded)

Question	Descriptors		Mean Rating
If you used the thumb knob and the arrow keys, which device did you prefer?	Arrow keys	Thumb knob	4.35
A full keyboard (allowing use of all alphabetical keys) would have made the PMA use?	More difficult	Easier	4.91
Response time after pressing keys was?	Fast enough	Too slow	5.48

> Great project — quite a bit better than having to use TOs. I hope I see it in use somewhere, sometime before I get out of the service or even in the civilian world.

> IMIS definitely needs to be an integral part of the AF [Air Force]. The AF will benefit greatly from the implementation of IMIS.

> Very good unit. If it were not for the waiting on the computer, it would be great.

There are several features of the IMIS that the technicians especially like. The most frequently mentioned features are the automated parts ordering, integration of technical data (no need to carry an armload of TOs), 1553 interface, simplification of the troubleshooting process, and automated work order close-out procedure. However, there are also several features of the IMIS Demonstration System they did not like. The most frequently mentioned problem with the IMIS demonstration speed was response time. The majority of the technicians commented about the slow system response, either as a system deficiency or a needed refinement. The IMIS Demonstration System user interface was the subject of several comments. The primary irritant from the user interface is the inconsistent use of the function keys and select keys (e.g., "F1 OK" to continue versus "F8 NEXT" to continue). In addition, a number of technicians remarked about the Demonstration System's tendency to freeze up, indicating that system reliability must be improved.

The technicians provided several suggestions to improve the system. These included changes such as providing a browsing capability, presenting more than one step at a time, and better integration of the diagnostic/rectification processes and the work order close-out process so that most of the information required for completing the close-out documentation is automatically generated.

A complete listing of comments made on the exit questionnaire is provided in Appendix D.

DISCUSSION

The IMIS field test was designed to evaluate the capability of the IMIS to support the maintenance diagnostic and repair processes. Earlier studies and analyses have indicated that the IMIS will reduce the time required to diagnose and repair a fault in an aircraft subsystem, reduce the consumption of spare parts, and improve the accuracy of maintenance data reporting. In addition, the studies have suggested that the use of an IMIS will make it possible for personnel with less extensive training on a subsystem to effectively troubleshoot and repair it. This field test was designed to examine the extent to which the IMIS Demonstration System is able to achieve these expectations and the desirability of implementing an IMIS for operational use.Impact of IMIS on Technician Performance

Impact of IMIS on Technician Performance

The study focused upon the ability of the IMIS to support two types of maintenance technicians: avionics specialists and non-avionics specialists (APG technicians).

- Avionics specialists — trained in the general principles of avionics maintenance; possess specific training and experience in maintaining the F-16 avionics subsystems used as test-beds for the study.
- Non-avionics specialists (APG technicians) — possess training and experience in general F-16 maintenance procedures but have no specific training on, or experience with, the F-16 avionics subsystems used as test-beds for the study.

The two types of technicians represented both ends of the spectrum of skills required to maintain the test-bed subsystems: the well-trained avionics specialist with experience in maintaining the subsystems and the APG technician with general maintenance skills but no specific training or experience on the test-bed subsystems. This section of the report examines the test results with regard to the ability of the IMIS to support each type of technician.

IMIS Support for the Specialist

The avionics specialist technicians were expected to successfully complete a high percentage of the fault isolation problems, using either the TO or the IMIS. Their performance met this expectation. The specialists were able to successfully isolate all the faults using either the TO or IMIS. In addition, they were able to successfully complete[16] all problems using the IMIS. However, they were able to successfully complete only 87 percent of the problems when using the TO. The failures were all due to not completing all checks and tests required to establish system health. This problem appears to be caused by the way system health requirements are presented in the TO, which makes it easy to overlook key requirements. With the IMIS, it is not possible to overlook required procedures. They are automatically presented at

[16] Successful completion of a problem was defined as completing all required subtasks, including fault verification, fault isolation, rectification, system health, and documentation.

the appropriate point in the process. The technician must perform the procedure or consciously choose not to perform it. This is an important advantage of the IMIS for both efficiency and safety reasons.

It was anticipated that specialist technicians would be able to perform troubleshooting tasks more rapidly when using the IMIS as their source of technical data than when using paper TOs. IMIS was expected to reduce troubleshooting times by providing more efficient diagnostic routines and by reducing the number of component replacements used in the diagnostic process. In addition, it was anticipated that additional time would be saved by the IMIS automatically inputting the close-out documentation to CAMS.

Time is saved in the fault isolation process by minimizing the number of tests and by reducing component replacements which must be made.[17] Time savings resulting from reducing the number of parts unnecessarily replaced can be significant because each replacement requires ordering the part from supply or removing a good part from a nearby aircraft. Technicians and supervisors estimate it takes the technician at least 15 minutes to order a part.[18] The IMIS automatically provides all the information required to order a part and orders the part via the RF link. Thus, the 15 minutes (or more) required to order a part is saved by IMIS. The technician can use the time saved to remove the part or for other maintenance activities while waiting for the part to be delivered.

The data collected in the field test provides support for the assertion that the IMIS can significantly reduce the time required to diagnose and repair faults in avionics subsystems. The use of the IMIS reduced the mean times to perform the test problems by approximately 27 percent. On average, the technicians required approximately 26 minutes longer to complete the problems using the TO. However, close examination of the data indicates that the primary source of the savings in time to perform the task was due to the use of the IMIS parts ordering and work order close-out capabilities.

The data demonstrates that the IMIS effectively supports avionics specialists performing diagnostic tasks on the test-bed subsystems. In addition, the use of the IMIS can result in significant time savings, reduce errors, and reduce parts consumption.

IMIS Support for the APG Technician

As indicated above, APG technicians were included in the study to test the assertion that, with the use of the IMIS, technicians with limited subsystem knowledge can successfully perform fault isolation tasks on the test-bed subsystems. APG technicians were selected for the non-

[17] The diagnostic procedures provided in the TO frequently require replacement of a component as a check to see if it will fix the problem. As a result, several good components may be replaced before the bad component is found.
[18] At least as much time is required if the component is "borrowed" from a nearby aircraft because the technician must open the appropriate aircraft panel, remove the component, annotate the aircraft forms, replace the part, close the panel(s), and annotate the forms.

specialist role because they receive no specific training on the test-bed subsystems, and no more than familiarization training with avionics subsystems in general. Thus, it was believed that they would represent a good test of the limits of the IMIS for supporting maintenance by personnel with limited training on the test-bed subsystems. In addition, the APG technicians were familiar with the aircraft, comfortable working around it, and cockpit qualified (a requirement to participate in the test).

The field test team had some reservations about including the APG technicians in the study. There was confidence that the technicians would be able to do at least a creditable job on the troubleshooting problems when using the IMIS. However, it was uncertain how they would do using the paper TOs. These concerns were alleviated somewhat during the pretest when an APG technician was able to successfully complete all the required tasks. However, it became clear after the first two test subjects APG technicians completed their problems using the TO that they were up to the challenge. The technicians started their first TO problems with obvious concern, but by the time they completed the first two problems, their anxiety had eased and their confidence began to build, as did their subsystem knowledge.

The APG technicians were able to successfully complete 99 percent of the problems with the IMIS and 69 percent of the problems with the paper TO. Thus, when they used the IMIS, their performance on this measure was essentially the same as the specialists using the IMIS and better than specialists using the paper TO. Also, when using the IMIS, the APG technicians' overall times to complete the problems were only slightly longer than the specialists times using the IMIS and, for most time measures, significantly faster than the times for the specialists when using the paper TO. The relative speed of performance of APG technicians using IMIS versus specialists using the paper TO are illustrated in Figure 6.

The APG technicians required many more "helps" to get through the problems. The avionics technicians received very few helps (the restrictions on providing helps were much more stringent for the avionics technicians). More helps were required for the APG technicians because they were totally unfamiliar with the test-bed subsystems and had had only limited training on the TOs for those subsystems. Helps were primarily for locating subsystem components, locating and interpreting information in the TOs, and using or reading the multimeter. Typically, several helps were required for an APG technician's first two or three problems. Few, if any, helps were required after they had completed the third problem and were familiar with location of the subsystem components. Nevertheless, it is significant that the APG technicians were able to successfully isolate faults in complex avionics subsystems that they had never worked on before. A high degree of success using the IMIS was expected. The level of success with the TO was something of a surprise because there was some concern about whether the APG technicians would be able to solve the problems at all.

One objective of this study was to demonstrate that, using the IMIS, APG technicians could troubleshoot complex systems as effectively as avionics specialists could troubleshoot the problems when using the TO. This objective was exceeded. The APG technicians were significantly more successful in performing the problems with the IMIS than the avionics

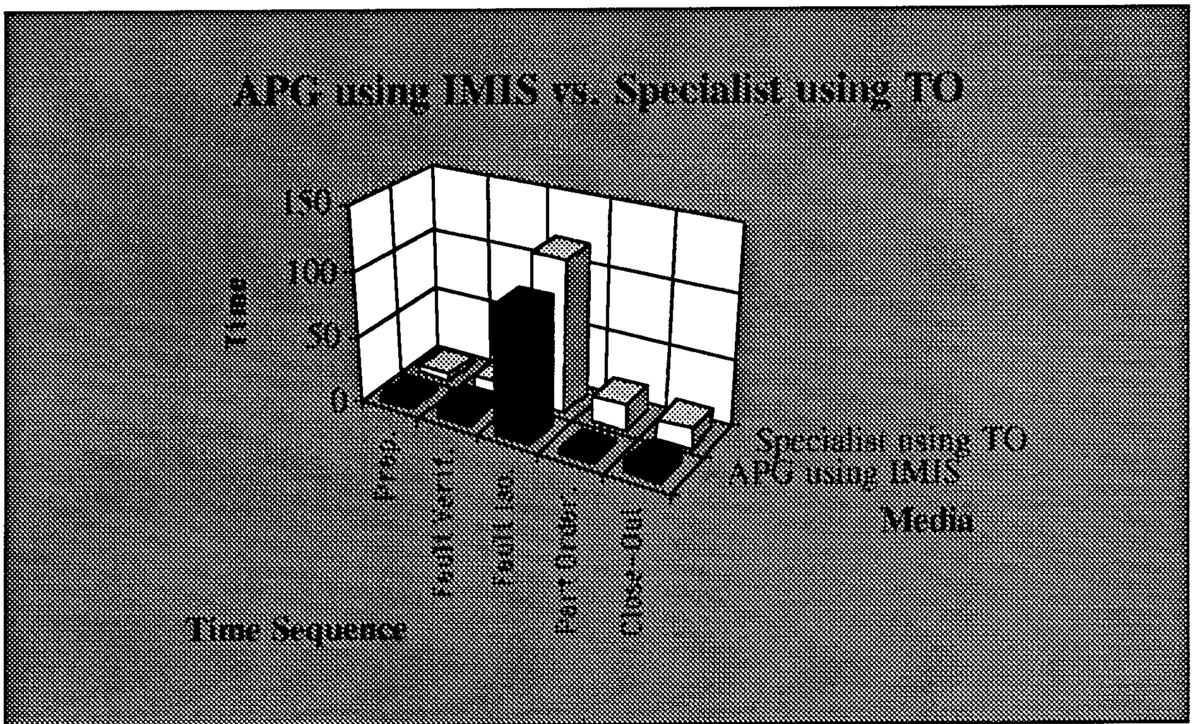


Figure 6. Relative Speed of Performance for Five Time Measures for APG Technicians Using IMIS versus Specialist Technicians Using the Paper TO

specialists were using the TO. More surprisingly, there was no significant difference in the performance of the APG and avionics technicians when both used the IMIS. When using the IMIS, the APG technicians are as capable as the avionics specialists in performing fault isolation tasks on the test-bed subsystems. However, this equality applies only when the IMIS provides adequate fault isolation procedures. It is unlikely that the APG technician will be able to handle those occasional problems that are not resolved using the diagnostic procedures provided in the technical data. The special training and experience of the specialist will be required to resolve these problems.

The achievements of the APG technicians when using the IMIS are especially noteworthy when their relative inexperience is considered. Most of the APG technicians who participated in the study were relatively inexperienced. Ten of the APG technicians were Skill Level 3 with less than one year of experience. By comparison, the specialists were relatively experienced. Eight were Skill Level 5 with between four and ten years of experience, and four were Skill Level 3 with between 12 and 18 months of experience. Thus, as a group, the APG technicians were relatively inexperienced, while the specialists as a group were relatively experienced. Nevertheless, the use of the IMIS made it possible for the APG technicians to perform the troubleshooting tasks as effectively as the specialists.

Parts Savings from IMIS

One major benefit anticipated from the IMIS is a reduction in the number of spare parts used. This reduction would result from technicians unnecessarily replacing fewer "good" parts (due to either the diagnostic strategy used or technician error). Both the field test data and the fault tree analysis provide evidence to support this assertion. The mean number of good parts replaced by technicians using the IMIS was significantly less than the mean number of parts used with the TO, and the fault tree analysis provided clear evidence that, for at least two of the test-bed subsystems, major reductions in unnecessary part replacements would result from implementation of the IMIS. The data also reveal some of the limitations of the IMIS diagnostics.

The data clearly illustrates the primary limitations of the IMIS diagnostics — the limitations imposed by the technical data input to the IMIS and the design of the subsystems under test. The data show that even though the IMIS diagnostic algorithm provides the most effective sequencing of tests to isolate a given fault, unnecessary component replacements will still be encountered unless the subsystem under test has adequate test points to permit isolating each component and the test points are accurately presented in the technical data. The F-16 FCR, HUD, INS, and associated fault isolation manuals provide good examples of this problem. Furthermore, because the data used for the IMIS diagnostics was based on the fault isolation manuals, the study provides a good example of how IMIS handles the problem, given the limitations imposed by the test-bed subsystem designs and the test procedures provided in the paper fault isolation manuals.

The diagnostic strategy used in F-16 fault isolation manuals tends to replace the component(s), most likely to cause the observed symptom first with little attempt to verify it is bad before removing it. Then, when that does not solve the problem, the technician is advised to either replace more components or conduct tests to narrow the problem. The IMIS takes a more systematic approach and evaluates the alternatives and associated costs against the information received from each action. As a result, if there is an inexpensive test that could eliminate a component from consideration, the test will be performed first. Problems 9 and 10 represent good examples of the two approaches. Both replaced the most probable component first because there was no way to eliminate it from consideration. When this did not fix the problem, the TO continued replacing components. However, the IMIS algorithm recognized an inexpensive test which could eliminate the two remaining suspect components from consideration. IMIS recommended that test be made first. The test led to the cause of the fault (wiring). The TO recommended replacing three good components before recommending the test that identified the problem. The result was three good parts used with TOs and none with the IMIS.

Most good parts replaced were replaced as part of the diagnostic strategy; the remainder were due to technician error. The technical-data-directed replacement of good parts appears to be the result of two factors: (1) the diagnostic philosophy of the technical data developers and (2) the design of the avionics subsystems themselves. The aircraft design limits the development of sound diagnostic procedures to some extent. If the design does not provide adequate BITs and test points, the developer of the fault isolation manual may not be able to provide adequate diagnostic procedures. However, the technical data writer must take full advantage of the available (or possible) test points to reduce the number of ambiguity groups. The F-16 is known for having many ambiguity groups. When ambiguity groups are present, the fault isolation manual provides no way to identify the faulty component, except to systematically replace the components in the group until the problem is fixed. When this happens, good parts are replaced unnecessarily. This appears to be the primary cause of the unnecessary use of good parts in this study. Unfortunately, since the IMIS technical data was developed from the fault isolation manuals, the ambiguity groups existing in the fault isolation manuals were also reflected in the IMIS data. In addition, the IMIS developers were limited to the tests and procedures provided in the TOs.[19] As a result, some of the inadequacies of the paper fault isolation manuals were carried over into the IMIS data base, preventing full realization of the benefits of the IMIS diagnostics.

It is unfortunate that program constraints prohibited refinement and extension of the IMIS technical data to take full advantage of the IMIS diagnostics. With a little ingenuity and effort, a good technical writer/analyst often can identify additional tests and ways of breaking up ambiguity groups. If the IMIS analysts had been permitted to break up the ambiguity groups and modify the IMIS technical data to better match the requirements of the IMIS diagnostic module, it is likely that additional savings in parts would have been achieved.

The fault tree analysis revealed another important observation — the potential of the IMIS diagnostics for reducing unnecessary part replacements is dependent upon the subsystem supported. The analysis demonstrated a very large difference in the ability of the IMIS to reduce parts consumption for the INS and for the FCR. The analysis indicated a potential reduction in the unnecessary replacement of good LRUs of approximately 74 percent for the INS and 38 percent for the FCR. However, the estimated savings for the HUD was only for a three percent reduction. The reason for this difference could not be determined from the available information. There are several interrelated factors which appear to contribute to the difference in impact. These include the complexity of the subsystem, the number of LRUs and rectifications per subsystem, the length of the fault trees, and the characteristics of the functions performed by the subsystem (e.g., information exchange versus computation intensive functions). Further study is needed to better understand this issue.

Support for Work Order Close-Out

The field test provided limited data to support the assertion that the IMIS will reduce the time to close-out a work order and enter the data into the CAMS. An adequate comparison of the IMIS and the current procedures for work order close-out and data input was not possible due to two problems:

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[19] The IMIS technical data was translated directly from the digital version of the fault isolation manuals to the format required by the IMIS. Technical content was not changed. Changes in technical content were not permitted because the intent was to use the data for operational maintenance activities during an unconstrained test, originally scheduled to follow the IMIS field test. Changes in the technical data would have required that the data be reverified.

a. It was not possible to develop a good measure of the time required to close-out the work order and input the information to CAMS, since the live CAMS data base could not be used, and there were no CAMS terminals available with access to the CAMS training data base. As a substitute, the technicians recorded the necessary information on paper. Time to record the information was recorded and combined with an estimate of the time required to gain access to a CAMS terminal and input the data.

b. The IMIS Demonstration System fully implemented the IMIS concept for the work order close-out and CAMS input processes. The IMIS concept (for an operational system) provides for the IMIS to automatically record most information required to close-out a work order. All the technician needs to do is verify that the information on the close-out form is correct and press transmit. The Demonstration System implementation did not automatically record this information. Thus, the technician was required to input the data either using the keyboard or by selecting from lists of alternatives.

The field test provided some limited data on the benefits of the IMIS for supporting the close-out process. The data indicates that, with the current IMIS Demonstration System, the time to close a work order and input the data to CAMS can be cut in half. When the close-out procedure is fully automated in IMIS, the time required for close out will be reduced to near zero, a savings of between 15 and 20 minutes.

IMIS Design Considerations

Although the IMIS Demonstration System effectively demonstrated the overall IMIS concept, there are several deficiencies in the system which must be avoided in any system developed for operational use. These deficiencies are discussed briefly below.

Speed

The most serious deficiency of the IMIS Demonstration System is the slow speed with which it retrieves and presents technical and management information. The system requires from one or two seconds to as long as two minutes to respond to an information request. The only process which is reasonably fast is moving from frame to frame within a procedure, where all the system has to do is present the next step (without graphics). A somewhat more complex action, such as responding to an input from a branching question, requires several seconds, typically three to eight. Very complex actions, such as updating diagnostics or retrieving data from a different part of the data base, may take one minute or more.

Although these times do not seem excessive to the casual observer, they do become burdensome as one gains experience in using the system, especially when working under time constraints. The technicians who participated in the field test were much less tolerant of the system's slow speed than were the managers participating in the End-to-End Demonstration (EED). The technicians in the field test used the system for several hours, under time pressure.

The EED participants used it for only two or three hours and not under pressure. Improving the speed of the system was the most frequent recommendation made by the field test participants for improving the system. An IMIS developed for operational use should present requested information within two seconds for at least 90 percent of the requests. No request should require more than 30 seconds to fill, and such instances should be rare.

Human Factors

The IMIS Demonstration System user interface is generally well done and provides a good starting point for development of an operational system. However, there is considerable room for improvement. The field test has highlighted several problem areas and produced some suggestions from the technicians for improving the interface.

One major problem with the interface is its lack of consistency in the Demonstration System's user interface. Next to system speed, the most frequent complaint from the technicians was the inconsistent use of "F1," "F8," and "Select" to make a selection. In some places, F1 is used to go to the next frame, in other places, F8 is used to go to the next frame. In some places F1 is used to choose from a menu, in other places SELECT is used to choose from a menu. Other inconsistencies are found in features such as the use of the hour glass when the computer is processing and the use of prompts.

The technicians recommended improvements such as presenting more than one step at a time so they can look ahead and see the next step, providing a browsing capability, and providing better locator information.

The IMIS Demonstration System provides a good starting point for the design of an IMIS interface. With the addition of a few additional features, correction of its weak points, and refinement of its rough spots, it could provide an effective user interface — assuming, of course, that the system's slow response time is corrected.

Designers of an IMIS for operational implementation would be wise to carefully study the IMIS Demonstration System user interface. It provides many examples of good practices but also offers some examples of awkward and ineffective practices. The human factors engineers will learn a lot and avoid costly errors in their own designs by spending several days using the system to perform tasks, by observing technicians and managers using the system for various tasks, and by talking extensively with technicians and managers who have used the system. Similar studies should be made of other IMIS like systems under development. See Quill, Kander, Wampler, and Wynkoop (1995) for a detailed discussion of IMIS human factors lessons learned.

Other Considerations

Technical Data

Proponents of the IMIS have emphasized its capability to reduce parts consumption and retest OK rates. The field test provided support for this benefit; however, the benefits were not as dramatic as expected. There is reason to believe that the inability of the IMIS to more dramatically demonstrate this benefit is, at least in part, due to limitations of the technical data used. If the IMIS analysts had had the freedom to develop new test points, which the IMIS algorithm could have, in turn, taken advantage of, it is likely that the number of good parts replaced when using the IMIS would have been reduced, perhaps dramatically. If additional test points are not possible, there is no better way than to replace parts until the problem is solved. In that case, no diagnostic-aiding system will achieve a dramatic reduction in the use of parts.

A related issue is the quality of the data in general. If the data input to IMIS is of poor quality, the benefits expected from the IMIS will not be realized. In other words, "garbage in, garbage out." There seems to be a commonly held misconception that all that is needed to gain the benefits of the IMIS is to convert the current technical data into the IMIS format and present it on the IMIS. The problem is not that simple. Much of the technical data in use today does not have the quality diagnostic information required to take full benefit of the IMIS diagnostic capability. Additional information, and a lot of "tweaking," is necessary to produce a quality IMIS data base. A small effort to enhance the technical data during the conversion process can pay large dividends.

IMIS and Maintenance Force Structure

One major finding of this study is the demonstration that APG technicians can effectively perform many of the tasks now limited to specialists, especially if they are using an IMIS. In the demonstration, a relatively inexperienced group of APG technicians (most at Skill Level 3) using the IMIS performed the troubleshooting problems faster and used fewer spare parts than a relatively experienced group of avionics specialists (most at Skill Level 5) using the paper TO. It is true that the APG technicians required some help to perform the tasks. However, these helps were primarily basic system knowledge (e.g., component location) given to compensate for the fact that they had had no training on the test-bed subsystem. These helps were given primarily for the first few problems. Very few helps were given on their last few problems. The types of information could easily be provided by adding an orientation to the avionics systems to the APG technical school. With the IMIS and the addition of a few days to the APG technicians technical school, APG technicians could perform many of the routine troubleshooting tasks on avionics systems, freeing the avionics specialists to deal with the most difficult problems. This approach would make a reduction in the number of specialists possible and would result in major savings in training specialists.

The demonstrated ability of the APG technicians to perform complex troubleshooting tasks on avionics systems when using the IMIS provides strong support for the Air Force initiatives to reduce the number of specialties required to maintain a weapon system. The idea is to reduce specialties by broadening the areas of responsibility of the technicians to include more aircraft subsystems. The findings from this study suggest that an even greater reduction of specialties than planned may be possible for IMIS-supported weapon systems. The demonstrated advantage of the IMIS for supporting the generalist technician makes the implementation of an operational IMIS even more essential.

CONCLUSIONS

The findings of this study support the following conclusions for F-16 avionics subsystems.

1. Fewer good parts are replaced when technicians use IMIS to perform fault isolation problems than when they use the TO.

2. Technicians require less time to complete fault isolation problems when they use the IMIS than when they use the paper TO.

3. Technicians require less time to complete work order close-out and documentation tasks when they use the IMIS than when they use the current procedures.

4. Technicians make fewer serious errors when using the IMIS than when using the paper TO.

5. APG technicians using the IMIS are able to perform fault isolation problems as effectively as specialists using the IMIS and more effectively than specialists using the TO.

6. The effectiveness of the IMIS for reducing part consumption varies from subsystem to subsystem. Use of the IMIS will result in large savings in parts (and dollars) for some subsystems but not for others. Additional research is needed to develop rules to determine which subsystems are likely to benefit most from the IMIS or to enhance the IMIS diagnostic module or technical data to achieve the same benefits for all subsystems.

The IMIS field test and demonstration mark the end of the very successful IMIS demonstration program. The program developed and demonstrated technology advances which promise to revolutionize Air Force maintenance operations. The concept and technology are initially being applied in the Joint Surveillance Targeting Attack Radar (JSTARS) and F-22 and will be incorporated in the Integrated Maintenance Data System (IMDS), currently under development for Air Force-wide implementation.

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ACRONYMS AND ABBREVIATIONS

ADI	Attitude Director Indicator
AFTO	Air Force Technical Order
AIP	Aircraft Interface Panel
APG	Airplane General
BIT	Built-in-Test
CAMS	Core Automated Maintenance System
CEMS	Centralized Engine Maintenance System
COSO	Combat Oriented Support Organization
CND	Cannot Duplicate
DB	Database
DMT	Dual Mode Transmitter
EED	End-to-end Demonstration
EU	Electronic Unit
FI	Fault Isolation
FS	Fighter Squadron
FCR	Fire Control Radar
FOD	Foreign Object Damage
GAC	General Aircraft Computer
GDES	GDE Systems
HUD	Heads-up Display
ICAM	Integrated Computer-Aided Manufacturing
IDEF	ICAM Definition
IETM	Interactive Electronic Technical Manual
IMIS	Integrated Maintenance Information System
IMIS DM	IMIS Diagnostic Module
IMIS DS	IMIS Demonstration system
IMDS	Integrated Maintenance Data System
INS	Inertial Navigation System
INU	Inertial Navigation Unit
IPB	Illustrated Parts Breakdown
IPS	IETM Presentation System
JCALS	Joint Continuous Acquisition Lifecycle Support
JSTARS	Joint Strategic Targeting Attack Radar System
LAN	Local Area Network
MANOVA	Multiple Analysis of Variance
MFL	Maintenance Fault List
MIW	Maintenance Information Workstation
MTTR	Mean Time to Repair
MLPRF	Modular Low Power Radio Frequency
MUX	Multiplex
NASA TLX	National Aeronautics and Space Agency Task Load Index
PC	Personal computer operating Microsoft Disk Operating System (MS DOS)
PDU	Pilots Display Unit

PMA	Portable Maintenance Aid
PSP	Programmable Signal Processor
RDR	Radar
RF	Radio Frequency
RTOK	Retest OK
SBSS	Standard Base Supply System
SSS	System Segment Specification
TO	Technical Order
WD	Wiring Diagram

APPENDIX A

ORDER OF PRESENTATION OF TEST PROBLEMS

Table A1 presents the test administration schedule used for data collection. The schedule illustrates the counterbalancing of treatments (IMIS vs. paper TO) and the randomization of problem order used to counterbalance the order of presentation effects.

Table A1. Test Administration Schedule with Order of Presentation of Problem by Media Used

Subject / Media/ Problems	**Subject / Media/** Problems	**Subject / Media/** Problems	**Subject / Media/** Problems	**Subject / Media/** Problems	**Subject/ Media/** Problems
Week 1- Day Shift		**Week 2 - Day Shift**		**Week 3 Day Shift**	
S1	**S13**	**S3**	**S15**	**S5**	**S17**
IMIS	**Paper**	**IMIS**	**Paper TO**	**Paper TO**	**IMIS**
I9	I9	H7	H7	F1	F1
F1	F1	F3	F3	H5	H5
H5	H5	I11	1II	I9	I9
F3	F3	H6	H6	I11	I11
I11	I11	I10	I10	H7	H7
H7	H7	F2	F2	F3	F3
Paper TO	**IMIS**	**Paper TO**	**IMIS**	**IMIS**	**Paper TO**
H6	H6	F1	F1	I10	I10
F2	F2	H5	H5	F4	F4
I1O	I1O	I9	I9	H6	H6
H8	H8	I12	I12	F2	F2
I12	I12	H8	H8	I12	I12
F4	F4	F4	H4	H8	H8
Week 1 - Night Shift		**Week 2 - Night Shift**		**Week 3 - Night Shift**	
S2	**S14**	**S4**	**S16**	**S6**	**S18**
Paper TO	**IMIS**	**Paper TO**	**IMIS**	**IMIS**	**Paper TO**
F2	F2	H8	H8	I10	I10
I10	I10	I12	I12	H6	H6
H6	H6	F4	F4	F2	F2
H7	H7	F1	F1	I11	I11
F3	F3	H5	H5	F3	F3
I11	I11	I9	I9	H7	H7
IMIS	**Paper TO**	**IMIS**	**Paper TO**	**Paper TO**	**IMIS**
H8	H8	I11	I11	F4	F4
I12	I12	H6	H6	I12	I12
F4	F4	F2	F2	H8	H8
F1	F1	I10	I10	H5	H5
H5	H5	F3	F3	F1	F1
I9	I9	H7	H7	I9	I9

Table A1. (Continued)

Subject / Media/ Problems	**Subject / Media/** Problems	**Subject / Media/** Problems	**Subject / Media/** Problems	**Subject / Media/** Problems	**Subject/ Media/** Problems
Week 4- Day Shift		**Week 5 - Day Shift**		**Week 6 Day Shift**	
S7	**S19**	**S9**	**S21**	**S11**	**S23**
Paper TO	IMIS	Paper TO	IMIS	Paper TO	IMIS
H7	H7	F1	F1	I11	I11
I11	I11	H5	H5	H7	H7
F3	F3	I9	I9	F3	F3
H6	H6	F3	F3	I10	I10
F2	F2	I12	I12	F2	F2
I10	I10	H7	H7	H6	H6
IMIS	**Paper TO**	**IMIS**	**Paper TO**	**IMIS**	**Paper TO**
F1	F1	I10	F1	H5	H5
H5	H5	H6	H5	I9	I9
I9	I9	F2	I9	F1	F1
F4	F4	I11	I12	H8	H8
I12	I12	F4	H8	F4	F4
H8	H8	H8	H4	I12	I12
Week 4 - Night Shift		**Week 5 - Night Shift**		**Week 6 - Night Shift**	
S8	**S20**	**S10**	**S22**	**S12**	**S24**
IMIS	Paper TO	IMIS	Paper TO	IMIS	Paper TO
H8	H8	F2	F2	I12	I12
F4	F4	I10	I10	F4	F4
I12	I12	H6	H6	H8	H8
F1	F1	I11	I11	H5	H5
H5	H5	H7	H7	I9	I9
I9	I9	F3	F3	F1	F1
IMIS	**IMIS**	**Paper TO**	**IMIS**	**Paper TO**	**IMIS**
F2	F2	I12	I12	H6	H6
I11	I11	F4	F4	F2	F2
H6	H6	H8	H8	I11	I11
I10	I10	H5	H5	F3	F3
H7	H7	I9	I9	H7	H7
F3	F3	F1	F1	I10	I10

APPENDIX B

SAMPLE DATA COLLECTION FORMS

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
HUD AE (MFL 002) / ELECTRONIC

PROBLEM# H6-E SUBJECT#.............. DATE:.................. D/C:.................. T/O: JJ / BH

LOG IN USING EMP# 01201 (DAVIS)

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

EVENT		TIME	COMMENTS	ADJ
Task Assignment				
Arrive at A/C				
Questions to "Pilot"?		Y / N		
Fault Verification	start		PIN OUT	
BIT (AUTO)	start			
Access: Connect 1553?		Y / N		
(Outcome: MFL HUD002)				
	finish			
	finish			
Test	start		PIN IN	
MUX ckt = 2.0 ohms				
(Outcome: OK)				
	finish			
Rect (HUD EU)	start			
Order part	start			
Pro-Super Co-ord				
	finish			
Remove	start			
	finish			
Install	start			
	finish			
	finish			
System Health	start		PIN IN	
HUD BIT (AUTO)	start			
SIMULATED	finish			
HUD OPS Ck	start			
SIMULATED	finish			
	finish			

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
HUD AE (MFL 002) / ELECTRONIC

PROBLEM# H6-E SUBJECT#.............. DATE:.................. D/C:.................... T/O: JJ / BH

LOG IN USING EMP# 01201 (DAVIS)

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

Job Closeout (Follow-ons not req'd)	start finish			
Task Complete Closeout MSG Rec'd?	Y / N			

CLOSEOUT MASTER INFO:

TM: B
WUC: 74BU0
AT: R
HOW MAL: 644, 290, 242, 255, or others applicable in -06 manual

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
HUD AE (MFL 002) / PAPER

PROBLEM# H6-P SUBJECT#.............. DATE:............... D/C:..................... T/O: JJ / BH

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

EVENT		TIME	COMMENTS	ADJ
Task Assignment				
Check out TOs				
Arrive at A/C				
Questions to "Pilot"?		Y / N		
Fault Verification	start		PIN OUT	
HUD OPS Ck	start			
(JG94-72-01)				
Access: Power On?		Y / N		
WPN Sys Initialization?		Y / N		
WPN Sys Fault Detection?		Y / N		
INS Alignment?		Y / N		
(Outcome: MFL HUD002)				
	finish			
	finish		Add'l TO research req'd? N / Y; time..................	
Test 1 (FI94-72 / T-1)	start		PIN OUT	
Assoc MUX faults?				
(Outcome: NO)				
	finish		Add'l TO research req'd? N / Y; time..................	
Test 2 (FI94-72 / T-2)	start		PIN IN	
MUX ckt = 2.0 ohms				
(Outcome: OK)				
	finish		Add'l TO research req'd? N / Y; time..................	
Rect (HUD EU)	start			
(JG94-72-06)				
Order part	start			
(9472A1)	finish			
Remove	start			
	finish			
Install	start			
	finish			
	finish		Add'l TO research req'd? N / Y; time..................	

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
HUD AE (MFL 002) / PAPER

PROBLEM# H6-P SUBJECT#.............. DATE:.................. D/C:.................. T/O: JJ / BH

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

System Health	start		PIN IN	
HUD BIT (JG94-72-01) *SIMULATED*	start			
	finish			
HUD OPS ck (JG94-72-01) *SIMULATED*	start			
	finish			
	finish		Add'l TO research req'd? N / Y; time.................	
Job Closeout	start			
	finish			
Task Complete				

CLOSEOUT MASTER INFO:

TM: B
WUC: 74BU0
AT: R
HOW MAL: 644, 290, 242, 255, or others applicable in -06 manual

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
INS AG: 145/100 (MFL 011) / ELECTRONIC

PROBLEM# I11-E SUBJECT#............. DATE:................. D/C:.................. T/O: JJ / BH

LOG IN USING EMP# 00998 (GREATHOUSE)

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

EVENT		TIME	COMMENTS	ADJ
Task Assignment				
Arrive at A/C				
Questions to "Pilot"?		Y / N		
Fault Verification	start		SHORT IN	
BIT (AUTO)	start			
Access: Connect 1553?		Y / N		
(Outcome: MFL INS011)				
	finish			
	finish			
Test 1	start		SHORT IN	
INSM 144/145 (AUTO)				
(Outcome: 145/100)				
	finish			
Rect 1 (INU)	start			
Order part	start			
Pro-Super Co-ord				
	finish			
Remove	start			
	finish			
Install	start			
	finish			
	finish			
System Health	start		SHORT IN	
INS Alignment	start			
Access: Power On?		Y / N		
WPN Sys Initialization?		Y / N		
WPN Sys Fault Detection?		Y / N		
(Outcome: FAIL; INS011)				
	finish			
	finish			

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
INS AG: 145/100 (MFL 011) / ELECTRONIC

PROBLEM# I11-E SUBJECT#........... DATE:.............. D/C:.................. T/O: JJ / BH

LOG IN USING EMP# 00998 (GREATHOUSE)

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

Test 2 INU -> HSI continuity *SIMULATED* (OUTCOME: OK)	start finish		SHORT OUT	
Rect 2 (HSI)	start			
Order part Pro-Super Co-ord	start finish			
Remove	start finish			
Install	start finish			
	finish			
System Health	start		SHORT OUT	
INS Alignment *SIMULATED*	start finish			
MAG HDG / Steering *SIMULATED*	start finish			
INS Stored HDG *SIMULATED*	start finish			
	finish			
Job Closeout (Follow-ons not req'd)	start finish			
Task Complete Closeout MSG Rec'd?		Y / N		

<u>CLOSEOUT MASTER INFO</u>:

TM: B
WUC: 51BA0
AT: R
HOW MAL: 290, 657, 658, 242, 255, or others applicable in -06 manual

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
INS AG: 145/100 (MFL 011) / PAPER

PROBLEM# I11-P SUBJECT#............ DATE............. D/C:.............. T/O: JJ / BH

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

EVENT		TIME	COMMENTS	ADJ
Task Assignment				
Check out TOs				
Arrive at A/C				
Questions to "Pilot"?		Y / N		
Fault Verification	start		SHORT IN	
INS Alignment (JG94-63-01)	start			
Access: Power On?		Y / N		
WPN Sys Initialization?		Y / N		
WPN Sys Fault Detection?		Y / N		
(Outcome: MFL INS011)	finish			
	finish		Add'l TO research req'd? N / Y; time..................	
Test 1 (FI94-63 / T-1) INS Alignment	start		SHORT IN	
Access: Power On?		Y / N		
WPN Sys Initialization?		Y / N		
WPN Sys Fault Detection?		Y / N		
(Outcome: FAIL; INS011)	finish		Add'l TO research req'd? N / Y; time..................	
Rect 1 (INU) (JG94-63-03)	start			
Order part (9463A1)	start			
	finish			
Remove	start			
	finish			
Install	start			
	finish			
	finish		Add'l TO research req'd? N / Y; time..................	

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
INS AG: 145/100 (MFL 011) / PAPER

PROBLEM# I11-P SUBJECT#............ DATE............. D/C:.............. T/O: JJ / BH

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

System Health	start		SHORT IN	
INS Alignment (JG94-63-01) Access: Power On? Y / N WPN Sys Initialization? Y / N WPN Sys Fault Detection? Y / N (Outcome: FAIL; INS011)	start			
	finish			
	finish		Add'l TO research req'd? N / Y; time.................	
Test 2 (FI94-63 / T-2) INSM 144/145 Access: Power On? Y / N (Outcome: 145/100)	start		SHORT IN	
	finish		Add'l TO research req'd? N / Y; time.................	
Rect 2 (HSI) (JG34-22-01)	start			
Order part (3422A1)	start			
	finish			
Remove	start			
	finish			
Install	start			
	finish			
	finish		Add'l TO research req'd? N / Y; time.................	

IMIS CONSTRAINED TEST DATA COLLECTION SHEET
INS AG: 145/100 (MFL 011) / PAPER

PROBLEM# I11-P SUBJECT#............ DATE............. D/C:............. T/O: JJ / BH

INS Present Position = Latitude: N 33221 Longitude: W 112224 Altitude: 1080

System Health	start		SHORT OUT	
INS Alignment	start			
(JG94-63-01)				
SIMULATED	finish			
MAG HDG / Steering	start			
(JG94-63-01)				
SIMULATED	finish			
INS Stored HDG	start			
(JG94-63-01)				
SIMULATED	finish			
	finish		Add'l TO research req'd? N / Y; time.................	
Job Closeout	start			
	finish			
Task Complete				

CLOSEOUT MASTER INFO:

TM: B
WUC: 51BA0
AT: R
HOW MAL: 290, 657, 658, 242, 255, or others applicable in -06 manual

APPEDIX C

MEANS, ANALYSIS OF VARIANCE, AND SHEFFÈ PAIRED COMPARISON TABLES

Variable: Percent of Problems Successfully Completed

Table C1. Mean Percent of Problems Completed

	TO	IMIS	Valid N
Specialist	81.94	100	72
APG	69.44	98.61	72
All Groups	75.69	99.31	144

Table C2. Analysis of Variance for Percent of Problems Successfully Completed

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	0.3472	142	0.0997	3.4838	0.0640
Media	1	4.0139	142	0.0899	44.6551	0.0000
Spec. x Media	1	0.2222	142	0.0899	2.4723	0.1181

Table C3. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Percent of Problems Completed

		{1}	{2}	{3}	{4}
Means		0.8194	1.0000	0.6944	0.9861
Specialist TO	{1)		0.0058	0.1047	0.0132
Specialist IMIS	{2}	0.0058		0.0000	0.9944
APG/TO	{3)	0.1047	0.0000		0.0000
APG/IMIS	{4}	0.0132	0.9944	0.0000	

Variable: Number of Parts Used

Table C4. Mean Number of Parts Used by Each Subject

	TO	IMIS	Valid N
Specialist	8.67	6.42	12
APG Technician	8.30	5.30	10
All Groups	8.50	5.91	22

Note: This analysis was based upon the total number of parts used by each technician. Thus, the maximum N was 12 per subject category. Data for two APG technicians were not used due to incomplete data from failing to satisfactorily complete a problem.

Table C5. Analysis of Variance for Percent of Problems Successfully Completed

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	6.0008	20	1.5329	3.9146	0.0618
Media	1	75.1705	20	1.4563	51.6192	0.0000
Spec. x Media	1	1.5341	20	1.4563	1.0535	0.3170

Table C6. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Percent of Problems Successfully Completed

Means		{1} 8.6667	{2} 6.4167	{3} 8.3000	{4} 5.3000
Specialist TO	{1}		0.0022	0.9168	0.0000
Specialist IMIS	{2}	0.0022		0.0153	0.2310
APG/TO	{3}	0.9168	0.0153		0.0003
APG/IMIS	{4}	0.0000	0.2310	0.0003	

Variable: Serious Errors

Table C7. Mean Number of Serious Errors Per Problem

	TO	IMIS	MAJOR
Specialist	0.69	0.29	70
APG	1.06	0.18	72
All Groups	0.87	0.23	142

Table C8. Analysis of Variance for Mean Number of Serious Errors Per Problem

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	1.2433	140	0.9033	1.3763	0.2427
Media	1	28.8491	140	0.8524	33.8442	0.0000
Spec. x Media	1	4.0041	140	0.8524	4.6973	0.0319

Table C9. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Serious Errors per Problem

		{1}	{2}	{3}	{4}
Means		0.6857	0.2857	1.0556	0.1806
Specialist TO	{1}		0.0919	0.1326	0.0163
Specialist IMIS	{2}	0.0919		0.0000	0.9273
APG/TO	{3}	0.1326	0.0000		0.0000
APG/IMIS	{4}	0.0163	0.9273	0.0000	

Variable: Time to Complete

Table C10. Means for Time to Complete

	TO	IMIS	Valid N
Specialist	149.29	123.64	59
APG	175.82	124.04	50
All Groups	161.46	123.83	109

Table C11. Analysis of Variance for Time to Complete

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	9,812.22	107	2,517.83	3.8971	0.0509
Media	1	81,118.05	107	1,287.15	63.0214	0.0000
Spec. x Media	1	9,243.61	107	1,287.15	7.1815	0.0085

Table C12. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Time to Complete

		{1}	{2}	{3}	{4}
Means		149.2881	123.6441	175.8200	124.0400
Specialist TO	{1}		0.0027	0.0030	0.0054
Specialist IMIS	{2}	0.0027		0.0000	0.9999
APG/TO	{3}	0.0030	0.0000		0.0000
APG/IMIS	{4}	0.0054	0.9999	0.0000	

Variable: Preparation Time

Table C13. Means for Preparation Time

	TO	IMIS	Valid N
Specialist	5	5.1806	72
APG	5.0972	4.5556	72
All Groups	5.0486	4.8681	144

Table C14. Analysis of Variance for Preparation Time

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	5.01	142	6.62	0.7570	0.3857
Media	1	2.35	142	5.62	0.4175	0.5192
Spec. x Media	1	9.39	142	5.62	1.6702	0.1983

Table C15. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Preparation Time

Means		{1} 5.0000	{2} 5.1806	{3} 5.0972	{4} 4.5556
Specialist TO	{1}		0.9761	0.9961	0.7378
Specialist IMIS	{2}	0.9761		0.9975	0.4774
APG/TO	{3}	0.9961	0.9975		0.5991
APG/IMIS	{4}	0.7378	0.4774	0.5991	

Variable: Fault Verification Time

Table C16. Means for Fault Verification Time

	TO	IMIS	Valid N
Specialist	9.65	10.57	72
APG	18.31	11.07	72
All Groups	13.98	10.82	144

Table C17. Analysis of Variance for Fault Verification Time

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	1,507.92	142	49.15	30.6784	0.0000
Media	1	718.84	142	41.59	17.2825	0.0001
Spec. x Media	1	1,196.42	142	41.59	28.7648	0.0000

Table C18. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Fault Verification Time

		{1}	{2}	{3}	{4}
Means		9.6528	10.5694	18.3056	11.0694
Specialist TO	{1)		0.8666	0.0000	0.6297
Specialist IMIS	{2}	0.8666		0.0000	0.9748
APG/TO	{3)	0.0000	0.0000		0.0000
APG/IMIS	{4}	0.6297	0.9748	0.0000	

Variable: Fault Isolation Time

Table C19. Means for Fault Isolation Time

	TO	IMIS	Valid N
Specialist	116.22	95.92	59
APG	132.72	96.86	50
All Groups	123.79	96.35	109

Table C20. Analysis of Variance for Fault Isolation Time

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	4,117.92	107	2,371.72	1.7363	0.1904
Media	1	42,687.27	107	1,084.93	39.3457	0.0000
Spec. x Media	1	3,274.17	107	1,084.93	3.0179	0.0852

Table C21. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Fault Isolation Time

		{1}	{2}	{3}	{4}
Means		116.2203	95.9153	132.7200	96.8600
Specialist TO	{1)		0.0134	0.0852	0.0292
Specialist IMIS	{2}	0.0134		0.0000	0.9991
APG/TO	{3)	0.0852	0.0000		0.0000
APG/IMIS	{4}	0.0292	0.9991	0.0000	

Variable: Part Ordering Time

Table C22. Mean Time to Order Each Part

	Time	Valid N
Specialist TO	19.42	53
APG TO	25.28	51
Specialist IMIS	1.16	45
APG IMIS	1.47	37
All Groups	13.04	186

Table C23. Analysis of Variance for Part Ordering Time

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	1.24	140	0.90	1.3763	0.2427
Media	1	28.85	140	0.85	33.8442	0.0000
Spec. x Media	1	4.00	140	0.85	4.6973	0.0319

Table C24. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Part Ordering Time

Means		{1} 19.4198	{2} 25.2827	{3} 1.1611	{4} 1.4730
Specialist TO	{1}		0.0000	0.0000	0.0000
Specialist IMIS	{2}	0.0000		0.0000	0.0000
APG/TO	{3}	0.0000	0.0000		0.9788
APG/IMIS	{4}	0.0000	0.0000	0.9788	

Variable: Close-Out Time

Table C25. Means Close-Out Time

	TO	IMIS	Valid N
Specialist	14.667	8.1667	72
APG	17.31	8.8169	71
All Groups	15.979	8.4895	143

Table C26. Analysis of Variance for Close-Out Time

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	193.88	141	9.36	20.7104	0.0000
Media	1	4,017.90	141	14.11	284.7037	0.0000
Spec. x Media	1	70.99	141	14.11	5.0305	0.0265

Table C27. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Close-Out Time

Means		{1} 14.6667	{2} 8.1667	{3} 17.3099	{4} 8.8169
Specialist TO	{1)		0.0000	0.0008	0.0000
Specialist IMIS	{2}	0.0000		0.0000	0.7841
APG/TO	{3)	0.0008	0.0000		0.0000
APG/IMIS	{4}	0.0000	0.7841	0.0000	

Variable: Documentation Errors

Table C28. Mean Number of Documentation Errors Per Problem

	TO	IMIS	Valid N
Specialist	0.0143	0.1143	70
APG	0.0833	0.0417	72
All Groups	0.0493	0.0775	142

Table C29. Analysis of Variance for Documentation Errors

Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
Specialty	1	0.0002	140	0.0776	0.0029	0.9570
Media	1	0.0604	140	0.0828	0.7296	0.3945
Spec. x Media	1	0.3562	140	0.0828	4.3031	0.0399

Table C30. Probability Matrix for Sheffè Post-Hoc Test of Differences Between Means for Documentation Errors

Means		{1} 0.0143	{2} 0.1143	{3} 0.0833	{4} 0.0417
Specialist TO	{1)		0.2426	0.5648	0.9558
Specialist IMIS	{2}	0.2426		0.9378	0.5219
APG/TO	{3)	0.5648	0.9378		0.8600
APG/IMIS	{4}	0.9558	0.5219	0.8600	

APPENDIX D

EXIT QUESTIONNAIRE COMMENTS

Exit Questionnaire Comments

<u>Question</u>: What did you like about IMIS as an aid to doing your job?

The speed with which you and IMIS can do a job, the graphics were good for aiding with wire troubleshooting.

The whole concept is pretty good. Go to aircraft, diagnose, order part, not have to carry paper.

The speed in diagnosing and accomplishing a task.

When the PMA was connected to the 1553 Bus, it was very quick and accurate.

Parts ordering, debriefing and job close-out were much simpler than using CAMS.

Information easily accessible, accurate, easy to understand.

It cut down on the mental frustration of my job and the amount of tech data that I would normally have had to go through to do my job. Also, the part ordering feature cut down part ordering time considerably.

It cut the time down to nothing.

You had one unit instead of many TOs. It gives you only necessary information, less confusion.

It makes sure everything is done in order.

The integration of all TOs and the ease of ordering parts.

The troubleshooting fault tree and the job guides. They replicated the paper ones very well.

It was very straight forward. It took everything associated with the system into consideration, and gave the choice to the technician as to the action he feels to be best. It made ordering parts very simple, actually it does it for you. It saves time on paper work. I feel with IMIS that anybody, regardless of experience, can work on the aircraft.

The ease of closing work orders and the ordering of parts. The troubleshooting was also helpful.

Simplified troubleshooting.

Easier than carrying a library of TOs.

Saved effort in fumbling through books when shooting wires.

Convenient way to order parts.

Integration with aircraft systems (BIT checks), faster than the aircraft (GAC).

Made troubleshooting easier.

It made troubleshooting much easier and eliminated tedious job of checking out tech data and equipment from support. I also feel that IMIS will decrease the down time of the aircraft.

IMIS was very helpful in all aspects of completing a job from starting the work order, to verifying a fault, and to rectifying the fault. The most impressive aspect of IMIS is parts order!

If the system is used on the flightline, it could speed up different jobs and take away a lot of other frustration with dealing with the different TOs.

The auto BIT feature was extremely helpful, and the recommended best action was a good feature as well.

It made unknown tasks easy to understand; parts ordering an job closings were fast.

I found it very helpful. With me being fairly new to my job, I hadn't used hardly any of the TO material, as far as FI are concerned. From just learning to use both, after some basic TO (paper) training I found IMIS much more easier.

It takes up the repetitious workload.

Parts ordering, CAMS interface, not having to carry a lot of books.

Makes troubleshooting very easy.

It works very well as aid.

Question: What did you dislike about IMIS.

There is nothing I can think of that would make me dislike this system.

Transition times between screens.

Some text is misleading. For example, hook up of the PMA to A/C could be clearer. INS task seemed to require more thought.

I personally read over the job guide before I do a job With IMIS, you can't really do that,

Periodic delays between screens.

It still had lock-ups and that you did not have the option to go back if you happened to hit the 'wrong' button during operational checks.

Typical prototype bugs.

The user interface. The hourglass should consistently go to a place on the screen where it is visible. As, as the PMA is transitioning is quite confusing. There is no cue that the machine is busy. It actually prints "Press F1 for OK," when you can't. Also, having three methods to select an option is not a good idea. Use F1, F8,, and Select consistently, not F1 for this F8 for that and Select for something else. Use <u>either</u> the thumb knob or arrow keys.

The fact that steps were given only one step at a time in the job guide portion. It can slow down a job.

It was a little heavy. A keyboard would have been convenient. When troubleshooting wires, it could be more specific about the whereabouts of some of the components, i.e., "station 88 disconnect...." A little slow at times.

The speed of the software. No link between part number and serial number removed (with work order close-out).

IMIS is slow.

Slow to process information at times.

Keys sometimes hard to press; desired result doesn't occur.

At times was a little slow.

In the short time I used the IMIS, I can't really say that I disliked anything about the system.

The pros definitely outweigh the cons. However, IMIS seems to sometimes get into slow modes, I. e., changing from screen to screen, giving completed task information.

I did not like the reliability factor. If you are in the middle of a job and it goes down, it tends to be frustrating.

The time it took to process during RF operations, the amount of breakdowns, and a few minor misleading or irritating display errors.

The screen is difficult to see unless you are looking at just the right angle. Sometimes when it is thinking, it doesn't let you know what it is doing and you are apt to get frustrated with it when you try to do something and it wont respond.

About the only thing I didn't like about IMIS is the thumb control for the cursor.

Nothing.

Speed, poor pictures, one step at a time. A page down or up t proceed would be nice.

It's too hard to get back to a step you miss. It takes to long to change screens at certain times.

How slow it is in processing information! Having to skip from F1 to the select key.

Question: What Changes would you make to improve the system?

None.

Less redundancy, e.g., safe for maintenance question being asked over and over. Make safe for maintenance an option to get to if you want to.

Allow the maintainer the option to look over the job before doing a job, so there are no surprises.

Speed of processing improvements.

Try and add some more prompts to the screens on choices. Breakdown pictures of LRUs could be a little more clear. Color screens would be great.

More detailed pictures, faster response time.

Fix user interface (see previous user interface comments).

Speed up the reaction time. It was slow at times.

Speed up the PMAs.

Continuity in using the system, i.e., no shifting between F1 and SELECT keys.

Give better instructions for some of the more obscure items, for example, disconnects and transformer assemblies.

If you remove a part it should update the work order. The speed and everything else was fine.

Process faster.

Add schematic/wiring diagram type diagrams. This is a must. From time to time we see a problem that "can't happen" according to the FI. In other words, there is nothing listed for "Pilot Detectable" or "Maintenance Detectable" faults. Thus there is no fault tree to follow. Since the avionics systems of the F-16 are so integrated, a component not in the "suspected bad" system can cause a malfunction. The only way, in most cases, to troubleshoot these kind of discrepancies is to break out the schematics and "chase" the signal flow.

Response time.

Other than a few minor computer glitches, the system worked well, It would be nice if the PMA could operate longer on a charged battery.

Make the system convert from page to page faster and fix the RF problems.

Improve reliability and response time.

Increase the amount of back light, drop a glare shield on it (maybe with solar panels), put a zoom feature on the pictures.

Try to speed it up on some things, make the keyboard a little more user friendly, unless you are really careful, the screws can become a FOD hazard in the cockpit.

I think that maybe a separate detachable mouse or maybe a track ball would be good improvement.

Quicker response times to the commands.

Speed.

Use a process or unit to speed it up.

Make the system memory faster. Sometimes it takes awhile between choices.

Speed up some of the reaction times. It was slow at some times.

Question: Other comments?

Good/excellent idea.

IMIS would be an outstanding system to supplement existing tech data. However, its ability to present the "big picture" of a problem appears to be limited and it does not explain why something is happening.

Thank you for the training on the jet. The hands on troubleshooting was very helpful People "in charge" were friendly and informative as to what was going on with the program.

It is difficult to form a real opinion of the system at this time, as a fair judgment can't really be made until the system is truly "in the field." But, I like what I see so far, and have every bit of confidence that your team will perfect this system and put it into use. It has been a pleasure to work with you.

Overall a good system.

IMIS definitely needs to be an integral part of the AF. The AF will benefit greatly from the implementation of IMIS.

I think this program is a good one and has been very educational for me.

Great project - quite a bit better than having to use TOs. I hope I see it in use somewhere, sometime before I get out of the service or even in the civilian world.

I really hope this system takes effect soon.

Very good unit. If it were not for the waiting on the computer, it would be great.

I like the idea and the concept! I hope to see it in the future on all A/C systems.

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