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# ABSTRACT

Future maintenance and diagnostics aids will have to face traditional system and troubleshooting problems, as well as those associated with highly complex integrated systems. An additional challenge is that this must be accomplished with a less experienced maintenance force. This paper describes current and planned developments in applying advanced computer concepts to the on-board, inflight fault detection problem for reduction of "Cannot Duplicate" type faults. It also discusses progress in computer aided, ground based troubleshooting for the further assistance of maintenance personnel to reduce the "Retest OK" problem.

# PROBLEM STATEMENT

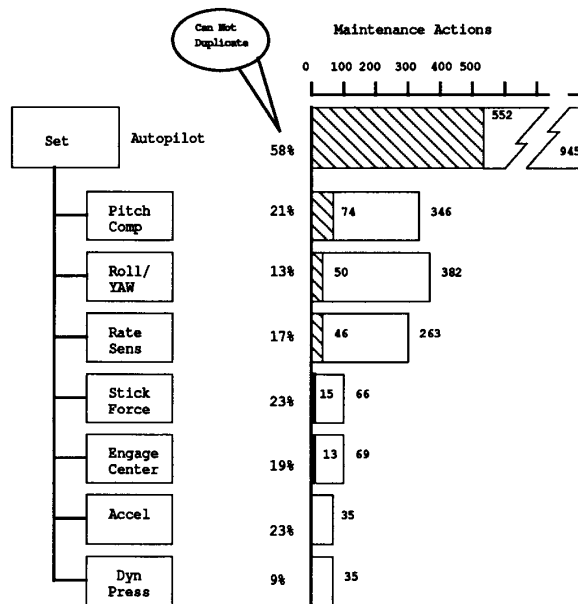
There are four main problems in the maintenance of military aircraft:

- Systems are becoming increasingly complex and highly integrated,
- The availability of experienced troubleshooters is decreasing,
- The fleet is aging, and
- The amount of documentation continues to escalate.

To provide maintenance support for maximizing the number of Air Force training and combat sorties required in the next decade and beyond, automated tools are needed to ease these major problems.

As the amount of electronics and the level of integration increases, the difficulty of identifying errors in systems and broken components makes troubleshooting to the lowest removable component a function of complex fault tree

navigation. Even with more sophisticated Built In Test (BIT), system level diagnosis remains difficult. Current repair statistics from the F-15 and F-16 fleet indicate that the Cannot Duplicate (CND) and Bench Check Satisfactory (BCS) or Retest OK (RETOK) rates for the Flight Control System (FCS), comprise 50 to 60 per cent of all maintenance actions. (See Figure 1)



Data for 13 Months; 107,000 Flight Hours

Figure 1. F-15 Maintenance Actions

The sortie rates of today's tactical fighter aircraft rely upon the ability to quickly assess and repair failed components in those systems. To increase the speed and accuracy with which Air Force technicians can fault isolate the FCS, we must develop maintenance aids to augment troubleshooting. (Ref. 1)

Because of budget constraints and the lengthy duration of new aircraft development

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cycles, the life span of the current and next generation flight control systems will be extended beyond the original design considerations. When systems age, their failure characteristics change, and new failure modes are manifested. This is because aircraft are subjected to extreme environments and significant operational readiness requirements. Moreover, wear and tear on flight control systems cause repeated maintenance actions. Wiring and connectors can be damaged and CNDs generated from repeated disconnecting and connecting of thick multi-wire bundles and multi-pin connectors.

With increased age and complexity comes increased documentation. The modification and upgrade process also generates a substantial number of configuration differences that need documentation. The F-16 has 2 major flight control modernizations and four models with four F-16A configurations alone.

If the data proliferation problem, typified by libraries of Tech Orders and Schematics, can be solved by automation, it must be implemented with the computer technology available and deliverable in the environment surrounding both the operation and maintenance of airborne systems. That environment includes interface requirements of the aircraft and the existing data collection system. The solution will likely be a field useable, portable maintenance aid for ground support. It must contain the validated testing procedures while presenting the requested level of information to assist fault isolation and maintenance action.

Airborne diagnostic systems will need to be passive, non-flight critical augmentations to traditional self monitoring and BIT. This restriction will be necessary until a method for verifying and validating non-deterministic software, such as expert systems, can be developed and proven. However, the airborne diagnostics must have information input from all current system monitors, sensors and LRUs to accurately and quickly identify the lowest level of failed component. It must also confirm the "wellness" and performance of properly functioning units. By adding "intelligence" to collect and evaluate the fault relevant data we will assist in isolation without the burden of adding dedicated sensors or BIT.

#### WORK PERFORMED

In pursuit of a capability to address the problems of maintenance and diagnostics in current and future Air Force flight control systems, a two pronged approach was undertaken. To support the ground based troubleshooting and

maintenance personnel, a knowledge based system for diagnostics capability was developed. This approach has led from a preliminary study to examine the feasibility of using expert systems to diagnose a failure in the angle of attack system of an F-15, to a full field test of an F-16 Flight Control Maintenance Diagnostic System. (Ref. 2, 3)

The studies and preliminary investigations were conducted on large symbolic type computing systems not far removed from lab development. As the needs of the field were identified and addressed, the hardware capability has expanded and the delivery package has been condensed. The initial study conducted by General Electric - Aircraft Control Systems Department concluded with the development of GEMS (GE Maintenance System). GEMS covered 10% of the F-15 flight control and included extensive help facilities and the ability to isolate faults down to the Line Replaceable Unit (LRU) including the wiring and connectors of the covered fault codes.

The follow-on contract was awarded to Honeywell Systems and Research Center and has led to a complete F-16 flight control ground diagnostic capability. A complete contemporary flight control systems was chosen as the object of investigation to encourage realistic approaches and answers for a full scale development. The Flight Control Maintenance Diagnostic System (FCMDS) covers the F-16A flight control suite, from the side stick controller to the horizontal stabilizer. The FCS includes 96 separate line replaceable units and over 10,000 feet of wiring. The F-16 already contains on-board monitoring capability and BIT that can aid the maintenance technician in the troubleshooting process, however, the information is not easily obtained or readily useable. The FCMDS provides a better troubleshooting aid and ready access to the data that is already there.

The history of the FCMDS began with the selection of the method to represent and manipulate the information about the FCS. At the time, expert systems development tools called shells were evolving as well as the process of representing facts as objects for computer programming purposes. This led to the selection of the programming shell KEE by Intellicorp as the development environment and an object oriented, model based approach for system knowledge representation and manipulation. The most significant decision was the representation of the way the system was physically connected. By modeling the way LRUs are connected and describing the signal characteristics between and through the hardware, the FCMDS is able to carry a direct representation of the system and reason about faults even if the symptoms have never been seen by the FCMDS before. The requirement to cover a

complete FCS also enabled the evaluation of earlier assumptions for comparison of scaling, timing and complexity.

The current system is in preliminary field evaluation by the Air Force prior to initiation of a full field test. The FCMDs is a tool for use on the flight line. It assists the technician both in troubleshooting and maintaining the F-16 FCS. To begin a troubleshooting session, current Air Force procedures are used in conjunction with standard debriefing and fault code generation. The FCMDs will also interface with the on-board capability to assist the technician in running the existing self test. It is also capable of downloading the inflight recorded data from 96 test points with associated angle of attack, airspeed and altitude. This information is now only made available by removing two LRUs to intermediate maintenance and translating the results from hexadecimal code.

At this point a list of suspect LRUs is generated. The FCMDs presents the suspect list in a pictorial format for ease of identification. The format also displays the relationships of the system elements. The suspect list is prioritized and matched with the applicable tests to reduce the list and identify the faulty element. The automatic selection of suspects and the prioritization is based on a weighted evaluation that includes LRU failure rates, accessibility, test equipment and personnel availability, time requirements, experience of technical experts and a divide and conquer strategy. This process in effect generates a flexible fault isolation tree.

As part of the continuing development, suggestions and recommendations from field technicians and experts were incorporated during the field demonstrations at MacDill Air Force Base, Florida. One of the primary troubleshooting problems identified by the field personnel was the inability to easily trace wiring in the numerous schematics and tech orders. The FCMDs answered the call by providing an end to end view of any selected wiring path with all relevant information tagged on each segment as a help function (See Figure 2). The individual connectors and wire runs can be selected by moving the display cursor. The delivery hardware for the field test will be a laptop sized computer although, when begun, all development and delivery was on a Symbolics computer system. Evaluations and results from MacDill include a high degree of potential user support, successful testing of the diagnostic approach, numerous improvements from field suggestions and a reinforcement of the KISS (keep it simple, stupid) principle.

Integral to the development of assistance

for troubleshooting is the development of assistance for paperwork. One of the objectives for the upcoming field test is the interfacing of FCMDs with the Core Automated Maintenance System (CAMS). The FCMDs will be able to upload information on individual aircraft prior to moving to the flight line and download diagnostic and logistic results after returning to the maintenance unit. This will make generation of Air Force form 329 the function of one button push and direct entry of the data automated for CAMS insertion. (Ref. 4)

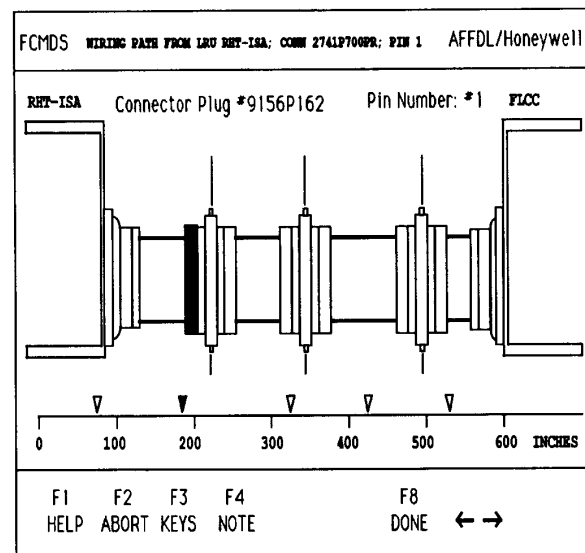


Figure 2. FCMDs Wiring Troubleshooting Diagram

The upcoming field test will take the FCMDs into as near a real environment as possible. It is scheduled to spend six months at each of two F-16 operating locations. The current software will be repackaged to run in a laptop computer with a simplified keyboard. The main purpose is to evaluate the capability and utility of the system. If the often predicted benefits of portable maintenance aids are to be validated, the field test of FCMDs should confirm its ability to decrease CNDs and RETOKs, and increase FCS availability.

The second prong of the development was implemented to attack the problems associated with airborne phenomena. The nature of flight control diagnostics and repair is complicated by the fact that troubleshooting must be done on the ground where evidence may not be available and the symptoms may not be reproducible. The goal of capturing and isolating CND type faults in the air, led to the ongoing flight test of a modified version of the GEMS ground system. Initial tests

have proven that a system with reasoning capability can collect and process information already available in the flight control system and isolate failures previously classified as a CND. Further tests will focus on expansion of coverage, implications for advanced flight control and vehicle management systems, and integrated air-borne/ground maintenance diagnostics.

Testing of the integrated system is a two phase process. The first phase tested on-line diagnostics for flight evaluation of an Angle Of Attack (AOA) subsystem fault. The scenario was to emulate a two degree mismatch between the left and right AOA probes on the F-15 HIDECA aircraft. It was not practical (due to flight safety) to actually impede one of the AOA probes, so the fault was emulated electronically to achieve the same results. The fault would emulate a mechanical malfunction such as a bent shaft or excessive friction in the vane rotor bearing. This type of fault would be difficult and very time consuming to diagnose on the ground and might be missed many times prior to finding the actual fault.

There are three test modes in the system. The first mode is the auto test mode. Data is collected at the time of the failure for use later in fact inferencing (i.e. a post flight diagnostic session). The auto mode uses the Ground Service Reporting System (GSRS) and incorporates reporting to the CAMS for Logistic reporting. The second mode is the on-request mode. This mode requires pilot interaction for use in sequential inferencing. The third mode is the normal mode when no failures are emulated. This mode was utilized to ensure the system did not produce any false alarms. The test points of the first phase are as follows:

20 test points were flown:

10 in the auto mode;

10 in the on-request mode;

4 in the normal mode (no fault).

The test points were flown at Mach 0.7 at 20,000 feet.

The results of the Phase I effort showed that there were no false detects in any mode. The auto mode correctly identified the failed LRU in 1.5 seconds. The on-request mode took 3 to 64 seconds to identify the failure. The length of time was required due to pilot interaction. The conclusion reached is that the auto mode is recommended for this type of failure.

Testing of the second phase of the integrated system will expand coverage of the on-

board system to include five more faults and will utilize both the auto mode and the on-request mode of operation. In each of the fault scenarios, disengagements of aircraft subsystems are emulated.

Scenario 1. A pin in the connector on the dynamic pressure sensor separates under conditions of high normal load factor. With pilot interaction the on-board system isolates the fault to one of the two possible connectors.

Scenario 2. A stabilator surface is impaired in its function. The pilot attempts to reset the aircraft pitch and roll CAS but fails to re-engage. Isolation is to the left stabilator actuator pin. This scenario is initiated by the fault detection capability of a flight control reconfiguration system being flight tested at the same time.

Scenario 3. A fault is experienced in the left stabilator actuator circuit and as a result the pitch and roll CAS disengage. They fail to re-engage on pilot intervention. The system isolates the fault to the hydraulic system.

Scenario 4. The INS platform stabilization fails under conditions of high roll rate. As a result, the auto-pilot system disengages. The pilot returns to straight and level flight. The system uses its inferencing power to isolate the fault to the auto-pilot disengagement for INS stabilization signal error.

Scenario 5. A card connector inside the pitch computer disengages under conditions of high normal loading. This causes the pitch and roll CAS to disengage. The pilot returns to straight and level flight and the failed connector integrity is restored. The system isolates the fault to the pitch computer Card A, "loose connection under loading."

The diagnostic process for each of these scenarios is to be included in the flight test scheduled to commence in November 1989. It is also expected that if an actual fault occurs within the flight control system during the flight testing process, the on-board system will be able to isolate the fault utilizing the same process as it would for the emulated faults. (Ref. 5)

The second phase of system testing will partition the integrated system into both air-borne and ground portions. (See Figure 3) In addition, provisions have been made to incorporate maintenance and diagnostic data into the CAMS to close the "Logistic Loop" and create a streamlined process for maintenance reporting. This will reduce the the paper work which tends to be the weak link in the post-flight maintenance

process. This post-flight processing can provide a data feedback loop to accurately assess the reliability and maintainability of systems and make enhancements to systems throughout its entire life cycle.

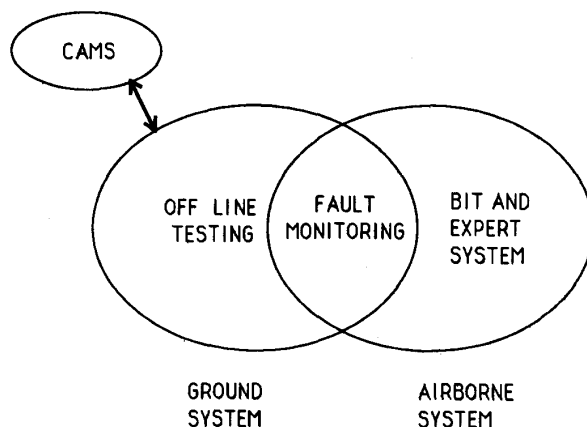


Figure 3. Integrated Diagnostic System

### CONCLUSIONS

Favorable results have been obtained in attacking the problem areas. Demonstration of the F-16 maintenance diagnostic system has shown that a complex flight control system can be modeled to troubleshoot all the aspects of the FCS including LRUs, sub LRUs, wiring, and connectors. The diagnostic system can easily handle the complicated aircraft configuration relationships when the troubleshooting process begins. The presentation of diagnostic information to the technician has been designed in a logical and meaningful manner for efficient troubleshooting. As the system was built, the amount of information that needed to be processed also increased. This direct correlation to the amount of technical documentation, as experienced with modifications and updates, can be handled without increases in physical size. From a deployment standpoint and considering operations at austere locations, the computerized FCMDs has a great advantage. This system is ready to be transitioned to the users on the flight line. The transition process will be able to be accomplished without a great deal of disturbance to present users and with a minimum of training.

The F-15 maintenance diagnostic system has demonstrated partitioning of the maintenance diagnostic system between airborne and ground based components. It can start the troubleshooting process immediately after the fault occurs,

and continue and complete troubleshooting when the aircraft is recovered for ground maintenance. This allows for a very efficient and timely process which will greatly reduce the number of maintenance man-hours.

Although the maintenance diagnostic systems have been demonstrated on a limited problem basis, the methods described in this paper are expected to be very effective on near term developments of integrated maintenance diagnostic systems for advanced technology aircraft as well as integrating processes for present systems. Because of the favorable results realized thus far, the conclusion drawn here is that the methods employed are at a point to evaluate and verify these principals with present day field technicians and contemporary flight control systems.

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Gary Smith is a Supportability Engineer in the Control Management Branch of the Flight Control Division of the Flight Dynamics Laboratory. Mr. Smith graduated from the University of Missouri - Rolla in 1979 with a B.S. degree in Mechanical Engineering. He has served in the Air Force for 4 years as an avionics technician. Prior to his current assignment, he served for eight years as an Electronics and Mechanical Engineer for the U.S. Navy. He is a member of the Society of Logistics Engineers (SOLE).

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