THE HONEYWELL ON-BOARD DIAGNOSTIC & MAINTENANCE SYSTEM FOR THE BOEING 777

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Abstract

Avionics have exhibited a phenomenal increase in complexity over the past twenty years. This increase in complexity has brought with it, the unfortunate side effect of a significant increase in difficulty of diagnosing the real reasons for a multitude of raw symptoms originating from these complex subsystems. The Integrated Avionics Architecture for the Boeing 777 is being designed with an unprecedented attention to fault detection and isolation capability to address this problem. A key element in this effort is an On-Board Diagnostic & Maintenance System (OMS) that integrates two diagnostic subsystems into the Airplane Information Management System (AIMS) cabinets: A Central Maintenance Function (CMF) and an Airplane Condition Monitoring Function (ACMF). The CMF diagnoses faults that were responsible for flight deck effects that are logged by the crew and facilitates rapid turn-around of the airplane at the gate. The ACMF captures parameters based on pre-defined trigger conditions for long term analysis of trends in Aircraft Systems and the Flight Crew. The Honeywell OMS constitutes another major evolution of diagnostic systems directed at reducing the operating costs for the airlines.

Introduction

This paper will introduce the On-Board Maintenance System (OMS) that Honeywell is building for the Boeing 777 airplane. Section I of this paper presents a background on the evolution of diagnostic systems into an CMF. Section II provides a similar background for the ACMF. Section III presents the OMS implementation in AIMS and the features of the Honeywell OMS. Section IV presents an overview of the 777 AIMS logistics that includes both line maintenance and shop maintenance.

Section I
Background on the CMF

The Problem on the Flight Line.

The primary purpose of a CMC is to assist in the analysis of flight deck effects and crew complaints from the arriving flight, diagnose the reasons behind these symptoms, isolate it to the Line Replaceable Modules (LRMs), replace them and bring the airplane back to its full operational state within the time allocated between flights.

The need for BITE

As airplane systems and the flight deck have progressed from mechanical and electro-mechanical instruments to software intensive digital computers, a serious problem has surfaced. It is no longer possible to perform simple, visual inspections to determine the reasons for a faulty element. Faults are no longer due to stuck mechanics, cracks, broken or missing linkages, etc. The maintenance crew is left to deal with a series of 'black boxes' full of micro-electronics -- one or more of which is no longer performing properly. Without any information from test points in the complex maze of interconnected black boxes, their actions are reduced to guesswork and shot-gun maintenance of replacing black boxes and hoping that the fault is eliminated.

This has been responsible for the no-fault-found problems with modern avionics -- on the commercial as well as the military side. The ROLM analysis[1] identified that 53% of the boxes removed from the airplane are later found to either re-test OK or cannot duplicate the fault. A similar problem exists on the commercial side where over half of the boxes removed from the airplane are later found to be non-faulty. This has a large financial impact on airline operations due to the need for spares, flight delays, and repeated maintenance actions.

BITE (Built-In Test Equipment) can be thought of as no more than the monitoring of these test points on a continuous basis by the various subsystems themselves, rather than relying on external test equipment to provide these measurements. An obvious advantage is the elimination of equipment removals to gain access to the test points. BITE has an additional significant advantage: the monitoring occurs at the same time as the flight deck effects, resulting in a much better chance of providing information that is useful to diagnose the problem. Without BITE, efficient maintenance on modern airplanes would be an impossible task.
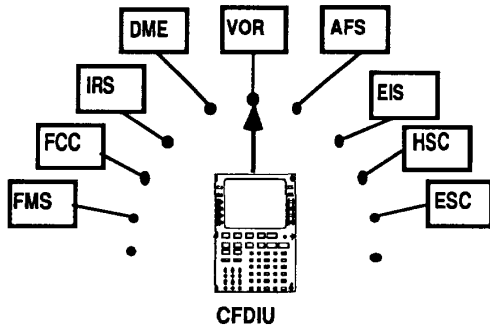
CFDIU

Figure 1. CFDS

Maintenance Aids for Diagnosis

CFDS (ARINC 604)

The Honeywell Central Fault Display System (CFDS) on the McDonnell Douglas MD-11 aircraft is an implementation of the ARINC Specification 604 which provides a convenient access to Airplane BITE and enables the maintenance crew to execute ground tests in the various sub-systems.

Symptoms from each of the LRUs are manually accessed, one at a time, by the cockpit mounted Control and Display Units (CDUs) (Figure 1).

The Boeing 747-400 CMCS[2] took another step forward in addressing the problem facing the maintenance crew by developing a centralized reasoning system that could consolidate the symptoms from multiple LRUs on the airplane and provide a diagnosis of the problem. It uses a Central Maintenance Computer (CMC) to process airplane BITE.

CMC

The CMC is similar to a CFDS in that it serves as a common collecting point for all aircraft maintenance related information. However, the CMC automatically collects the symptoms from all of the LRUs. More importantly, it uses the information to formulate an airplane view and isolate the fault that explains all of the symptoms that are being generated on the airplane.

As shown in Figure 2 the CMC collects fault reports from the FCS, FMS, Cabin and Autopilot LRUs. It then suppresses the secondary symptoms originating from the downstream LRUs and concentrates on the primary symptoms that are at the input of the LRUs. Finally, it consolidates these reports and determines that the power bus is the culprit that explains all of the sensors being inactive. A single message is presented to the maintenance crew that zeroes in on the real problem.
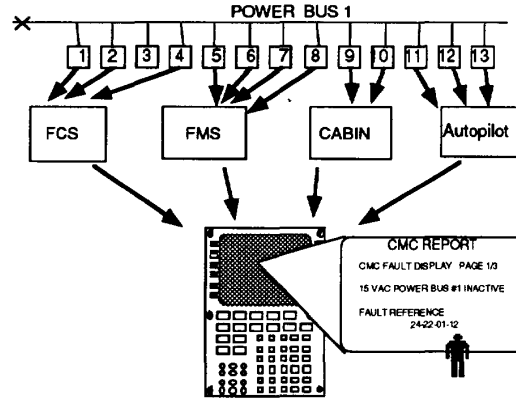

Figure 2. Maintenance interface with CMC

Having a Central Maintenance Computer that generates the messages to the maintenance crew provides other benefits as well. It is a convenient way of suppressing nuisance messages generated by individual sub-systems that are unaware of airplane conditions that make these messages invalid. An additional capability provided by a central interpreter on the airplane is the correlation of flight deck effects to fault reports from LRUs that could explain them.

Section II
Background on the ACMF

The Airplane Condition Monitoring System is different from the CMCS in that it concentrates on predicting events rather than as an aid at the gate in determining the reasons behind the event after it has occurred. An example use of the ACMS is to determine the number of times that a particular type of aircraft has exceeded its margins on approach to a specific airport. If the airline concludes, after detailed analysis, that this needs to be improved, a change in approach procedures for that airport would then be instituted.

Evolution from early flight recorders

The origin of the ACMS can be traced to Flight Recorders[4]. Starting with early photographic recorders from the 1950s used for test flights, the current day magnetic flight recorder capabilities have been gradually expanded to support research, accident analysis and cassette loaded quick-access systems. Airline programmability for the recording of parameters that are not mandated by the regulatory authorities is a more recent evolution.

Typical Use of the ACMF

The ACMS is used as an aide to long term maintenance of aircraft systems. The health of the engine is monitored by analyzing engine trends. This is then used to schedule maintenance on the engines to prevent significant disruption in airline operations as a result of the

unavailability of spares at remote locations away from the airline maintenance bases.

The ACMS is also used for life extension of the engines if they are determined to be performing well within limits . Other uses include the monitoring of fuel consumption to support any warranty claims. The ACMS is also an excellent mechanism to track down elusive, intermittent problems that only occur under certain conditions.

<u>Integration of CMF and ACMF</u>

<u>ARINC 624</u>

The ARINC 624 Report[3] provides guidelines for an On-Board-Maintenance System (OMS) for the next generation of Commercial Aircraft.   The On-Board-Maintenance System (Figure. 3), includes both the Central Maintenance System as well as the Airplane Condition Monitoring System (ACMS). Some of the advances from the Boeing 747-400 CMCS are: a new user-friendly graphical user interface using Maintenance Access Terminals (MATs) in place of CDUs; a new protocol for communication; expanded BITE in member systems; an On-Board Maintenance Documentation Function and integration of the Airplane Condition Monitoring Function.
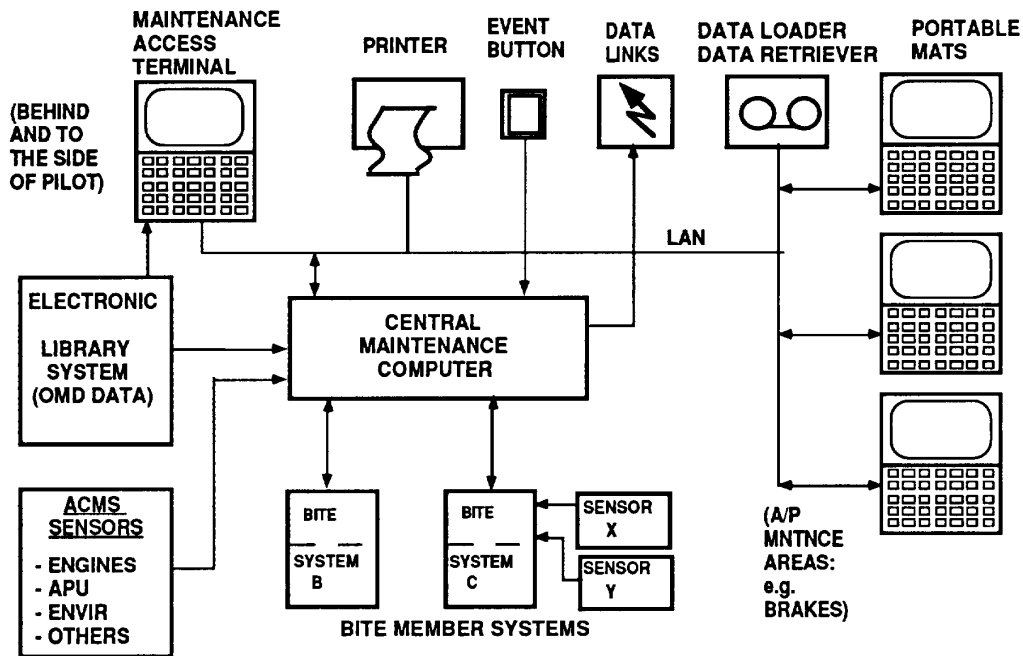

Figure 3. The ARINC 624 On-Board Maintenance Architecture

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The Honeywell OMS Implementation

The OMS is implemented as two of the functions in AIMS as shown in Figure 4.
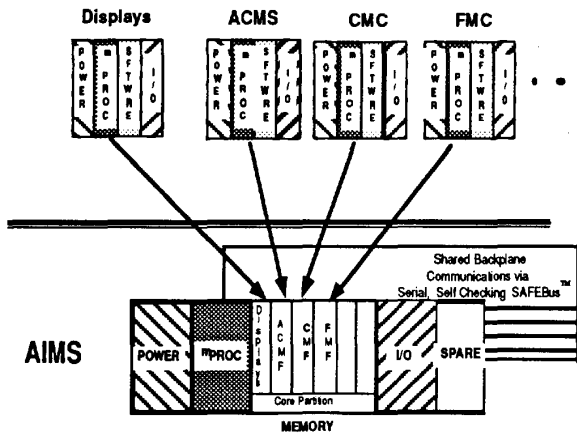

Figure 4 Honeywell OMS in AIMS

The Honeywell OMS is a model based implementation which uses an avionics model to diagnose the problem. This is different from using thousands of logic equations to anticipate the potential scenarios and determine a mapping of possible symptoms to faults.

An engineering tool called SAIFR (System Aide for Integration and Fault Reporting) is utilized to capture individual subsystem models of Fault Response Behavior. SAIFR then analyzes these models and determines any inconsistencies or inadequacies in BITE coverage for correction. Once these are rectified, it then generates an airplane level diagnostic model that is used by the airborne CMF algorithm to map symptoms to faults.

The model based approach (Figure 5) in combination with an integrated systems approach to maintenance provides significant advantages over existing systems.
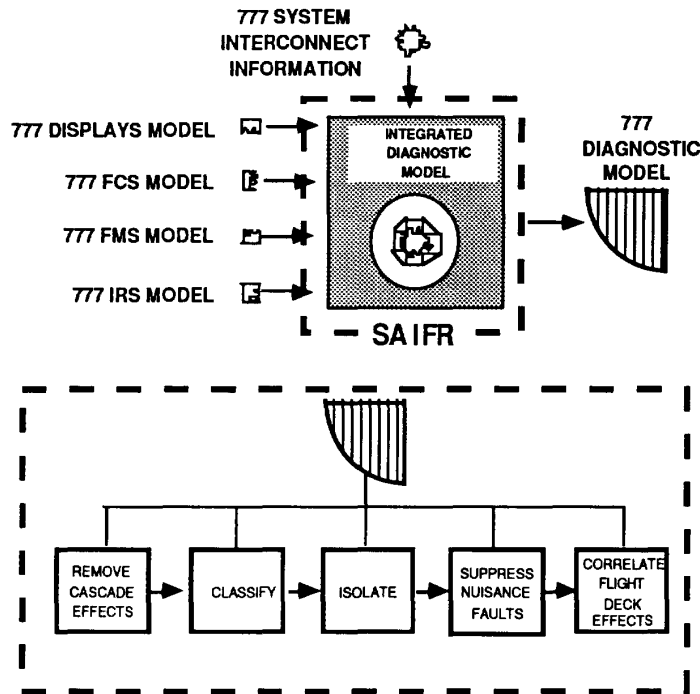

Figure 5. Model Based Diagnostics

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Gaining Maintenance Crew Credibility

Getting the maintenance personnel to trust a CMF rather than replacing boxes is probably the biggest challenge and the most significant contribution that we can make in reducing the no fault found problem.

The use of SAIFR allows us to determine the inadequacies before introduction to airline service and a specific step in the new technique suppresses nuisance messages that are responsible for loss of credibility.

Standardization of BITE

Lack of BITE standardization is a significant problem that produces inconsistent symptoms and results in erroneous diagnosis.

We have put the mechanisms in place that include infrastructure and organization as well as tools such as SAIFR that will enforce standardization of fault reporting and BITE in next generation Honeywell LRMs. In addition SAIFR is being provided to Boeing in order to extend this consistency across the airplane.

100% tracking of Flight Deck effects

We take advantage of the integration of the Displays function with the OMS in AIMS to ensure that every flight deck effect that is generated by the Displays Function has a corresponding OMS Fault Message that is correlated with it.

Separation of Hardware Faults from Software Errors

Software has taken on an increasing burden of the functional requirements in avionics. While the reliability of hardware has steadily increased resulting in very high MTBF (Mean Time Between Failure), the MTBUR (Mean Time Between Unconfirmed Removals) has not kept pace. A primary reason is the replacement of a good (hardware) box on the airplane with another good (hardware) box in the hopes that the problem will go away. In reality, software errors or design errors that did not anticipate flight conditions under which these symptoms exhibit themselves are the real cause of the problem. The software in the box that came off the airplane is identical to the one in the new box that went in, resulting in a recurring problem.

AIMS has built-in features that isolates hardware faults from software errors. Unlike systems that have promised this capability in the past by adding monitoring to existing designs, a new self-checking concept is used that incorporates this capability as a fundamental element in the basic design.

User Interface designed for the maintenance crew

A new graphical user interface is being developed using X-windows. This will eliminate the cryptic messages that are a result of the limited screen space and capability of CDUs. The maintenance crew is presented with plain English explanations of the diagnosis.

ACMF Implementation

Airborne Component

The airborne element of the ACMS monitors parameters that have been programmed using the Ground Based Software Tool (GBST). Upon the satisfaction of pre-defined trigger conditions, parameters are collected, processed and stored in memory.

As is shown in Figure 6, a large portion of the airborne software is generated by the GBST and uploaded for execution with the resident software in the unit.
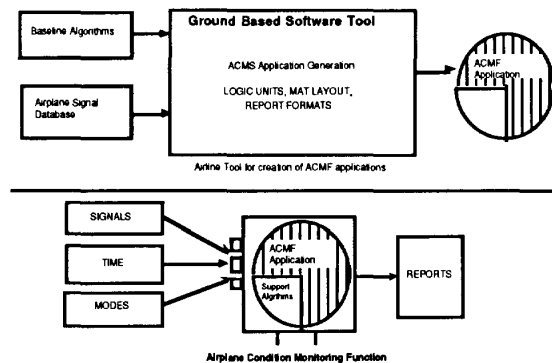

Figure 6. ACMS

Ground Based Software Tool (GBST)

The GBST is used to set up the trigger conditions for event recording, determine the action to be taken upon the trigger event and generate report formats. The tool then generates applications that are executed on the airplane.

The ACMF on the 777 continues the evolution with a more powerful GBST and more features for airline programmability.

Section IV

Maintenance Logistics for the 777 AIMS

The intent of the Honeywell AIMS design is to isolate faults at the flight line to the proper module and minimize the need for test equipment and airline maintenance shops. The unit

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