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# REMOTE MAINTENANCE MONITORING USING A DIGITAL DATA LINK

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## Abstract

The purpose of this paper is to present a concept for upgrading the military aircraft maintenance approach in the future. The evolution of digital avionics in both military and commercial aircraft is creating changes that affect today's approach to maintenance. Commercial aviation has made significant progress in the direction of maintenance monitoring using a digital data link. This paper presents the status of maintenance-monitoring efforts within the commercial airlines and, recognizing the differences that exist between the military and commercial application, proposes an aircraft maintenance concept for the military in the 1990s.

## Background

The sophistication of new aircraft systems currently being developed suggests that a new maintenance approach may be needed. The employment of Built-In Test (BIT) in avionics Line Replaceable Units (LRUs) to isolate faults can reduce the organizational maintenance activity to replacing designated components at a low-skill level. The isolation of faults not identified with BIT can typically involve sophisticated and expensive Automatic Test Equipment (ATE) and highly skilled technicians or engineers. With the trend toward increased packing density on printed circuit boards, and in turn, on Shop Replaceable Units (SRUs), the cost of these units is escalating. All of the above factors contribute toward potentially high maintenance costs in the Avionics Intermediate Shop (AIS). In an austere budget environment the maintenance activity is subject to budget cuts, resulting in reduced maintenance capability. This situation presents a critical problem in an environment where command emphasis is placed on operational readiness. In response to this problem, operational availability projections have become increasingly important to systems under development; however, this is often translated into achieving improved reliability of the system. The maintenance approach has a significant influence on the downtime, and extended periods of downtime will affect operational availability more than poor reliability.

Before proceeding with the discussion of a maintenance concept for the 1990s, it is appropriate to present some of the concepts that characterize current military aircraft maintenance. Flight operations, maintenance, and logistics are separate entities within the military. The AIS at wing level supports the operations of the wing, and the logistics or supply activity supports the AIS. Each of these activities (operations, maintenance, and supply) operates independently through the use of separate communications facilities.

Each operational aircraft wing is self-sufficient with intermediate-level maintenance capabilities. Avionics maintenance capabilities include extensive automatic test equipment to fault-isolate both LRUs and SRUs. The Air Force intermediate-level maintenance facility currently requires 4500 square feet of air-conditioned space; therefore, dispersal of the maintenance facility to forward operating bases presents major problems. With the increased sophistication of aircraft in the 1990s, the Air Force intermediate-level maintenance shop may become even larger, more costly, and less mobile. As a result of these factors, it is the objectives of this paper to suggest that a new maintenance concept for aircraft may be appropriate for the 1990s.

## On-Condition Maintenance Monitoring for Commercial Aircraft

Maintenance of aircraft used by the commercial airlines is regulated by the Federal Aviation Administration. The airline companies may perform preventive maintenance at scheduled intervals or they may conduct preventive maintenance by replacing engine components at specified performance thresholds. Many of the airline companies adopt the second approach as the most cost-effective from the standpoint of maintenance and loss of revenue because of aircraft unavailability. The performance threshold approach requires a system to monitor performance thresholds such as temperature, pressure, and fuel consumption during normal engine operation. This on-condition monitoring capability evolved from the Aircraft Integrated Data System (AIDS) developed primarily for flight safety purposes in the early 1970s. Monitored data were analyzed to identify components requiring maintenance. However, the analysis was conducted off line, which introduced significant delays between recording of the data and the preventive maintenance action to replace components.

In 1979 some of the airlines pioneered in transmitting the on-condition monitoring data to ground facilities for immediate analysis to identify components that should be scheduled for replacement. This approach is being used today by TWA, Delta, and United Airlines for scheduling maintenance on the DC-9, the Super 80, and the 757/767 aircraft. The ARINC Communications Addressing and Reporting System (ACARS), augmented with an auxiliary terminal, is used for transmission of the data (see Figure 1). Typically, engine-monitoring data are transmitted at 5-minute

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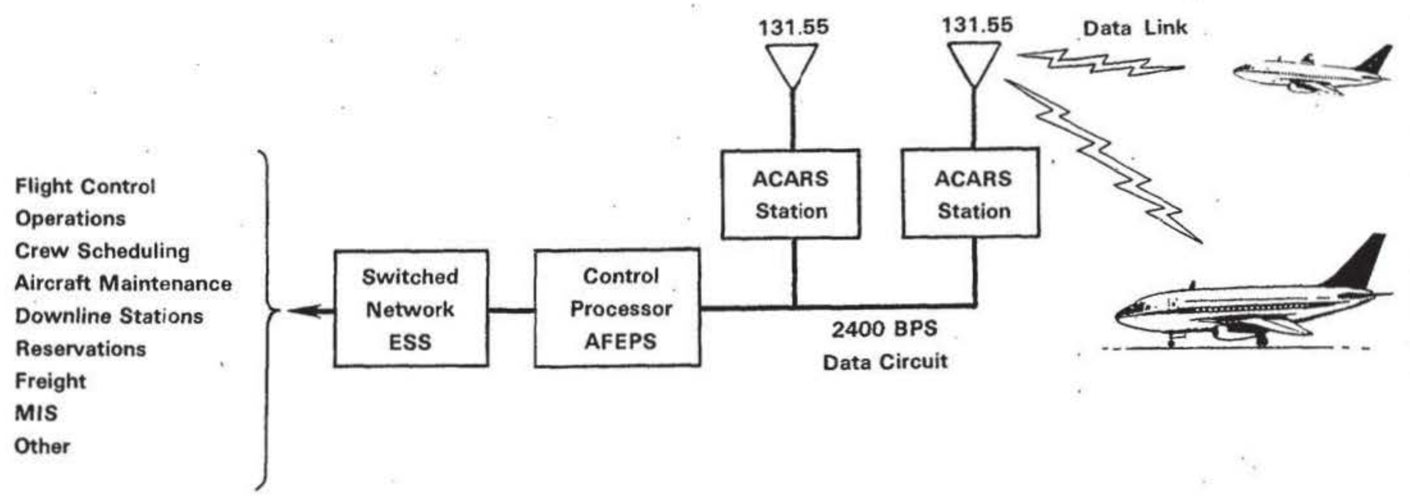



Fig. 1 ARINC Communications Addressing and Reporting System (ACARS)

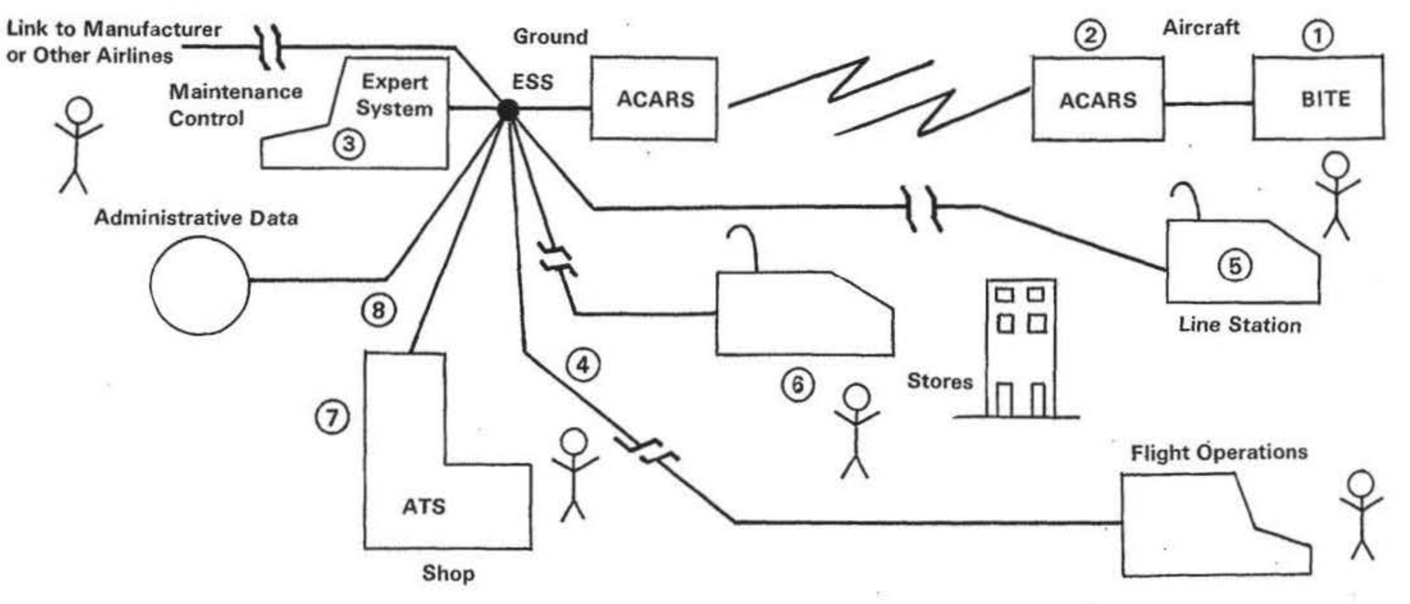
intervals during a climb and 30-minute intervals during cruise. A single VHF channel (131.55 MHz) is used by ACARS for transmission of digital information. Maintenance-monitoring data represent only 15 percent of the current digital traffic load; however, this will increase as more airlines implement remote maintenance monitoring. Once received at the ground station, these data are analyzed to determine the subsystems requiring replacement. The aircraft flight schedule is then analyzed to determine the appropriate location to accomplish preventive maintenance with a minimum disruption of operations.

## Concept for Avionics Interconnected Maintenance System (AIMS)

The airline community is now considering an expansion of its aircraft maintenance concept. Aeronautical Radio, Inc., has proposed a concept for using ACARS to transmit avionics fault information derived from BIT data. The concept, illustrated in Figure 2, is to format BITE (1) results into an ACARS (2) message and transmit the message to ground maintenance control whenever a system failure occurs. Ground maintenance analyzes the data with an "expert system" (3) that emulates the diagnostic logic of the maintenance engineers to diagnose faults. Should additional data be required, query messages are sent to the aircraft until a diagnosis is made. Once the diagnosis of the fault is completed, flight operations (4) is queried for a flight plan and a schedule is established to perform the required maintenance. The appropriate maintenance activity (line station) (5) is notified of scheduled maintenance, stores (supply) (6) is notified of the required component, and the Avionics Test Shop (7) is notified of the fault condition of the LRU being replaced. Finally, a data base file that records the maintenance activity is updated (8).

## Military Maintenance Monitoring

The military has pursued on-condition monitoring in parallel with the commercial airlines. The



first effort in on-condition monitoring was with the C-5A aircraft. The Malfunction, Analysis, Detection, and Recording System (MADAR) monitored more than engine performance [1,100 test points, including avionics, engine vibration, pressure, temperature, and airframe stress (1)]. Initially, the monitored data were transmitted to ground stations for processing. Difficulties with workload during missions and the quality of the data forced a modification of the system to replace the direct data transmission with a recorder and off-line processing with a human quality control interface. Over the years this system was used, and an extensive data base of recorded performance information was established.

A more recent effort in on-condition monitoring is the Turbine Engine Monitoring System (TEMS) for the A-10/TF-34 engine. This program consists of in-flight and ground hardware to sense and analyze engine parametric data for fault detection, isolation, and trending. Currently, the Air Force is completing a Squadron Integration Program that will integrate the TEMS capabilities into the maintenance and logistics capabilities for the A-10/TF-34 engine before operational implementation of the system. TEMS is complemented by the Comprehensive Engine Management System (CEMS), which is a ground-based system that supports the engine management community with trend analysis of performance data, engine status, and inventory control. Although TEMS will interface with CEMS, there apparently is no serious consideration being given to transmitting TEMS data to CEMS ground station via a data link. Additional information on the TEMS concept is available in References 2 and 3. The Navy has a comparable program for engine monitoring for the A-7 aircraft, referred to as the Engine Integrated Consolidated Maintenance System (EICMS).

The military implementation of on-condition monitoring presents a different scenario than the airline implementation. Commercial aircraft will normally fly standard routes with minimal change in engine conditions, whereas military aircraft engines are subject to continual change in engine condition. This presents difficulty in establishing a baseline for on-condition monitoring. The military has, however, supported on-condition monitoring as part of reliability-centered maintenance.* To implement this policy there is an Integrated Turbine Engine Monitoring System (ITEMS) being initiated to expand the TEMS concept to new engines under development.

<u>Central Integrated Test System (CITS)</u>

The B-1 aircraft also has a planned in-flight engine performance monitoring system as part of the CITS. The engine monitoring does not encompass the sophistication of TEMS (primarily time and temperature data) but does include maintenance monitoring of avionics subsystems. Failed subsystems are identified with BIT and the information displayed for air crews. Data from CITS are recorded for later analysis using ground maintenance facilities.

*Reliability-centered maintenance is a maintenance concept that allows the condition of the equipment to dictate the need for maintenance or the extent of repair required.

<u>F/A-18 Avionics Fault Tree Analyzer (AFTA)</u>

The Navy's new digital F/A-18 aircraft employs extensive BIT for avionics. Many of the F/A-18 avionics subsystems have gone beyond the requirement to isolate faults to WRAs (Navy equivalent of LRU) and are actually providing data to isolate to SRA (Navy equivalent of SRU). The mission computer is used to integrate the BIT data for all WRAs into fault messages that are maintained in processor memory. A flight-line tester, referred to as the Avionics Fault Tree Analyzer (AFTA), has been developed to access and analyze the BIT data (4). The analyzer serves as an "expert system" that conducts a diagnostic analysis emulating an experienced maintenance technician in order to isolate a fault to the SRA level. Although the AFTA is currently ground support equipment, the functions performed could be incorporated into the airborne processor or in a ground system with fault data transmitted to the ground station using a data link.

## A Proposed Maintenance Concept Using a Data Link

Although the concept of using a data link for on-condition engine monitoring has not been adopted within the military to date, there seems to be sufficient motivation for considering this approach for the 1990s. Figure 3 illustrates a concept for remote maintenance monitoring that integrates both engine monitoring and avionics fault analysis with ground processing facilities using a data link. The proposed aircraft system in Figure 3 incorporates the capabilities of the F/A-18 AFTA integrated with the on-board computer. The AFTA currently is a passive device that has been designed to analyze the results of BIT data. To facilitate isolating faults to the SRU level, it may be necessary to augment AFTA with a limited capability to generate test signals. The mission computer would provide the interface between the on-board fault analyzer (AFTA) and a data link to the ground maintenance system. Avionics fault and engine-monitoring data would be formatted into maintenance messages for transmission over a data link. Messages from ground maintenance facilities requesting additional data would be processed by the mission computer, which issues appropriate commands to the fault analyzer.

The concept of operation for providing maintenance status information to ground stations would be to initially transmit baseline information at the beginning of a mission. Subsequent messages would be sent only when the status changes outside preset limits. The volume of data for this type of operation would place minimal demand on a data link system. Should further system design reveal that ground communications facilities would not be within range of aircraft, the system could store data and provide a "dump" of monitored data when aircraft are within range of a ground station.

The ground system centers around the AIS maintenance facility but includes interfaces with both flight operations, specialized repair centers (SRCs), and the supply system. The avionics fault data will be analyzed to identify SRAs needing replacement. Expert systems supported by highly trained technicians at SRCs will query the

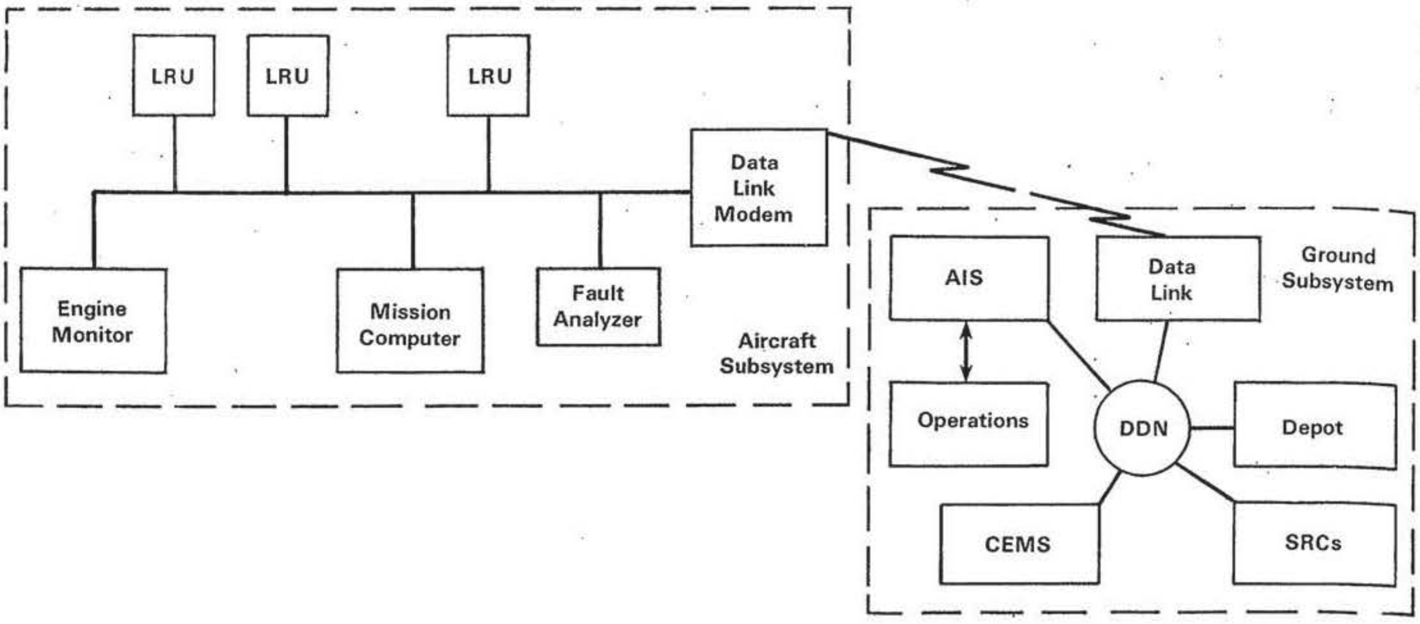



Fig. 3  Proposed Maintenance Concept Using a Data Link

information to resolve ambiguities and isolate faults to the SRA level. By using this approach, diagnosing failures should be more effective than the classical approach of trying to reproduce the maintenance problem in a "shop environment." Once the faulty SRA is identified, the system locates a replacement in the supply system. Immediate action is taken to have the part dispatched to the base where the flight will terminate so that the faulty SRA can be replaced and the avionics restored to full operational capability. The current alternative to this approach is to wait until the aircraft has returned to base and is turned over to maintenance personnel.

Although the time advantage in transmitting fault information over a data link may not seem significant for a short mission, the additional lead time until maintenance personnel are actually diagnosing faults can result in a significant delay. In an environment in which rapid turnaround of aircraft to maintain a high sortie rate is important, the use of a data link to provide the maintenance facility with fault data in real time becomes very significant.

In addition to transmitting avionics fault messages over a data link, engine-monitoring messages would similarly be transmitted using the same facilities. The main difference in the engine data would be the actions required by the ground maintenance system. Engine-monitoring data do not necessarily indicate an existing fault condition and, as such, urgency of maintenance action is not the issue; rather, the issue is scheduling preventive maintenance in an efficient manner to optimize maintenance resources and minimize the unavailability of the aircraft.

<u>Data Link Requirements</u>

As mentioned previously, the volume of maintenance data that would be transmitted by each aircraft for status reporting of fault information is minimal. The volume of data for engine-monitoring messages would be somewhat greater but would still be considered a minimal demand on the data link system. This is presuming that the frequency of transmission of the engine-monitoring data is comparable to that employed over the airline ACARS (between 5- and 30-minute intervals). The data requirements for the system would mainly be determined by the number of aircraft using the system in a given area. Assuming a maximum of 50 aircraft using a single 3 KHz channel with a digital modem similar to ACARS, there should be adequate capacity.

An alternative to using a voice channel would be to establish a series of maintenance messages that could be transmitted over planned data links such as the Joint Tactical Information Distribution System (JTIDS). This alternative would only accommodate aircraft equipped with JTIDS, which, in the case of the Air Force, may be a small percentage of the aircraft inventory. Similarly, the Navy will not have a JTIDS data link capability on many aircraft that will be operational in the 1990s. Although the data link capacity available through JTIDS would accommodate low-priority maintenance messages, the software changes needed to process additional messages could present problems at this stage in the development. For these reasons a UHF voice channel with a digital modem, similar to the ACARS digital modem, would appear to be the preferred approach. The ground communications system to interconnect operators with maintenance and supply facilities would use existing digital transmission facilities such as the Defense Digital Network (DDN).

<u>Advantages of Remote Maintenance Using a Data Link</u>

The concept of using a data link to transmit maintenance data to military ground facilities could have the following significant advantages:

- Avionics faults would be identified to an

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