Affordable Embedded Aircraft Health Management Systems

Kenneth G. Blemel
Management Sciences, Inc.
6022 Constitution Ave., NE
Albuquerque, NM 87110
505-255-8611
kenneth_blemel@mgtsciences.com

Title: Affordable Embedded Aircraft Health Management Systems

All aircraft benefit from instrumentation that provides diagnostics for condition based maintenance and prognostic health management programs. This paper will present a NAVAIR program that is developing a "smart connector" with embedded programmable instrumentation circuit for data collection and intelligent processing. The purpose is to provide real time passive monitoring with very little weight and cost, a key requirement for aging aircraft.

The paper will start with areas of flight critical aging aircraft that benefit from real time monitoring – such as detecting corrosion weakened structures, intermittent shorts and opens on wiring, wear out of fuel pumps and control motors, degrading power supplies, and malfunctioning flight controls. Next, the author will present an overview of how the Smart Connectors distributed in the aircraft wiring form a framework for real time health monitoring without sky high costs for data collection, 'black box" instrumentation and special software.

Next the author will describe how using inexpensive wireless micro-instruments packaged into aerospace connectors can be used to monitor the aircraft components. An example will show detecting wiring shorts, opens and other measures of the health of the electrical wiring. This example will be continued to show how adding inexpensive micron fibers enable monitoring of leaking liquids, active corrosion and inspecting for structural defects.

The author will use a live demonstration to show examples of the Smart Connector processing "business rules" that are procedures that diagnose the health states of electrical components, wiring harness health, and incipient damage due to corrosion.

Next the author will present how the "Smart M38999 Connectors" with embedded processing and reasoning is being transitioned to new platforms like the JSF, to AV-8B and the logical path to use for continuous health management on aging aircraft like the AV-8B as part of the upgrades of the engine monitoring system.

TABLE OF CONTENTS

1. INTRODUCTION

Embedded Instrumentation (EI) is needed to monitor the health status of structures, avionics, fuel, wiring, landing and other systems in aging aircraft. This paper describes a how a set of connectors each made with a microprocessor forms a new class of EI for addition to aging aircraft.

The most pervasive subsystem within any aging aircraft is the wiring subsystem. The wiring reaches into almost every deep corner. However, typically wiring "gets no respect," yet it is critical to the functioning of the total system. In March 2008 US airlines halted flights of hundreds of aircraft to inspect the wiring. By gathering and processing information flowing on the vehicle wiring system the overall health and status of the vehicle components, including the wiring system itself, can be assessed. Additionally, by connecting sensors to the wiring harness, additional status and health information can be obtained about structures and operating components.

For example, a simple fiber woven into the overbraid of a cable can be pulsed periodically to check for abrasion that will lead to short circuits. Assuming the wiring integrity has not been breached, the return pulse will be normal. Should a chaffing situation be occurring, the fiber will be broken or severely degraded so that the chaffing actions can be identified, and corrected.

As an example for monitoring other systems, a wiring bundle that is routed through a sump area can include a graded index fiber that becomes highly lossy when in the presence of liquids. Loss of transmission of light from a sensor would identify a leak or contamination.

2. BACKGROUND

Embedded instrumentation (EI) for real time flight operations quality assurance (FOQA) with monitoring, diagnostics and prognostics is becoming ever more important to identify the current health and operational capability of aging aircraft equipment.

Diagnostics and Prognostics

Diagnostics and prognostics of the health of aircraft systems have a different meaning to different people and are often confused. Diagnostics can mean simply a warning or "idiot lights" that tells when an event or condition has happened. The definition of "prognostic" also changes. For most, a prognostic is a warning that something probably will happen, for example that a fuel pump is wearing out and likely to fail soon. The aircraft operators consider a low fuel indication a prognostic.

Historically the diagnoses are based on changes in measurements of operational capability and significant changes in signatures such as shaft vibration or rate of cooling which exceed a threshold value.

Over the past few years there has been increasing interest in extending the traditional statistical analyses for diagnostics using sensor data in real time. One reason for this interest is that not all important health parameters can be obtained directly from sensors. Many "state of health" parameters can only be inferred indirectly from other evidence such as operating hours, temperature, vibration signatures, and other pertinent data. [1]. Inference models using Bayesian inference methods can use this data to perform predictions.

For prognostics, Bayesian modeling and simulation techniques can make a probabilistic estimate of the remaining life of components such as auxiliary power units, fuel pumps, thrust bearings and rotating components. However the remaining useful life of such components is also a function of applied stresses.

Amount of fuel and gross takeoff weight is commonly used to determine the ability to safely reach a destination. For aging military aircraft and highly stressed service aircraft (e.g. refueling tankers) there is interest in mission prognostics which apply the historical and expected stress factors of an upcoming mission into the prognostic model. For example, mission prognostics for components in the engine and power train would rely on probabilistic models based on prior mission experience information plus an assessment of expected mission stresses based upon the mission planning. With this approach, the current state of degradation can be modeled with the stresses expected during upcoming mission operating conditions to determine the probability of mission success.

Barriers

The need for timely diagnostics and prognostics is continuing, but the costs to implement on-aircraft data collection keeps growing as consultants and third party developers propose the costs of hardware and software to implement solutions which invariably include installing on-board sensors as data sources; wiring, digitizers and recorders memory for data collection; radios or data ports for offloading collected data, and data analysis centers.

The value proposition of an EI system is to provide early detection that enables a lower cost corrective action by preempting a higher cost situation. To be cost effective, any diagnostic system must itself be affordable as well as worthwhile. Affording the data offload and analysis is a major factor in determining the return on investment. Cost of a data center and support staff is one reason a simplistic sensor based approach with offload of data to data centers for statistical analyses has not gained favor because these programs suffer from high personnel infrastructure costs resulting in a poor return on investment.

Weight of the EI is another issue because increased weight implies increased fuel consumption, reduced operating range, and additional system stresses. If the weight, caused by introduction of EI, does not adversely affect the system, then considerable gains in system uptime, availability, logistics and safety could be made.

Reliability of the EI is a concern because unreliable EI would need more maintenance and spare parts, driving up life cycle costs.

It is intuitive that adding EI to an aircraft requires extensive testing and certification because of the need to meet safety requirements. Plus, there are other factors such as meeting electrical magnetic interference (EMI) limits.

Recent efforts

The Joint Strike Fighter (JSF) program was one of the first with design requirements regarding having a systemic Air Vehicle Instrumentation System (AVIS). The AVIS was initially proposed as an extended flight data recorder with offload to a data center for analysis. However, JSF wanted was hundreds of sensors providing data in addition to collection of built-in-test and flight parameters. A Broad Agency Announcement (BAA) solicited concepts that would cut life cycle costs.

3. THE "SMART CONNECTOR" CONCEPT

As with any complex highly automated machinery, the wiring harnesses reach into all (or nearly all) compartments of an aircraft. The ubiquitous nature of wiring makes it an ideal source for placing the data collection and processing infrastructure. With weight on wheels the distilled information can be offloaded from various sectors in the aircraft to an on-board or airport internet web-site for transfer to a central computer.

In 1995 the Office of Naval Research funded Management Sciences to develop a miniature instrumentation circuit called the "Sentient Instrumentation Controller" (SIC) for creating underwater monitoring systems. The SIC was architected to be a low power hybrid computer with analog inputs, digital processor, analog outputs, and digital outputs. The prototype for the SIC was about the size of a half stick of chewing gum, made possible by using high density interconnect (HDI) packaging developed at General Electric.

In 2000 NAVAIR published a need for monitoring of full authority digital engine controllers (FADEC) and other avionics. MSI proposed the SIC as a viable solution that could be placed inside a specially constructed mil-spec connector.

NAVAIR liked the "Smart Connector" concept for several reasons. First, the processors would be very small, adding less than an ounce of weight each. Putting the processor into a connector eliminated the need for additional wiring. Low cost for the electronic circuitry and using the connector as the package was innovative. In mass production the SIC could be produced for less than twenty dollars each in quantities needed for the NAVAIR fleet. Being located in the wiring connectors would eliminate otherwise expensive cost for changing the design of hundreds of avionic units. Access could be through unused pins found in the connectors.

A major unexpected plus would be that the health state of flight critical wiring harness could be assessed to identify the location of shorts and open circuits caused by operational factors or battle damage.

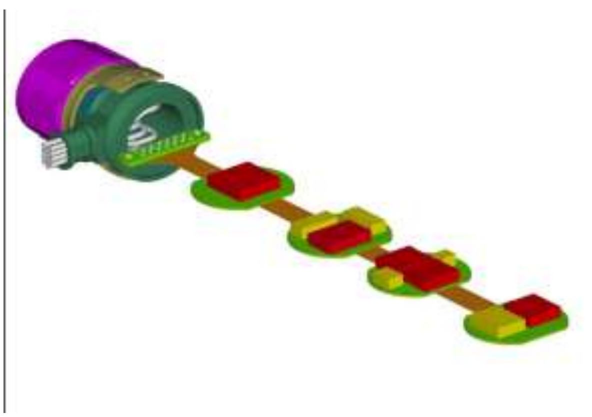

Figure 1 Circuitry added to the back shell of a connector.

There would be definite advantage if the processor could be robust enough and readily programmable for specific algorithms needed for monitoring engines, electrical power systems, flight controls, etc.

In 2005 the SIC was awarded US Patent 6,938,177. Today the SIC is currently being upgraded to have a 32-bit processor which includes 64 megabits of local memory and also USB and Ethernet ports, wireless communication, and support for gigabits of memory. This improved design is sponsored by the JSF program office and is called the Embeddable Programmable Instrumentation Circuit (EPIC).

4. THE ROLE OF SOFTWARE FOR EMBEDDED EI

Historically efforts to develop the algorithms have consumed tens of man-years and cost running into several millions of dollars. This time and cost creates a real problem in the case of instrumenting aging aircraft.

There is a better way than developing millions of lines of programming; the real time operating system for the Smart Connector hosts an "Intelligent Rules Engine" for processing the sensor data and performing base lining, diagnostics and prognostics.

The "Rules Engine" is a logic switched algorithm that simplifies the programming of complex software applications. The logic switching aspect builds the EI software "on the fly" as the operating domains which affect diagnostics change from preflight to altitude to landing.

Beginning in 2003 several DoD programs such as sponsored by the Office of Naval Research and the US Air Force funded development of auto-coding for generating diagnostic and prognostic subsystems. The auto-coding process feeds a set of rules called "metadata". The metadata are a stored set of rules for constructing a model. The metadata is processed with a generic application called a "Rules Engine", which as its name implies, produces the application and situation specific model from the a set of rules which replace hard coded software.

The capability of processing diagnostics, and prognostics with a "Rules Engine" was demonstrated in 2004 for monitoring parameters on a Navy F/A-18. This demonstration included data collected during several phases of flight.

Wired or Wireless Networking

Connectors are ideal places to house BlueTooth and Zigbee circuits which are just two of several options for adding wireless communication over the relatively short distances in an aircraft. If wireless transmissions during flight operations are a concern, the information can be transmitted when a safe "weight on wheels" exists.

Wired communication does not necessarily require additional wiring. Communication can be accomplished using shielded wires as a viable option for the high energy environments of military aircraft. Recently Boeing was received a patent for transmitting data at high speeds as acceptable noise over the relatively low data rates carried by a Mil-Std-1553 bus.

Once the need and feasibility of a wireless EI system is determined, the time and cost to deployment divides into system engineering, prototyping of the EI hardware and software, followed by testing of data processing and communications. The System Engineering effort that defines the architecture is most important as the number of Smart Connectors in the aircraft directly impacts weight and costs.

The Systems Engineering activities include the determination of placement of smart connectors, the use and integration of sensors and the situation specific processing algorithms to be implemented in the "Rules Engine."

Expansion Capabilities

After the initial EI framework is installed, more Smart Connectors can be strategically added to reap additional benefits. For example, a network of corrosion monitoring sensors can be added in corrosion prone areas. Worthwhile alerts can be directed to the crew. For example, a "Smart Connector" with sensors that detect leaking "blue water" under toilets can be installed to provide early warning of situations that can lead to wiring faults and potentially to arc-fault fires.

Embedded Health Management Capabilities

A network of several Smart Connectors, each with 32 bit processors and tens of gigabytes of memory forms a powerful distributed computer. The processing power can be used to hold baselines and perform statistical analysis to predict when service actions will be required. Given early detection, there can be an on-board prognosis of faults occurring that potentially interfere with mission safety or mission success, Given this warning actions can be taken to reduce the probability of the fault occurring. Other fault reporting, connectivity (including network or data centric) reporting capabilities can be readily included in the overall system capabilities and the information is readily accessible within the EI subsystem.

Implementation

The EI approach using "Smart Connectors" is scalable and can be used across the spectrum of types of aircraft. The Smart Connectors can be added wherever there is enough space (usually a few centimeters) to mount the connectors at existing electrical harness connectors. In cases where electrical harnesses do not exist, a similar package can be used which has a wireless transmitter to deliver the data to and among other processors.

5. CONCLUSIONS

A system engineered approach is appropriate for adding connector based embedded instrumentation in strategic locations aging aircraft. Once installed, this cost effective EI can perform effective IVHM system at a fraction of the cost of adding new avionics and wiring.

REFERENCES

[1] "Autonomous Situation Awareness and Autonomous Logistics", K. Blemel, TFD Group User Groups and Conference, 2006

[2] "An Automated Goal Seeking Approach to Machinery Prognostics and Life Extension", K. G. Blemel and C. Stern, Society for Machinery Failure Prevention Technology, 2005

BIOGRAPHY

Kenneth G. Blemel *is a co-founder and Vice President of R&D for Management Sciences, Inc. Ken has successfully guided MSI research and development in IR&D, BAA, and over fifteen SBIR, and STTR contracts. Ken is recognized for seminal work in developing "Smart Connectors" and "Smart Wiring Systems" for embedded diagnostics and prognostics. Ken holds several patents including electronic hardware and methods for electronic microsystems used for implementing wiring based tests and diagnostics. Mr. Blemel has published many technical papers and has participated in several panels, most in the area of software and embedded systems for reliability, maintainability, and logistics. In 1987 was awarded the Best Technical Paper of the 41st Quality Congress of the American Society of Quality Control. He has a BS in Applied Mathematics (Engineering) from the University of Cincinnati and an MS in Applied Mathematics (Engineering) from the University of Rochester NY.*