Next Generation Data Acquisition Technologies for Aging Aircraft

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ABSTRACT

Traditionally, OLM systems have been tailored for each aircraft type based on what specific measurements and analysis tools are perceived to be required at the time. This paper focuses on the data acquisition technology used to measure the flight parameters and how it's stored. The benefits that arise from using modern Commercial-Off-The-Shelf (COTS) solutions versus traditional bespoke systems are examined. A case study of a HC-130H is introduced which has recently used such systems –this platform is topical given its proliferation to more than 60 nations with varying climates and the varied applications it encounters. Finally, new technologies that are finding their way into applications such as Flight Test Instrumentation (FTI), in particular Ethernet and other open standards, that will allow newer OLM systems to provide a better fatigue profile of the aircraft while driving down cost are discussed.

INTRODUCTION

The widely accepted practice conducting Operational Loads Monitoring (OLM) applications for ageing aircraft is of particular importance when the aircrafts loads or flight profile change. This typically arises when an aircraft's role changes or it is flown in an environment where the conditions may change the fatigue profile. A particularly good example of such a platform is the Lockheed C-130 which is used in a variety of applications and in more than 60 nations around the world. Traditionally, OLM systems have been tailored for each aircraft type based on what specific measurements and analysis tools are perceived to be required at the time. This paper examines current and future Commercial Off-The-Shelf (COTS) solutions and what benefits these offer to OLM applications.

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FLEXIBLE COTS SOLUTIONS

A data acquisition effort designed to collect data to assess the impact of aircraft use beyond initial manufacturing is often necessary as an aircraft's role changes during its life. Adaptability can be particularly important as there is no guarantee that an aircrafts' fatigue profile will remain the same in the future and it may be necessary to alter the system. An aircraft's fatigue life depends on several factors beyond the number of hours in use, such as

- Flight role
- Number of take-offs and landings
- Payload weight and distribution
- Environment
- Different pilot flying practices
- Servicing intervals

OLM systems that have been tailored for each aircraft type, based on what specific measurements are required at the time, can often lead to inflexible 'black box' systems with bespoke hardware and software that might only ever be used on one aircraft type. Generally the qualification of the hardware, and occasionally the software, is expensive and maintenance costs are high which often results in a poor return on investment. The time taken to debug and qualify the system means that it's possible the system may become obsolete before even getting into service. Subsequent reuse of the system will be difficult or not cost effective if it is incapable of being adapted or upgraded.

COTS solutions designed to be modular and upgradable over a long lifetime can avoid many of the disadvantages inherent with bespoke systems. Some of the benefits of COTS include [1]

- Cost – can easily be a factor lower
- Future Proof –new technologies and upgrades can be integrated at low risk
- I/O – a wide range of avionics interfaces available; support for future standards
- Flexibility – expandable and programmable, as the needs or flight profiles change the system configuration can be changed to suit
- Cost of Ownership – spares are standard product; production equipment lead times are lower
- Environmental qualifications: Mil-Std-810/461 already a baseline
- High quality software that is freely available

In particular, COTS can take advantage of new acquisition, processing and data storage technologies that emerge as a result of requirements in other aerospace instrumentation fields. The most demanding of these fields is of Flight Test Instrumentation (FTI).

OLM AND FTI DATA REQUIREMENTS

The development of COTS OLMS solutions follows the work in other aerospace fields. OLM programs share some similar data acquisition requirements as FTI applications, such as the need to obtain reliable data that satisfies the analysis requirements. Flight test is always the most challenging due to the heavy demand for high-speed sensor, databus and video data. Table 1 illustrates the typical differences between FTI and OLM data acquisition fields.

The same equipment concept is easily adapted to other functions since in the majority of cases the building blocks are identical, only the application is different. These highly accurate data acquisition systems are often flexible and use off the shelf chassis and modules. The expensive and time critical nature of FTI applications – often in highly hostile environments – necessitates a highly rugged and reliable solution. Such systems are capable of acquiring high quality data and environmentally qualified for typical OLM applications.

Table 1. Comparison of typical differences between FTI and OLM data acquisition fields.

	FTI	**OLM**
Number of Parameters	Thousands	Thousands
Data Rates	50K to >2M sps	1 – 100 sps
Data Storage	Onboard and telemetered	Onboard
Data Processing	Real-Time and Post flight	Post flight

OPEN STANDARDS

Open standard are publicly available, vendor neutral and do not rely on commercial intellectual property. Open standards have many advantages over proprietary systems due to increased flexibility, longer lifetimes, reduced cost and future multi-vendor support. There are several open standards which OLM applications can take advantage of –, notably for data storage and extraction and for inter chassis data transfer.

One of the most significant set of open standards in recent times for aerospace data acquisition is Ethernet. Ethernet is proven, well understood and widely adopted technology for data transfer in most industries. Increasingly, it is being adopted by the aerospace community – for example the Airbus IENA [2] and the CTEIP Integrated Network Enhanced Telemetry (iNET) standards [3]. iNET is addressing and bringing about a standardized approach to meet the needs and requirements of aerospace applications including systems management, time synchronization and Data Acquisition Unit (DAU) configuration.

A previous barrier to Ethernet's adoption, i.e. a reliable method of synchronizing data from multiple chassis, has been removed with the development of the IEEE 1588 Precision Time Protocol (PTP) – defined in the IEEE 1588-2002 standard [4]. Using the PTP, data can be synchronized across a large network with a high degree of accuracy (typically within <100ns).

Ethernet has several practical advantages over traditional inter-chassis communication protocols [5][6] including

- Standard open interfaces and protocols
- Significantly less wiring
- Higher data rates and improved time synchronization
- Reduction of programming and troubleshooting time during installation and test
- Reduced cost and ease of integration with COTS equipment
- A flexible future-proof architecture

There are also open standards available for describing hardware configuration. In order for a meta-data standard to be useful it must meet a minimum set of criteria i.e. it must model the domain effectively, be adaptable, vendor independent, extendable and based on XML [8]. One such standard is XidML®, an XML metadata standard for the aerospace community, which provides a vendor-neutral hardware configuration platform that describes how data is acquired, processed and packaged for transmission, storage or reproduction. This allows an end user to deploy a multi-vendor system without requiring ad hoc mechanisms customized to the software interfaces provided by each specific hardware manufacturer.

RECORDER STANDARDS

There are ruggedized COTS Solid State Drives (SSDs) and CompactFlash® (CF) media available that remove the need to purchase expensive proprietary media. Standard file systems, such as FAT32, enable a PC to see media as a removable storage drive and thus the files are instantly accessible with no need for an expensive dedicated data transfer unit. Standard PC card readers and SATA interfaces mean data transfer is no more complicated than downloading data from consumer electronics. This media permits the storage of high bandwidth data in real time at an affordable cost, precluding the need for complex data reduction processes in flight. This improves system reliability and qualification costs and it preserves all raw data enabling detailed analysis to be performed.

Open file formats enable users to use freely available tools to extract or mine the relevant data from the device. One such file format is the Packet CAPture format (PCAP). PCAP is a popular and lightweight packet capturing file format used by numerous network programs. It is free and open source, so there is no cost or licensing issues with using or modifying it, and there is a huge community already supporting it. There are numerous software tools available supporting it including the popular network analyzer Wireshark®.

By combining ruggedized COTS storage media with an efficient file format, months of uninterrupted, continuous recording is possible. For example, Figure 1 shows that a 64GB CF card can hold approximately 1086 hours of data at 8000 samples per second (i.e. 500 samples per packet with 16 packets recorded per second).

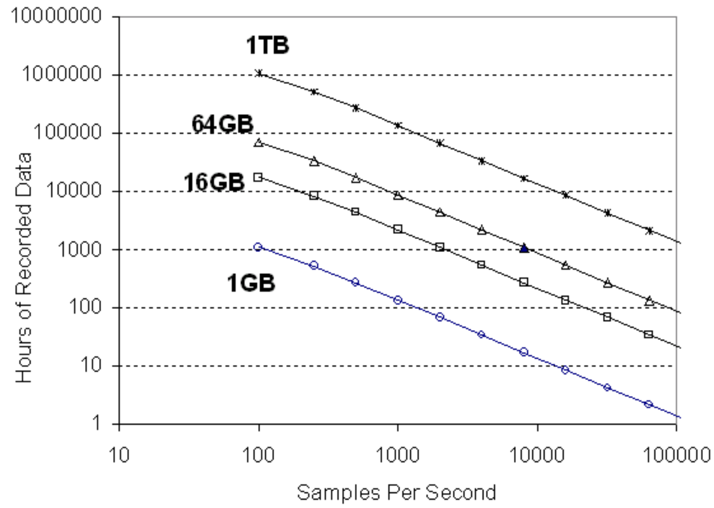

Figure 1. Hours of Recorded Packetized Data.

Ethernet also has benefits for data recording systems including reduced equipment costs, reduced maintenance costs and reduced service times [5]. Ethernet switch architectures enables simple data isolation for dedicated recorder applications by using source or destination IP or MAC address filtering. Furthermore, using Ethernet based technologies as a common core communications infrastructure technology for data acquisition, recording and mining activities can remove the need to physically remove and replace the storage medium in an aircraft. There are examples of such remote data transfer via Wi-Fi and other technologies for maintenance data [7].

HC-130H CASE STUDY

The United States Coast Guard employs the HC-130H for long range search and rescue, drug interdiction, illegal migrant patrols, homeland security, and logistics. Currently, the life-limiting critical fatigue component for the C-130 fleet is the Center Wing Box (CWB), making it a prime structural focus area. The safe useful life of the C-130 wing structure was questioned in 2002 following a retrofitted C-130 fire tanker crash [10] and the discovery of cracks in the CWB of other C-130s by the U.S. Air Force earlier than models had predicted [10].

The USCG expressed interest in participating in an assessment of the effects of corrosion and fatigue on the CWB with the U.S. Air Force Academy's (USAFA) Center for Aircraft Structural Life Extension (CAStLE). This included the collection of representative flight data for the purposes of updating and validating finite element tools. To this end a HC-130H was instrumented with an ACRA CONTROL KAM-500 DAU which monitored the following:

- Wing beam, and other fatigue critical locations (33 strain gages)
- CWB's thermal environment (11 Resistance Temperature Devices)
- Cabin pressure, temperature and humidity (pressure, temperature, and humidity transducer and remote probe)
- Position, altitude, ground speed, true and magnetic course (GPS receiver)
- Acceleration (2 DC single-axis accelerometers)

- Cabin pressure and aircraft static pressure (2 Precision Pressure Transducers)
- Flap Position (Sensor)
- True airspeed, weight-on wheels, ramp door position, and flap position (KAM-500 analog voltage monitoring module)

The DAU was customized by plugging COTS modules into a standard chassis to produce the desired system. It weighed 8lbs and used an integrated CF recording module to store data. The CF card (3Gb and 4Gb) were easily accessible via an external slot. The system and card extraction is shown in Figure 2. The system was configured to record whenever the aircraft DC power bus is energized. The KAM-500 DAU runs on hardwired finite state machines as opposed to microprocessors, thus it is live on power-up. This "always on" approach ensures that virtually all flight data will be collected, as no one needs to remember to activate the recorder prior to flight. The CF card was removed and replaced approximately every three weeks and sent to CAStLE for processing.

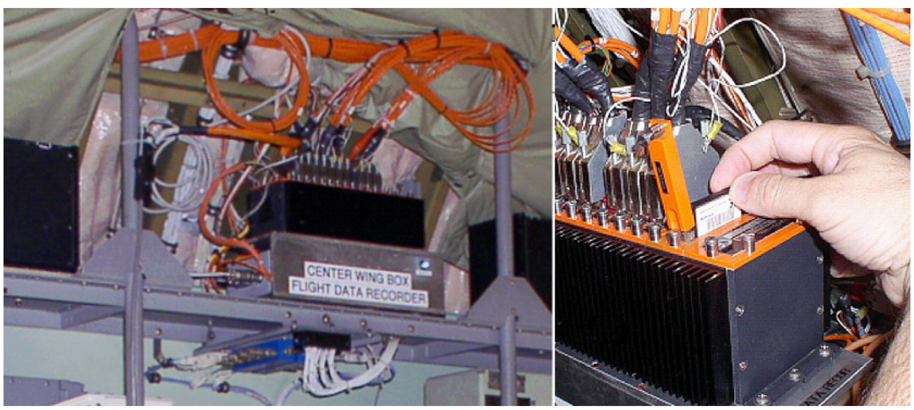

Figure 2. The KAM-500 System Installed on the HC-130H Centre Wing Box.

The original one year program was extended to 5 years and collected over 2800 in-flight hours of data. This provided usage data to supplement that previously collected through inference from survey of aircrew and fleet managers. The actual flight data showed that in general the operating environment was less severe than anticipated and thus the overall fleet age and the rate at which subsequent EBH is accumulated were reduced.

The new CWB life limit was defined in terms of USAF Equivalent Baseline Hours (EBH) i.e. flight hours times the mission severity factor. Aircraft life was extended for the majority of the fleet with 22 aircraft gaining hours and 5 loosing. This resulted in approximately three additional operational years until CWB life limits reduce the unrestricted fleet to 16 aircraft. Additionally, over 2800 hours of in-flight pressure, humidity, and temperature data was made available for future study topics, including environmentally assisted cracking and corrosion. Details of on-going Finite Element Modeling efforts have been published [11].

EMERGING TECHNOLOGIES

As microelectronics continue to decrease in size and increase in power due to higher density micro-electronic chip fabrication, technologies that were previously impractical (due to size, cost or usefulness) are becoming viable options for the next generation of data acquisition products. These can provide useful high resolution data that may have been previously unavailable due to sensor, acquisition, storage or processing limitations. Some examples include wideband, Field-Programmable Gate Array logic devices, computer processing power and solid-state memory devices. Additionally, these new chips have allowed the size of DAUs to shrink from a system that occupied half a rack of equipment to a DAU that occupies a fraction of the space, while at the same time improving performance, reliability and functionality.

Current developments have led to viable alternative or additional data sources. For example, solid-state cameras are now available that are small and rugged enough to be placed in restricted space areas or outside the aircraft with little modification to the aircraft structure. Such cameras can provide more information than an open/closed status or a flap angle setting switch for example. The necessary processing tools are readily available, in many cases distributed through the public domain – hence basically free. Large high speed memory chips mean that data as well as video can now be stored simultaneously, over many hours of flight, at an affordable cost. It is worth noting that back in the 40s and 50s, using a camera to record the instrument readings periodically was often one of the only sources of instrumented information available to the maintenance crews on the ground [12] - digital techniques again make this technology a potentially valuable supplementary data source.

In the near future 'smart sensors' will be available that will perform the sensing and measurement of the signal at the sensor location, typically providing a serial output allowing large numbers of sensors to be digitally read with only a few wires – vastly reduce wiring requirements [13][12]. Wireless, self-powered sensors could simplify this further [14] while nanotechnology, microelectromechanical systems (MEMS) and computational advances like artificial intelligence [15] and distributed computing could eventually lead to self-repairing and ageless structures [16]. These developments may be many years off – however, it is essential for their continual evolution that open system architectures are used [17].

CONCLUSIONS

The use of common configurable COTS hardware and software technologies available today can reduce the cost of purchase, cost of ownership, support, reliability and maintainability of OLM requirements. Furthermore, they also offer the possibility to upgrade to new technologies and alter the systems application by virtue of their modular nature and the commonality of hardware. The case study highlights how a COTS data acquisition system can not only meet the requirements of an OLM program but stay in use for additional unanticipated data gathering. Future applications, such as usage monitoring or testing aircraft modifications, could easily be facilitated by simply altering the DAUs modular elements – if so required. The cost saving from hardware, training, qualification, testing etc. are significant compared to bespoke systems.

The future prospects of fully integrated, smart systems are exciting with the potential for more detailed data with positive implications for flight safety and maintenance programs. Such rapid developments can be exploited by DAUs that are designed to facilitate a future upgrade path via modular replacements. However, these may be some time off and are likely only in new airframes. Many aircraft operators, military and civilian, are keen to extend the existing lifetime of their current fleet. COTS solutions offer both current affordable ways to do this and the ability to be upgraded or integrated with next generation systems as they are adopted. Integrated systems will likely still use line replaceable units (LRUs) over an Ethernet bus as these are already being introduced on next generation airliners like the Boeing 787 [19].

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