Smiths Industries Flight Data/Cockpit Voice Recorders

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INTRODUCTION
This paper is intended to provide an avionics manufacturer's industry perspective of modern recording and diagnostic monitoring systems for aircraft applications. Smiths Industries Voice And Data Recorder (VADR®) product line combines reliable, rugged, entirely solid-state technology with proven data recording expertise available in a variety of packages. The VADR® product family consists of Cockpit Voice Recorders (CVRs), Flight Data Recorders (FDRs), combined function (CVR & FDR) recorders, and Integrated Data Acquisition And Recorder System (IDARS) and Health and Usage Monitoring Systems (HUMS) equipment. All models are Authorized to Federal Aviation Administration (FAA) TSO-C123a and TSO-C124a performance requirements, and also meet the functional and performance standards of European Organization for Civil Aviation Electronics (EUROCAE) ED-55 and ED-56A.

The company's flight data recorders are fitted to over 6,700 military aircraft and became the US Air Force and US Navy standard for all aircraft in 1988. The US Army, US Coast Guard, Federal Aviation Administration, and many civil and allied nations' military fleets also make extensive use of Smiths Industries recorder products and systems.

Compact, light weight, and affordable, the VADR® is applicable to virtually any aircraft, offering a unique advantage to those aircraft previously constrained by the weight and bulk of traditional data recording systems. The VADR® single box solution measures 3.4"H x 4.25"W x 7.5"D (8.6cm x 10.8cm x 19.0cm) and weighs 6.5 to 9.3 pounds (2.9 to 4.2 kilograms), depending upon configuration.

WHAT IS NEW IN FDR/CVR TECHNOLOGY

BACKGROUND OVERVIEW
Aircraft monitoring systems have been around since almost the beginning of aviation. In an industry so constantly striving for perfection and improved performance, developers and operators have always tried to increase aircraft performance understanding, enhance operations and reduce costs. Data acquisition and recording systems have come a long way since the first mechanical foil recorders. Aircraft monitoring requirements have also grown apace. Aircraft mishap recording has grown primarily from civil regulatory requirements. Regulations are in place now which will increase parameter-recording

requirements over four fold. Concurrently, with the development of increasingly complex, higher performance vehicles, the need for more information and increased reliability has grown. Aircraft operators and manufacturers have evolved a variety of specialized monitoring equipment to support system, performance and component life tracking needs. Increased operations tempo, greatly increased complexity of newer aircraft and requirements for more expeditious support activities has led to a need for dramatic improvements in aircraft monitoring system capabilities. With the advent and growth of solid state electronics capabilities and concurrent software systems, dramatic improvements in data acquisition, recording and processing of aircraft data is possible today. Today recorders are required to support multiple requirements and multiple functions as illustrated in Figure 1.

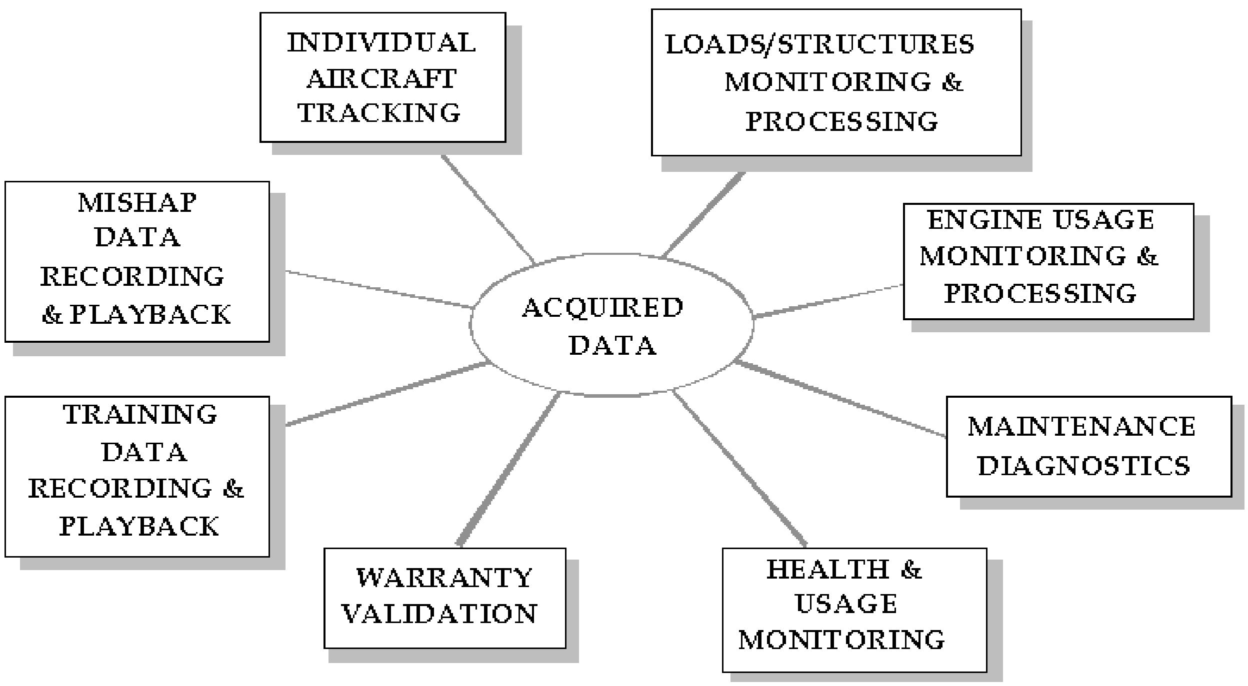

Figure 1: Modern Aircraft Monitoring System Functions & Relationships.

EVOLUTION OF AIRBORNE RECORDER SYSTEMS

Development of recording systems applied to aircraft has its origins in the audio recording and playback equipment produced during the early decades of the twentieth century. Recordings for musical entertainment and of the spoken word for radio and archival uses drove technology toward magnetic wire, tape and metallic foil media. The increase in civil passenger air travel during the 1930's, 1940's, and 1950's demanded that information be preserved should a crash occur.

The first mandate for flight data recorder installations in the United States was issued by the Civil Aeronautics Board (the predecessor of today's Federal Aviation Administration) in the late 1950's. Crew voice recording was mandated in the early 1960's, and throughout the next two decades the number of data parameters and time duration of both cockpit voice and flight data recorded was increased. After several incidents from which recorders did not survive crash impact, fire, and water immersion, standards for the crash survivability were upgraded and put in force during the 1990's.

Despite the evolution in recorder function and performance standards, the basic system architecture concept remained much the same during the span of more than fifty years. Recorder systems were comprised of three pieces of equipment: Cockpit Voice Recorder (CVR), Flight Data Recorder (FDR), and Flight Data Acquisition Unit (FDAU). Each avionics box required its own basic circuitry, power supply, and chassis, mounting hardware, connectors and wiring. The size, weight, and power inherent to such a system architecture made it difficult at best—and often impossible—to apply recording systems to military tactical and smaller civil aircraft, despite the need. Industry responded to the need by applying new technology solutions to implement multi-function recording devices in new, innovative packaging.

SMITHS INDUSTRIES RECORDER SYSTEMS EXPERIENCE

Smiths Industries Aircraft Monitoring Systems

It is now well over 30 years since the first Smiths Industries aircraft monitoring system was developed. That system, for engine health monitoring in the Hawker Siddeley Trident airliners, was housed in a half ATR box and sampled just 13 parameters – temperatures, pressures, vibration and speeds – translated them into digital format and recorded the data on an on-board tape recorder. On landing, the tape was taken to a ground-based facility for processing and analysis.

Simple the system may have been by today's standards, but the foundations had been laid for the future. It had been appreciated that if the actual behavior of the engines could be recorded and analyzed, much could be determined about the stress and strains being experienced in flight. This could be used to interpret the wear on components, the 'amount of life used' and used to calculate remaining 'safe life' of the component. In essence, manufacturers were beginning to develop a concept of "on condition maintenance" being actively pursued to this day.

Smiths Industries Flight Data Recorders and Cockpit Voice Recorders

Smiths Industries has been building military crash protected memory (CPM) flight data recorders for almost 20 years. Initiated by the US Department of Defense in the late '70s, SI initially won a contract to provide modern, solid-state data acquisition and recording equipment for the US Air Force F-16 under the Crash Survivable Flight Data Recorder (CSFDR) Program. This was shortly extended and enhanced under the US Air Force Standard Flight Data Recorder (SFDR) and US Navy Standard Flight Incident Recorder (SFIR) Programs eventually to over 44 aircraft types in over 20 countries around the world. Solid-state CPMs have evolved from the initial 56Kbyte memories of the mid '80s to 72Mbyte production units today with even larger units in development. Acquisition and recording has grown from the early 13-parameter units to applications today monitoring hundreds of parameters.

The Future of Aircraft Monitoring Systems

Today, commercial flight data recorders flying in many of the world's fleets record only a small, limited set of parameters on a variety of recording media technologies. Data availability and usage is quite restricted. However, electronics technology has made dramatic improvements in capabilities, ruggedness, signal interfacing and processing capability. Single use systems have been multiplying for applications such as engine monitoring and structures recording. This is just scratching the surface. Today's aircraft monitoring systems do more than just acquire and record aircraft signals. Typically, the information is monitored for accuracy and results calculated and recorded in real time to support rapid feedback, reduced data volume and immediate output to other systems. Today's systems have grown much more capable, supporting multiple functions within a common chassis. This not only reduces acquisition, integration and support costs, but also allows for the sharing and correlation of data between functions. For example, flight parameters such as g force acceleration and angle of attack across the air intake will affect engine performance and can be related to engine temperatures and performance. On an increasing number of aircraft flight parameters can be directly correlated with airframe fatigue stresses and fatigue life, eliminating the need for costly dedicated strain gauges. SI has developed special algorithms supporting this trend under a concept called Fatigue Usage Monitoring System (FUMS). The future of aircraft monitoring is further functional integration, expanded signal monitoring, greater recorded resolution and data fidelity and increased reliance for improved maintenance management, focused maintenance diagnostics, reduced life cycle support cost and aircraft service life extension. The Smiths Industries Integrated Data Acquisition and Recording System (IDARS) exemplifies this trend

EVOLUTION OF SMITHS INDUSTRIES' CONCEPTS

The multi-function nature of Smiths Industries compact, rugged airborne recorder systems expanded the range of feasible applications. More and more civil and military fleet operators were finding that the availability of small and reliable yet affordable recorder systems could satisfy safety-related mandates as well as the need for accurate information to support improved aircraft maintenance logistics practices. The US and their Allied Military services pioneered efforts such as the Aircraft Structural Integrity Program (ASIP) and Comprehensive Engine Monitoring System (CEMS) to gather flight data for analysis and refinement of aviation fleet logistics management.

While the need for expanded collection of aircraft flight data remained strong, the desire for recording of aircrew and radio traffic audio was not well satisfied, especially in military applications. Smiths Industries was asked to develop a recording system that would add audio recording capability to the other functions of the data recording process. What evolved and introduced to the market in 1995 was the unique Voice And Data Recorder (VADR®). The VADR® is a very small combined data and audio recorder, which matched the CVR and FDR functions of conventional systems but in a compact, low weight, and entirely solid state design (Figure 2).

Figure 2: Compact, Rugged and Reliable: SI's Voice And Data Recorder (VADR®).

The VADR® was an instant success, but fell short of meeting the demand for acquisition of a large number of individual directly connected analog data signals. The conventional approach was to apply a FDAU or newer Digital FDAU (DFDAU) to gather signals and format them for transfer to a data recorder, but this meant undesired growth in system size, weight, complexity, and cost. It was determined, instead to approach the need with a system solution., that the VADR® concept should expanded to include greater signal interface capacity for a large number of analog and discrete inputs and yet retain the single box architecture (Figure 3). The concept of the Integrated Data Acquisition and Recording System—the IDARS—was born, and the initial platform applications to date include:

- USAF/USN T-6A (JPATS)
- USAF UH-1N
- USAF B-1B
- USAF U-2S
- USAF KC-135
- Brazil AL-X (Super Tucano)
- Eurocopter EC.135, BO.105 & BK.117
- UK Chinook HUMS
- UK Sea King HUMS
- UK Puma HUMS
- UK Lynx HUMS
- NATO Flying Training Canada (NFTC) program

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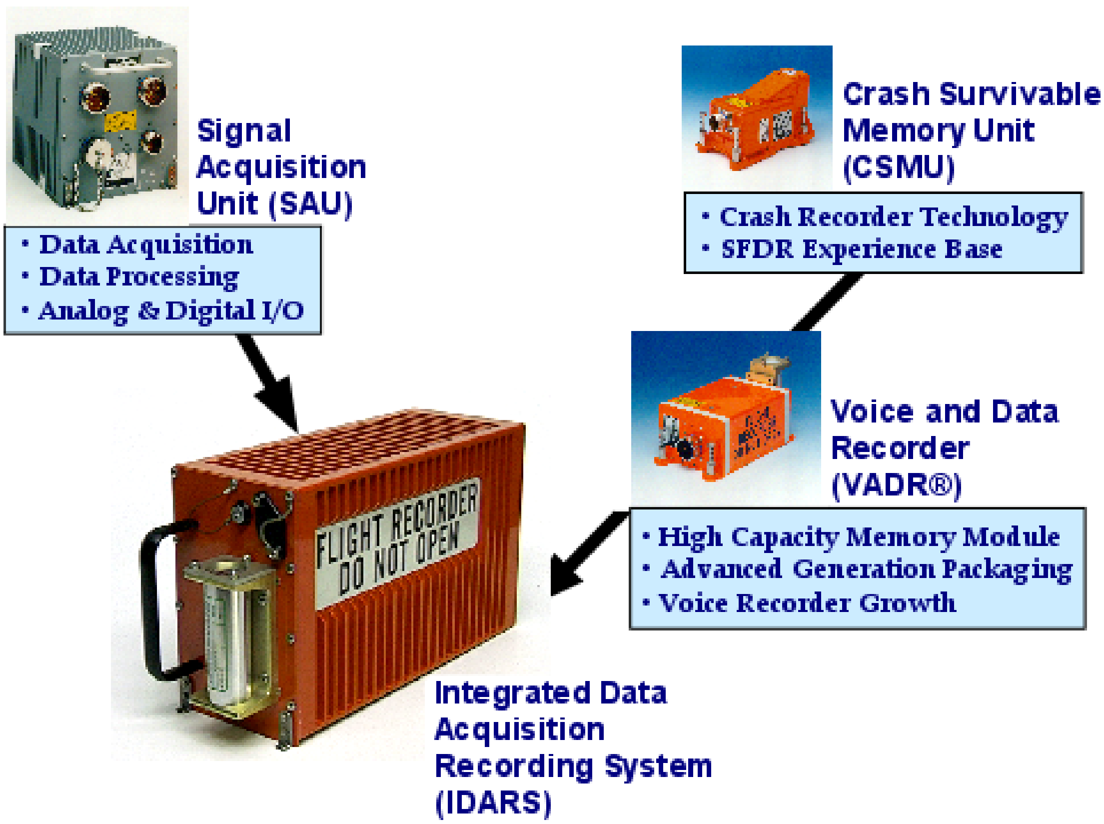

Figure 3: Smiths Industries IDARS Evolution

INTEGRATED DATA ACQUISITION AND RECORDING

GROWING DATA ACQUISITION PERFORMANCE NEEDS

Newer aircraft applications and the need to extend the life of existing aircraft has led to the need for more and better data on aircraft usage. At the same time, aircraft upgrades have led to a premium on available avionics space on aircraft. Cost is always important. The Integrated Data Acquisition and Recorder System (IDARS) is designed to meet these needs. In a single box, the IDARS (Figure 4) includes circuitry for extensive direct analog interface, acquisition and processing, data storage in mass memory, crash-protected memory and removable memory.

Figure 4: SI's Single Box Solution—Integrated Data Acquisition And Recorder System (IDARS).

IDARS CAPABILITIES

The IDARS acquires and processes all aircraft sensor data, stores relevant data on the integral Crash Protected Memory (CPM) and/or the external Data Transfer System, and displays relevant exceedances, alerts and data on the Cockpit Control Unit (CCU). The IDARS consists of a chassis assembly and a set of plug-in electronic Circuit Card Assemblies (CCAs). The IDARS accommodates up to five CCAs with all data communications and power distribution handles through the rigid multiple layer motherboard. Conditioned power is supplied to all CCAs with the exception of the CVFDR subsystem, which has a separate power-supply, for electrical isolation. The CCAs are partitioned into the following subsystems:

- Flight Data Acquisition Unit (FDAU)
- Cockpit Voice and Flight Data Recorder (CVFDR)

Flight Data Acquisition Unit (FDAU)

The IDARS FDAU provides monitoring and acquisition of flight data and sensors including analog, strain gauge, frequencies, low level AC/DC voltages, MIL-STD-1553, ARINC-429, RS-422, discrete signals, etc. It also provides outputs for various status and Built-In-Test (BIT) data and outputs for use by other system components for crew alerts and data display. Table 1 indicates input/output capabilities of the IDARS FDAU.

Signal Type	Available
AC/DC and Synchro Inputs	80
Variable Frequency input	8
Input Discretes	96
Output Discretes	8
Phase Reference Inputs	6
Low-Level Differential DC	14
RS-422 / RS-485	6
MIL-STD-1553	2
ARINC-429 Inputs	8
ARINC-429 Outputs	3

Table 1: DAPU/IDARS Input / Output Capacity

The IDARS FDAU is the primary analog/discrete/digital data acquisition, processing, compression and storage management component of the DAPU. It is capable of:

- Capturing data parameters
- Sampling data parameters
- Analyzing relevant conditions and changes
- Calculating resultant parameters
- Compressing data and managing data storage
- Performing the flight data acquisition functions for the CPM

The FDAU processes all parameters that are required by appropriate regulatory agencies for incident/mishap investigations. These parameters are buffered at the sampled frequency with no compression and sent to the CVFDR subsystem via an RS-422 communications channel for recording in the CPM.

Cockpit Voice Recorder and Flight Data Recorder (CVFDR) Subsystem

The IDARS CVFDR provides data collection and incident/mishap recording of audio data, aircraft flight and system parameters to support post incident analysis. The IDARS CVFDR subsystem consists of:

- Voice Processing Unit (VPU) CCA
- Crash Protected Memory (CPM)
- Acoustic Beacon

The CVFDR meets the operational requirements of EUROCAE ED-55 and ED-56A and FAA TSO-C123a and TSO-C124a. The flight data rates, interface and storage capabilities meet the standard of Aeronautical Radio, Inc. (ARINC) 573/717/747 and ED-55. These data rates meet or exceed those required for normal maintenance functions. The formatted data to the CPM is via a dedicated serial interface. BIT data is available through a separate RS-422 interface. In compliance with regulatory requirements, the VPU is functionally and electrically isolated from the other DAPU subsystems with the exception of an RS-422 serial interface.

The acoustic beacon is a mechanically integrated, water (fresh or salt) activated, device. It is compliant with EUROCAE ED-55, as well as applicable FAA Technical Standard Orders and ARINC standards.

GROWTH BEYOND DATA ACQUISITION AND RECORDING

GROWING PERFORMANCE TO MORE ADVANCED DATA USE

Today, the need for accurate, detailed aircraft and aircraft subsystem performance recording and analysis is well established. The requirement for operational readiness rates is higher than ever before. Maintenance costs, which are a significant factor in life cycle costs, have also risen dramatically. Modern aircraft monitoring equipment coupled with comprehensive ground support and analysis systems can offer improved aircraft availability and a greater safety margin.

CURRENT MULTIFUNCTION MONITORING

Engine monitoring is done on nearly every engine produced or in service today and has directly led to increased performance and lower maintenance costs. For example, an engine that had lower temperatures and less vibration than another could be expected to be serviceable longer, and therefore its maintenance cycle could be extended. Similarly, an aircraft experiencing lower flight stresses and less turbulence during flight could be expected to use less of it's structural fatigue life. The advent of accurate data recording allowed this tracking to become a reality. A very dramatic example illustrating the variation in seemly similar flight is the experience of the Red Arrow flight team in the UK. There it was found by employing structural recorders that the wingman typically experienced aircraft structural stresses double, triple or even higher over that of the flight lead.

THE FUTURE: COMPREHENSIVE HEALTH AND USAGE MONITORING

The integration of airborne monitoring and diagnostic systems with multifunction ground data analysis and support systems provides an evolving capability for very accurately tracking aircraft usage, system / sub-system life and supporting fleet management and maintenance. These systems improve airworthiness, improve reliability, and reduce aircraft cost of ownership by detecting and diagnosing potential and actual failures, monitoring usage, automating test procedures and providing advance warning of potential equipment failures and collecting valuable data for routine maintenance.

Smiths Industries' HUMS Overview

The Smiths Industries HUMS extends IDARS into a proactive maintenance and diagnostic system. It monitors nearly 200 parameters vital to aircraft operation – continuously acquiring, processing and storing data. Data is distributed for storage and retrieval in internal mass memory, in removable storage (a Data Transfer Module or DTM) for routine maintenance, and with cockpit voice data in a crash-protected memory (CPM) to support incident analysis like the IDARS. HUMS upgrades IDARS to include the addition of special purpose circuit cards to support HUMS vibration monitoring and other growth maintenance functions. Sensors around the airframe provide input on engine and gearbox vibration, rotor track and balance, avionics and overall aircraft performance. Essential health data is provided to the flight crew, while more detailed information is stored for later use by ground support technicians. Fatigue life usage can also be calculated in real time. SI can offer total system integration, production of major elements of hardware and software, installation design, aircraft installation and logistics support in the field.

Data Acquisition and Processing Unit (DAPU)

The DAPU acquires and processes all aircraft sensor data, stores relevant data on the integral Crash Protected Memory (CPM) and/or the external Data Transfer System, and displays relevant exceedances, alerts and data on the Cockpit Control Unit (CCU). The DAPU consists of a chassis assembly and a set of plug-in electronic Circuit Card Assemblies (CCAs). The DAPU accommodates up to five CCAs with all data communications and power distribution handles through the rigid multiple layer motherboard. Conditioned power is supplied to all CCAs with the exception of the CVFDR subsystem, which has a separate power-supply, for electrical isolation. The CCAs are partitioned into the following subsystems:

- Flight Data Acquisition Unit (FDAU)
- Cockpit Voice and Flight Data Recorder (CVFDR)
- Vibration Monitoring System (VMS)

Flight Data Acquisition Unit (FDAU)

The Flight Data Acquisition Unit (FDAU) functions as described in the IDARS section above.

Cockpit Voice and Flight Data Recorder (CVFDR)

The Cockpit Voice and Flight Data Recorder (CVFDR) functions as described in the IDARS section above.

Vibration Monitoring System (VMS)

The VMS functions include comprehensive rotor, drive train, gearbox, engine and structures health monitoring, diagnostic data acquisition and maintenance processing. Key capabilities include:

- Automatic or manual collection of vibration and optical tracker data from a series of flight regimes
- Collection of spectra from a series of flights for trend monitoring
- Capturing random spectra at the user's request for later analysis of intermittent events
- Communication of vibration alarm (exceedance) conditions
- Collection of spectra for health monitoring
- Calculation of rotor and blade maintenance adjustments based on track and vibration data

The VMS is a high performance data acquisition and processing subsystem hosted on one or two double-sided Vibration Acquisition Unit (VAU) CCA. The DAPU chassis supports up to two VAU CCAs. When configured with two CCAs, 48 vibration channels, 20 speed sensor channels, and 4 blade trackers can be accommodated, as listed in Table 2:

Signal Type	**Available**
High Band Vibration Channels	48
Speed Sensor Channels	20
Blade Tracker Channels	4

Table 2: VMS Input / Output Capacity

The digital signal processor (DSP) based design provides measurement and processing capability to allow most faults to be diagnosed on-board the aircraft. As with the APU, programmability if sampling rates, gains and input characteristics is a key feature of the card. The VAU DSPs eliminate the need for specialized analog acquisition circuitry and phase lock loop acquisition methods. Growth capability for incorporation of neural network technologies via software upload has been designed in.

BENEFITS OF RECORDING, CONDITION MONITORING, AND DIAGNOSTIC SYSTEMS

The reality is that aircraft are being kept in service for longer and longer and their mission requirements are continuously being revised. As a fleet ages, maintenance costs continue to grow. Concurrently, the pressure to increase maintenance productivity, reduce maintenance man-hours and improve aircraft readiness continues to strain the current force structure. Better understanding of aircraft actual usage, more accurate and timely information on needed aircraft maintenance actions and improved tracking of component usage is critical to realizing gains in aircraft readiness. Comprehensive aircraft monitoring is the key to this achievement.

A comprehensive aircraft monitoring system with associated sensors can support significant gains in reduced maintenance man-hours and increased aircraft and component life extension. Typically supported functions include:

- Mishap/Incident Recording, Playback and Analysis
- Training
  - Aircrew Tactical Training
  - Maintenance Training
- Warranty Recording
- Aircraft Usage Monitoring,
  - Individual Aircraft Tracking (IAT)
- Airframe Structures Monitoring
  - Loads/Structures Monitoring
  - Aircraft Structural Integrity Program (ASIP)
- Engine Health and Usage Monitoring
  - Low Cycle Fatigue
  - Engine Structural Integrity Program (ENSIP)
- Transmission Health Monitoring
- Rotor Monitoring

Each of these functions may be inter-related and many aircraft parameters are used for multiple functions. Therefore a comprehensive aircraft monitoring system is both necessary and cost effective. Use of accurate aircraft usage data can lead to more accurate tracking of aircraft structural life usage and an extension of calculated remaining life. Similarly, engine usage tracking can lead to earlier identification of incipient engine health problems, but more significantly to more accurate tracking of actual engine life usage and eventual conversion to an on condition maintenance program and engine overhaul cycle.

CONCLUSIONS

Modern technology has a lot to offer the operating organizations. Better, more comprehensive monitoring of aircraft components, systems and performance coupled with enhanced means of transferring and analyzing the recorded data can provide big payback. An adaptable, integrated, low cost solution is critical to affordably realizing this benefit. The VADR® and IDARS are leading the market for this capability with:

- **Light Weight**
- **Small Size**
- **Reduced Power**
- **Integrated Single 'Box' Solution**

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AUTHOR'S BIOGRAPHY

Jeffrey L. Brooks, Program Manager, is an honors graduate in Electrical Engineering from Michigan Technological University, a licensed Private Pilot, and a member of the International Society of Air Safety Investigators (ISASI). In his more than 20 years of professional work he has been involved with the design, production, and flight test of navigation, guidance, and recording/monitoring avionics systems for both fixed- and rotary-wing civil and military aircraft.