A VISION OF
FUTURE CRASH SURVIVABLE
RECORDING SYSTEMS

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INTRODUCTION

For more than 40 years recording of flight data has developed from scratches made by stylus on aluminum foil, recording a handful of parameters, to silicon memory chips recording thousands of digital bits. There can be no doubt to the value obtained from airborne crash survivable recorders, however the perpetual enhancements in aircraft systems leads to the need for more data to be recorded as aircraft operation and performance become ever more sophisticated. This creates a moving target for the crash investigation community and recorder manufacturers to contend with.

Today many aircraft incorporate centralized processing to automatically present information tailored to flight and operational conditions, and much of this data consists of the parameters processed for airborne recording. As changes emerge to the traditional partitioning of avionics by functionality to a design based on partitioning by flight criticality or operational applications, centralized processing increasingly impacts current systems/subsystems, customers and regulatory agencies. Gains in onboard computational power make more sophisticated onboard diagnostic and prognostic software a reality, but the emphasis tends to be on the ease of use, cost effectiveness, flexibility and integration and little thought to the airborne recording. As new technologies are introduced, it should be as a means to enhance safer air travel and utilize the effect of computational power to provide system flexibility and growth, while maintaining a minimal impact on recording systems and aircraft integration.

EVOLUTION OF FLIGHT SAFETY & DATA MANAGEMENT

In the early 1940s, with the boom in civilian passenger aircraft, the Civil Aeronautics Board (which evolved into the FAA) demanded that a record of the flight be protected beyond the impact of the crash. Several models of recorder designs were tested until in 1953 General Mills produced a yellow sphere – known as the Lockheed 109-C flight data recorder (FDR) - in which 5 Signals were recorded directly from discrete/analog sensors. Some of the significant events in the history of data management and recording include :

In 1957 the CAB mandated aircraft over 12,500 pounds carry a FDR, this was the dawn of the jet age (DC-8, B707 introduction).

In the early 1960s recording of the pilot's voice on the aircraft was initiated.

In 1965 CVRs were mandated on large passenger aircraft.

About 1970 up to 25 Discrete/analog Signals recorded, aircraft digital complexity increased and FDAU systems were introduced.

Early 1970s QAR were introduced, recording the output provided by the FDAU.

In 1975 GPWS required on large passenger aircraft.

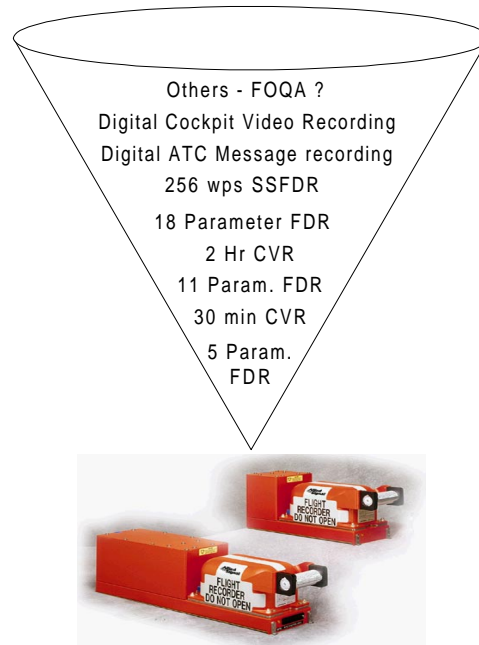In early 1990s TCAS became mandatory.

Early 1992 Solid State recorders were produced.

July 1997, number of mandatory FDR parameter increase (11 to 18 parameters)

1   March 1999 NTSB Safety Recommendations:-

▪ 2 Hr SSCVR standard

- Independent power supply source (10 minutes)
- Datalink message recording

Others - FOQA ?
Digital Cockpit Video Recording
Digital ATC Message recording
256 wps SSFDR
18 Parameter FDR
2 Hr CVR
11 Param. FDR
30 min CVR
5 Param. FDR

Figure 1 - The Requirements Funnel Effect

The progression of mandated changes to date have necessitated re-design and re-certification costs, for both the recorder and aircraft installation. CVR and FDR recording requirements will, in the near term, be further expanded based on the developing EUOCAE WG-50 specifications for Digital Message recording and possible airborne Video recording. Digital messages are cockpit communications that have replace the traditional voice, i.e. datalink messages.

Current Crash Survivable Recording Systems

Current state of the art airborne recorders are independent and physically separate systems. Solid State flash memory records 4 channels of cockpit audio for a duration of 30 minutes or 2 hours in one unit, and 25 hours of flight data at rates up to 256 – 12 bit data words per second in a separate unit.
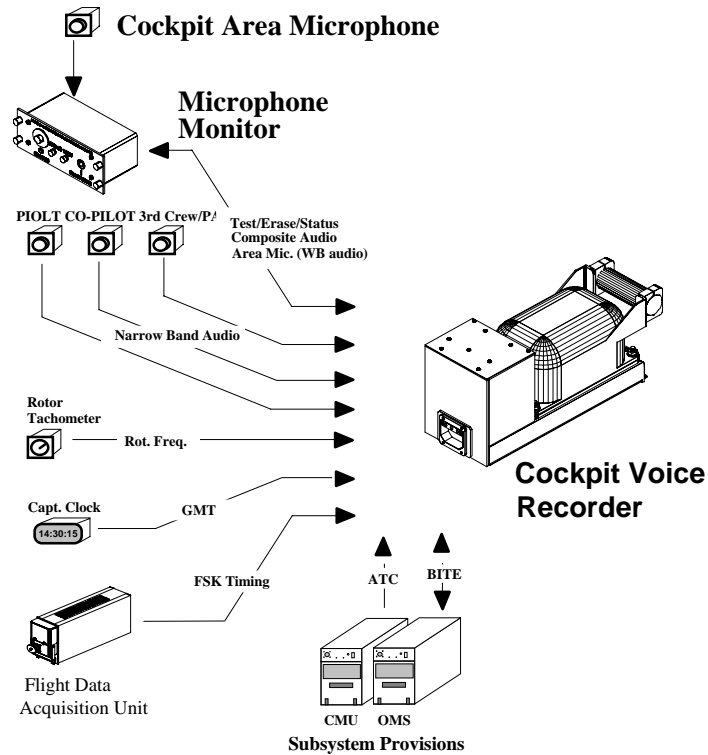
Figure 2 – Cockpit Voice Recorder System
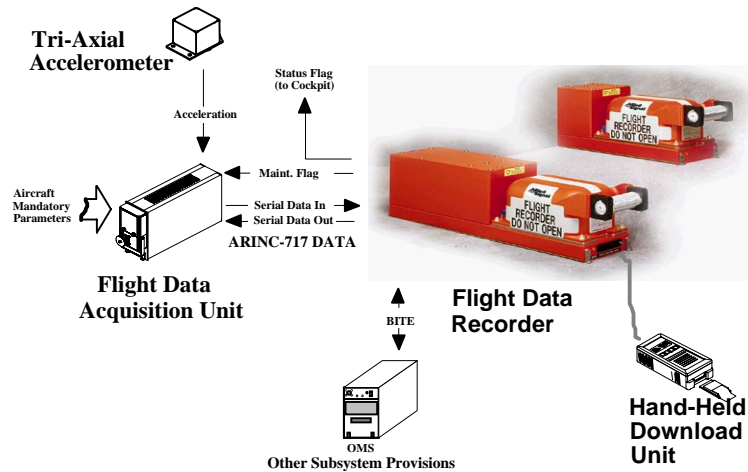
Figure 3 – Flight Data Recorder System

The 12 bit words can adequately manage the required resolution, accuracy and rate of change of modern aircraft systems and sensors. The latest generation of digital aircraft (the B777), using the 256wps rate, records approximately 870 parameters on the FDR. This FDR operates in an identical way to some of the older "11 parameter" FDR installations, where the FDAMS collects the sensor information.

The key element of today's airborne flight data recording systems is the FDAMS, which acts as the central processor for the remotely distributed sensors, discrete inputs and data-busses. As one of its outputs the FDAMS provides mandatory data to the FDR via a single ARINC-

573/717 data stream. This data stream may be configured per aircraft type or customer preferences and contains industry standard 12 bit words at rates of 64, 128 or 256 words per second. The FDAMS can typically provide the following inputs to interface with multiple systems and sensors:

- 60   programmable 3 or 4 wire inputs
- 127   discrete inputs
- 48   ARINC 429 DITS Ports
- 18   identification discretes
- 3   Marker beacon discretes
- 1   FDEP/STP Tx/Rx Port (429)

Evolving Systems and Data Availability

Aircraft system configurations are driven by operational, technical and regulatory requirements and further complicated, for international operators, by the fact that FAA and CAA/JAA requirements tend to overlap. Requirements will continue to evolve to enhance the safety of air travel, and safety improvements enforced due to lessons learned from little information on antiquated crash survivable media.

In the transition towards "Free Flight" where the Reduced Vertical Separation Minimum are implemented, the potential exists for an increase in TCAS Traffic and Resolution Advisories, along with Wake Vortex occurrences, hence the need to monitor the aircraft's Altitude Drift. Also, within the Cockpit, displays have evolved from basic round dial instruments to very sophisticated multifunction displays with living color and graphical displays in a bid to enhance aircraft situational awareness. This compounds the need of the Crash Investigator for MORE Data and the further expansion of the recording requirements "Funnel Effect".
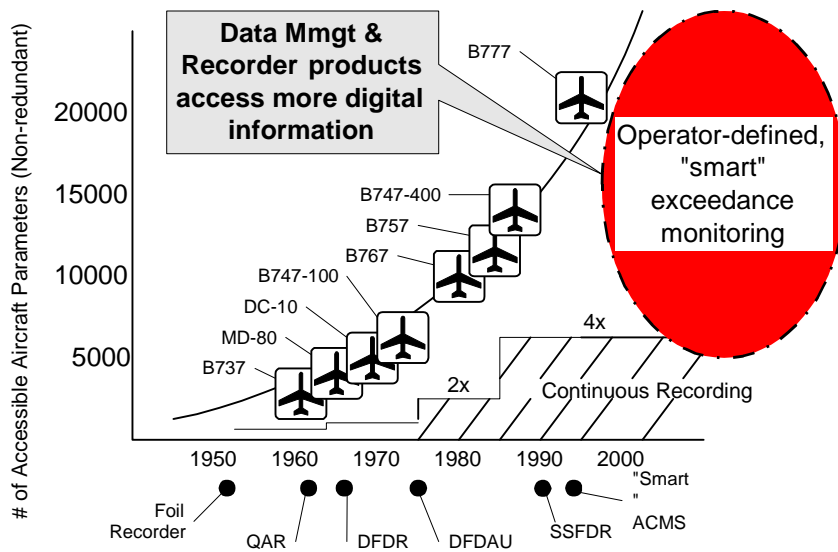

Figure 4 – Technological Advance of Airborne Recording Systems

Many systems have evolved as individual safety systems. In today's technological advanced aircraft, systems and sub-systems are combined within a single Line Replaceable Unit (LRU), for example the FDAU can now contain the ACMS, FDAMS and QAR functionality.

The Boeing 777 has a single avionics cabinet containing multiple systems interfaced with a single backplane – this is the future of airborne avionics.

COMBINED COCKPIT VOICE AND FLIGHT DATA RECORDERS

The subject of combining both cockpit voice and flight data information into a single crash survivable recorder has been discussed for some time. As a result of aircraft disasters in the late 1980s and early 1990s where one (or both) of the individual crash survivable recorders were destroyed, the NTSB recommended cancellation of the existing Technical Standard Orders (TSOs) in favor of newer TSOs (C 123 and TSO-C 124). These TSOs were based upon the more stringent crash survivability requirements of ED-55 and ED-56 Rev. A.

In 1992, an industry-wide meeting discussed ways to improve the probability of 100% post crash data recovery for both the cockpit voice and flight data information. AlliedSignal proposed that one way was to have combined recorders in a dual-redundant installation (i.e. two separate crash survivable recorders storing both the cockpit voice and flight data information) on the aircraft. Further, these combined recorders should be installed in vastly different locations on the aircraft, such that in a worst case scenario at least one of the recorders would be subjected to a less severe post-crash environment. Aircraft manufacturers agree with this basic philosophy, but have yet to implement a dual-redundant recorder installation on any commercial aircraft being currently produced.
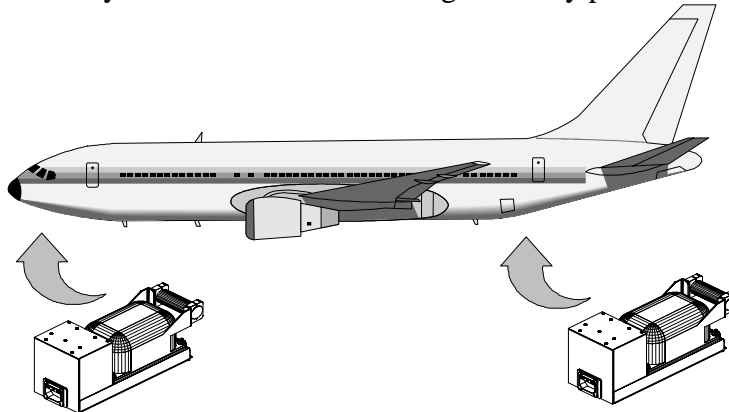
Figure 5 – Dual Redundant Recorders

Enhancing Data Survivability

In the interim, the industry has taken steps to improve the probability of 100% data recovery. First, it had been noted that in the majority of cases where the data has been unrecoverable after an aircraft disaster was due to a post-impact fire. It was also concluded that in many cases, the post-crash fire was not the short, high intensity scenario covered by qualification to the existing TSOs, but due to a much lower intensity, with substantially longer duration fire. Therefore EUROCAE, included the low intensity fire requirement (10 Hours at 260°C) into ED-56 Rev. A. The NTSB and FAA have also acted in increasing the existing high intensity fire survivability from 30 minutes to 60 minutes (50,000 BTUs, 1100°C) in TSO-C123a and TSO-C124a which superceded existing TSOs. in August of 1998

Recording System Maintainability

Another major cause of unrecoverable data (or a "poor" recording) after an aircraft disaster, is due to broken and/or damaged recorders which were unable to record the necessary information due to an internal or system level fault.

Historically, electro-mechanically-based CVRs and FDRs have suffered in terms of overall reliability and performance due to their basic design. Recording head and tape wear, motor belts and bearings, etc. will degrade over time in the severe environments encountered on commercial air transport aircraft. This cause has been dramatically improved by the introduction of all solid-state crash survivable recorders, where non-volatile memory devices have replaced the electro-mechanical tape based recording systems. Since there are no longer any moving parts in Solid State recorders, basic reliability (as expressed in Mean-Time-Between-Failures) has improved dramatically by at least 5-fold. Additionally, since there are no moving parts in the recording system, there is no degradation over time in the quality of the recording. In the past, the quality of the recording has been greatly effected by where in the "maintenance cycle" the recorder is when data is extracted from it (i.e. if it has been a long time since the last overhaul of the unit, head/tape wear, motor bearing wear, etc., will naturally cause a lower quality recording).

Accident Analysis with Solid State Recorders
Several recent accidents of commercial aircraft have demonstrated the effect of the Solid State Recorders. The AlliedSignal SSFDR and SSCVRs have performed flawlessly with 100% recovery and no errors in the data. In one particular investigation the NTSB started with a download of the SSFDR contents at 9:00 am and by 1:00 pm of that same afternoon a full animation of the final moments of the flight were available for review.
As a result of the survivability and maintainability of Solid State recorders the NTSB have released Safety Recommendations to mandate solid-state cockpit voice and flight data recorders by 2005, i.e. retrofitting of all tape based recorders to solid-state. Many commercial airlines are already doing this on their own based on economic (cost-of-ownership) arguments.
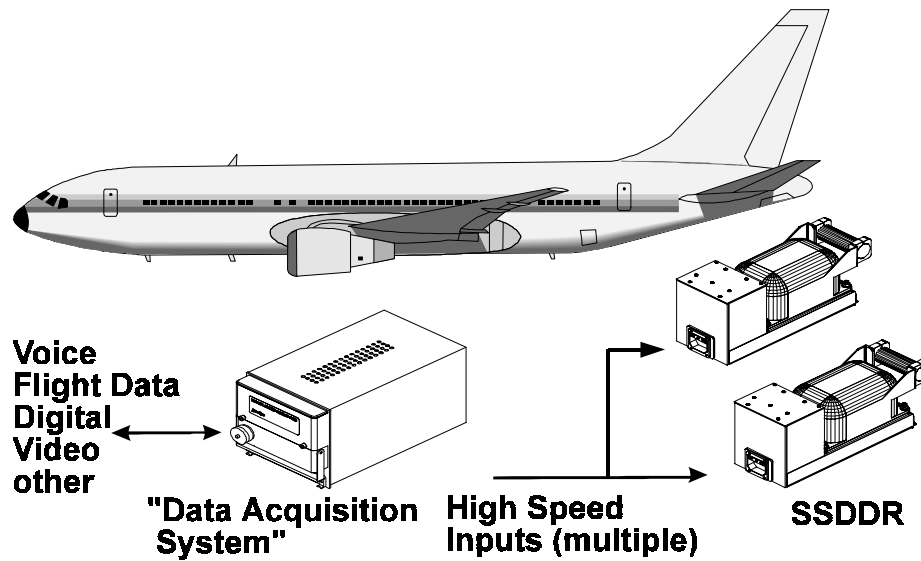

ADVANCED DIGITAL DATA RECORDING SYSTEMS

The industry (primarily EUROCAE WG-50) is presently developing specifications for recording of CNS/ATM systems information that, although not currently recorded, may be desirable to be stored in crash survivable recorders on-board the aircraft. Examples include:
- CNS/ATM digital datalink (replacing the historical voice radio link),
- Cockpit Video,
- Increasing number of mandatory flight parameters (to align with FAA requirements),
- Navigation and Surveillance information (future systems).
- Direct Digital Audio Inputs (in lieu of analog conversion and sampling)

There is continuing debate within industry on the benefits of adding some of these new information sources to the airborne crash survivable recorders. As already discussed, combining Flight Data and Cockpit Voice within a single unit is relatively simple, but may be quickly obseleted by any future recording legislation.
To avoid recurring changes to aircraft interfacing and the recorder itself; a new recording system philosophy is required. This new architecture can be an extension of the existing "Data Acquisition System" as the central processing component, accompanied by multiple high-speed serial interfaces to dual Solid State Digital Data Recorders (SSDDR).

Figure 6 – Solid State Digital Data Recorder (SSDDR) System

In this proposed new system the crash survivable recorders are reduced to simply recording digital information received on high-speed serial interface(s). The recorders need not know the specific source or type of information being recorded, but simply recording the digital data as it is received under a yet to be defined rule set. The processing of information and digitization would therefore take place in other avionics within the aircraft and transmitted to the redundant recorders. If developed suitably, this architecture can provide the following benefits:

1) Dual redundant Crash Survivable Recorders - Reduces airlines spares and logistic support and provides improved probability of 100% data recovery.
2) Crash survivable recorder need not require modification to meet changes in recording requirements.
3) Lower system cost - data processing and digitization process moved to highly integrated avionics subsystems (instead of the recorders themselves, which are subject to more severe operating environments)
4) Minimizing Installation costs by reducing wiring required for growth systems.
5) Eliminating the need to add other crash survivable recorders for additional information storage
6) Minimize cost impact for the recorder itself. The price of two redundant recorders would only be on the order of 50% more than the total price of today's separate FDR/CVR combination.

In this architecture, the crash survivable recorders need sufficient memory capacity and input bandwidth to handle current and future requirements,. Such a proposed architecture is a large deviation from today' s crash survivable recording system. Memory allocation could be software loadable to provide flexibility for operator customization as sub-components are added in future. The SSDDR memory partitioning could distinguish between data types and thereby enable selective data downloading.

2   Audio Inputs

For the Cockpit Voice Recorder the audio for each of the 4 Channel Inputs is provided as an analog signal to the CVR input. The source of this is the aircraft's Audio Summing Amplifier that interfaces the Flight Crew's intercom and direct voice communication systems. Within the CVR the analog is sampled, compressed and stored as digital information. Modern airborne audio systems have the capability to provide direct digital audio as the output. Hence the processing from digital to analog to digital can be eliminated and the digital audio fed directly to the CVR thereby providing a superior quality signal.

Avionic Local Area Networks

Recent system architectures and interfaces have employed the use of Local Area Networks, such as Ethernet (as defined in ARINC-646), within the aircraft. These architectures will assist in reducing software modification costs and development time for planned, incremental software upgrades which will provide system growth. It should be possible to update, modify or add functionality with minimal impact on other systems. This is the basis for the next generation of Enhanced Airborne Flight Recorder currently being defined by AEEC. LANs will provide significant growth margins and will utilize the bandwidth more efficiently than current databusses, with expected Data rate of greater than 100kbps.

Sustaining Data Recording in abnormal situations

It is always a source of debate as to how much more data could actually be recorded when the aircraft itself is falling apart (breaking wires, etc.). One step in the process is to move the recorder in or near the cockpit area so as to minimize the amount of wiring which could be "disconnected" during such a catastrophe. Operating Solid State Recorders from an independent power source is not an issue, but the major problem arises as to what other equipment must also still be operating in order for the CVR or FDR to be receiving data. With the current installation, the Cockpit Area Microphone is powered directly from the CVR. Therefore it seems reasonable to assume that there would be a good chance to keep recording from at least the cockpit area microphone . This is possible if the CVR were powered and it was located relatively close to the cockpit area, so as to maximize the probability of the interconnection (between the CVR and Control Panel/Area Microphone) remaining intact. For other audio to be recorded the radio communication panels, audio multiplexer unit, microphones, etc. would need to remain active. This is more unlikely due to the physical distribution of the components in the aircraft.

For the SSFDR, the case is completely different. Since the data is being obtained from a multitude or aircraft systems and sensors (with a lot of wire in-between) through the DFDAU (or equivalent), the likelihood of retaining a lot of the flight data for recording purposes after a major catastrophe (like TWA 800) is much more remote. However, like the CVR, the probability would be greatly improved if the SSFDR were also located near the Electronic Equipment Bay (where the DFDAU is located as well as most of the other LRUs with which it interfaces). In other words, the SSFDR is a very small piece of the flight data recording system, and that many other systems must be powered (with intact wiring, etc.) to get useful information.

Due to survivability characteristics, we know that the cockpit area is not the best place for crash survivable recorders. However, an improved installation would have dual redundant Solid State Digital Data Recorders (SSDDRs) with combined flight data, cockpit voice,

digital messages, and video. One would be located in the traditional area (in the aft of the aircraft), and the other near the cockpit area. Both could be supplied with an independent power source to allow for a few more minutes of recording after the main power can no longer be supplied (10 minutes is recommended by the NTSB). To provide maximum installation flexibility, the recorder form factor requires revision.

AlliedSignal have demonstrated, with their AR-Series recorders, which are TSO C-123a and C-124a compliant, that the recorder's physical size and weight, can be reduced dramatically from the current ½-ATR-Long format (19.6"L x 6.1"H x 4.8"W) and 18 – 20 pounds, to one of only 9.0"L x 5.5"H x 4.5"W and less than 9.0 pounds.

Figure 7 - Physical Size Reduction of Crash Recorders

The significant size, weight and power reduction makes the application of Solid State recorders for small aircraft particularly appealing. Thereby enabling the safety envelope to be increased.

Cockpit VIDEO Recorders

The development of Flight Instrument Displays and cockpit automation has increased the need of the Crash Investigator for Cockpit Video Recording.

While no doubt more efficient in controlling the aircraft than humans, computers do not ask the questions "Why.?" or "What.?", and could implement inappropriate modes or characteristics under unusual circumstances, and often in high workload situations. In several crashes the crew were either unaware of the systems potential responses or had given the system an incorrect command. There has also been CFIT events where the crew felt that the aircraft was performing in a perfectly normal manner. While all new automated systems follow the same general principles, pilot interfaces vary dramatically. A pilot can no longer "fly the gauges..". Similarly the Crash Investigators no longer have the remnants of the gauges to glean additional information as they try to piece the clues together.

Therefore a need for video recording of the main instrument panel is desired by both pilots unions (IFALPA) and accident investigators in order to correlate what is displayed with that recorded. From a human factors perspective the cockpit environment would also be informative, however pilot's unions do not as readily accept this. Pilots and safety officials agree that privacy legislation similar to current voice recorder laws would be needed to keep video footage protected from court cases and Freedom of Information Act requests.

The system requirements are being drafted by EUROCAE (WG50) and may be the basis of any future FAA/JAA considerations. Technical issues will include:-

- recording duration,
- resolution (sufficient to read multifunction displays to ensure proper data presentation),
- refresh rate (frames per second recording),
- color or monochrome images,
- number of cameras and coverage (2 or 3 may be needed to view the front instrument panel, and another may view the overhead panel).
- suitable data compression techniques,
- capacity – dependent on the above listed factors.

Crash Recorders Growth Potential

Operator concerns over existing airborne recording systems can be readily accommodated by a new architecture and software functionality, which provides incremental growth and the proposed Solid State Digital Data Recorder system.

Certifying agencies could ensure recording requirements for new systems are established during development. Conceivably as new aircraft systems are developed, the relevant information (from ANY new system that has an airworthiness effect) could automatically be added to the recording system.

Incremental expansion of FDR frame size could take account of increasing memory density, without the need to double the recorder frame size each time expansion is required, as with current philosophy.

Some ARINC 429 labels should be reserved for the output of information to the flight recorder, and FDAMs manufacturers could then ensure the mapping of these labels to spare data words. Designers of new systems would then be required to ensure that flight recorder data was broadcast on these labels. The installer would then only need to connect to the data bus in order to add the parameters to the recorder.

Calibration checks should combine the review and analysis of recorded data with on aircraft calibration checks.

The installation of dual combined units in lieu of the single recorder systems provides a solution to operating with a single unserviceable recorder for extended time periods.
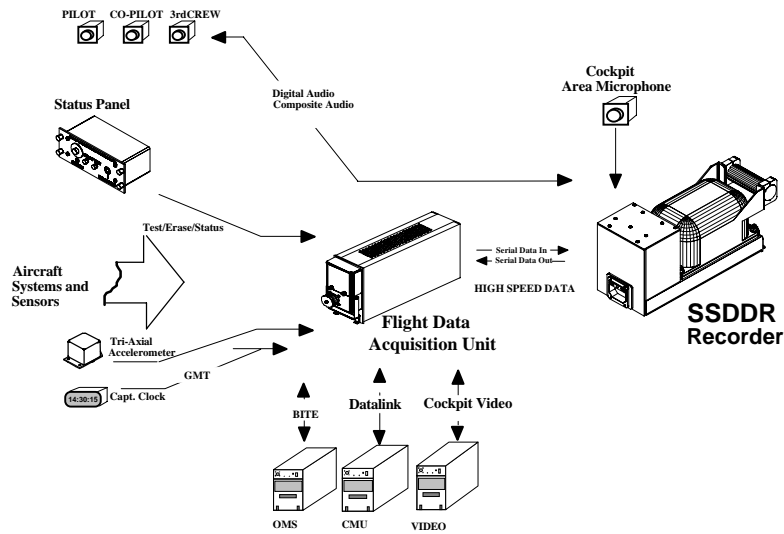
Figure 8 - Enhanced Airborne Recording System

CONCLUSION

The introduction of much more reliable and crash survivable solid-state recorders into the commercial air transport fleet will greatly improve the probability of 100% data recovery after an aircraft disaster. A new and radical recording architecture can readily include the benefits of identical and redundant crash survivable recorders, and provide growth to add new requirements, and recording systems or components with minimal impact to the overall system. Basing the architecture on a Flight Data Acquisition Management System as the central processing component with multiple high-speed serial interfaces to the Solid State Digital Data Recorder (SSDDR) enables a relatively inexpensive solution.

Solid State technology also provides the potential for increasing the Flight Safety envelope by providing recorders of smaller size, weight and power for smaller aircraft not currently required to carry crash recorders.

Preservation of valuable information is also readily provided by the co-location of the primary Recorder and Cockpit Area Microphone.

Elimination of the frustrating requirements funnel effect of constantly updating the crash recording system can be made simple and straightforward for operators, crash investigators, aircraft manufacturers, installers, designers and recorder manufacturers.

References

1) Proceedings, 14th AIMS Symposium, Sept 15-17, 1987; "The Role Played by FDR in Understanding Windshear Phenomenon" by D.Grossi (NTSB).

2) Royal Aeronautical Society Proceedings; Recording Aircraft Accident Data, 20-21 Oct, 1997.

3) "Black Box" by Vanda Sendzimir; Invention and Technology; Fall 1996

4) National Transportation Safety Board – Safety Recommendation ; A-99-16 through –18; dated March 9, 1999

List of Abbreviations

AIMS	Aircraft Integrated Monitoring System
ARINC	Aeronautical Radio Incorporated
ATC	Air Traffic Control
ATM	Air Traffic Management
CAA	Civil Aviation Administration
CAB	Civil Aeronautics Board
CFIT	Controlled Flight into Terrain
CNS	Communication, Navigation and Surveillance
CSMU	Crash Survivable Memory Unit
CVDR	Cockpit Video Digital recorder
CVR	Cockpit Voice Recorder
DFDAU	Digital Flight Data Acquisition Unit
DFDR	Digital Flight Data Recorder
DITS	Digital Information Transfer System
EE Bay	Electronic Equipment Bay
EGPWS	Enhanced Ground Proximity Warning System
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FDAU	Flight Data Acquisition Unit
FDAU	Flight Data Acquisition Unit
FDEP	Flight Data Entry Panel
FDR	Flight Data Recorder
GPWS	Ground Proximity Warning System
IHAS	Integrated Hazard Avoidance System
JAA	Joint Aviation Administration
MTBF	Mean Time Between Failures
NTSB	National Transportation Safety Board
QAR	Quick Access Recorder
RNAV	Radar Navigation
RVSM	Reduced Vertical Separation Minimums
Rx	Receiver
SSCVR	Solid State Cockpit Voice Recorder
SSDDR	Solid State Digital Data Recorder
SSFDR	Solid State Flight Data recorder
TCAS	Traffic Alert and Collision Avoidance System
TSO	Technical Standards Order
Tx	Transmitter
WG-50	Working Group No. 50 (EUROCAE)