THE TECHNICAL DEVELOPMENT AND IMPORTANCE OF AIRCRAFT RECORDING SYSTEMS FOR AIR SAFETY INVESTIGATION

Author: Mr P. Mayes, C.Eng, F.RAe Soc, M.ISASI
Chairman Flight Recording Working Group,
International Society of Air Safety Investigators
Canberra, Australia

Introduction

"Truth is never more important than in aeroplane accident investigation, where half-truths, the product of cursory, incomplete or ill-conceived and loose thinking, may place the lives of men and the future of aeroplanes in jeopardy".

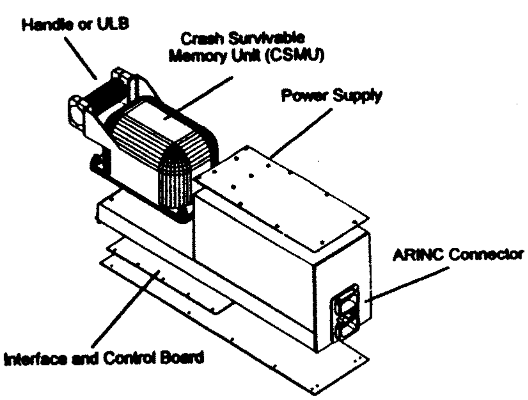
The lecturer continued with: "Take the modern aeroplane. It requires tens of thousands of drawings even to build it, miles of electrical cables, large areas of metal sheeting, thousands of rivets and screws, dozens of boxes of radios, electronics and other equipment, all in themselves made up of many parts.

Now, crash that aeroplane into the ground and the product is up to half a million separate fragments, each fragment bearing boundaries never produced by man".

So spoke Fred Jones (1) of the Royal Aircraft Establishment, Farnborough, England in 1968, one of the foremost wreckage analysts in the world. However with the development of turbine-engined aircraft, which operated at higher altitudes and faster speeds than their piston powered predecessors, the task of accident investigation became increasingly difficult when relying on conventional wreckage examination techniques. Aircraft and their systems have kept pace with the evolution of technology so that today aircraft have fly-by wire control systems, electronic instrumentation, complex flight management systems with enormous computing power and advanced composite structures. In the event of an accident involving a modern aircraft there is only minimal information to be gleaned from the wreckage examination. It is in this regard that the role of the flight recorders has become fundamental to successful accident investigation and to improvements in air safety.

Almost every jet powered aircraft in regular public transport operations today is fitted with two crash protected flight recorders. The Cockpit Voice Recorder (CVR) records the audio environment on the flight deck while the Flight Data Recorder (FDR) records the aircraft operational and systems data.

FIGURE 1
FLIGHT RECORDER



This paper examines the development of

flight recording for air safety investigation, outlines the main regulatory milestones, explains the changing technology used in flight recorders and provides examples of how flight recording has been instrumental in accident investigation.

Regulatory History

The first Civil Air Regulation in the United States of America for flight recorders was called Amendment 100 and it became effective in April 1941 (2). It was a very simple regulation requiring that altitude and radio transmitter operation (on and off) should be recorded. The date for compliance was subsequently revised three times until it was rescinded in June 1944. The Civil Aeronautics Board (CAB) took the action because of maintenance difficulties and lack of replacement parts because of the war effort.

In September 1947 the CAB introduced a new requirement for flight recorders to be fitted in aircraft with a maximum take off weight of 10,000 pounds or more, which recorded altitude and vertical acceleration. However, there were no instruments available of proven reliability to meet the requirement and the CAB again rescinded the requirement on 1 July 1948.

During the next nine years the civil aviation authorities met with industry representatives and developed a better definition of flight recorder requirements in conjunction with the development of suitable hardware. Finally in August 1957 the CAB adopted regulations requiring FDRs to be installed after July 1958 in all aircraft over 12,500 pounds weight, that would be operated in air carrier service above 25,000 feet altitude. The parameters to be recorded were airspeed, altitude, direction, vertical acceleration and time (commonly termed the basic five parameters). In September 1959 the regulations were refined to establish a minimum retention period of 60 days and to define that the recorder should operate continuously from the take-off roll to the end of the landing roll.

In 1966 the United States introduced the requirement for a CVR to be fitted in conjunction with the FDR. The CVR was required to record all radio communications to and from the aircraft, interphone communications between the crew, sounds from the flight deck and signals identifying navigation and approach aids. An additional (sixth) parameter, radio transmitter operation (off and on), was added to the FDR to provide for correlation between the two recorders.

September 1969 was a significant milestone in aviation history, and for flight recording. This was the date of the certification of the first wide-body transport aircraft (the Boeing 747). The United States introduced a regulation that all large aircraft certificated after 30 September 1969 and all turbine-engine powered or certificated for operation above 25,000 feet, should be equipped with expanded parameter recorders. The additional parameters included lateral acceleration or side slip angle, pitch and roll attitudes, pitch turn position, control or control surface position for pitch, roll and yaw, thrust of each engine, position of each thrust reverser, trailing and leading edge flaps or cockpit flap control positions and angle of attack (if available) (3).

Following four accidents where the flight data recorder could not be recovered because the wreckage was in deep water and could not be located, a requirement was introduced in 1974 for each recorder to be equipped with an approved device to assist in locating the recorder under water. This device is referred to as an Underwater Locator Beacon (ULB).

Flight recorder requirements remained essentially unchanged in the USA until 1988 when the Federal Aviation Administration (FAA) issued a comprehensive package of recorder rule changes. These changes followed from numerous recommendations made by the National Transportation Safety Board (NTSB) because of difficulties with the existing recorder equipment and deficiencies in essential flight data required for complete accident analysis. The changes included: the elimination of old technology flight data recorders on "narrow body" jet powered transport aircraft; the increase in the number of mandatory parameters to 28 on aeroplanes with digital databuses; the addition of a highly desirable (non-mandatory) parameter list; the expansion of the requirement to include smaller multi-engine, turbine-powered aircraft carrying 10 to 19 passengers; the inclusion of rotor craft in the requirements; and the modification of the cockpit audio recording to improve the recording of conversation between crew members (4).

In parallel with these developments in the United Stated, many countries in Europe and other parts of the world, introduced similar flight recorder requirements. For example, on 10 June 1960 a Fokker F27 aircraft crashed while attempting to land at Mackay in Queensland, Australia. All 29 people on board died in the accident and the board of inquiry was unable to determine any definite factors underlying the accident. They recommended that all Australian turbine-powered transport aircraft over 5,700 kg maximum take-off weight (MTOW) should be equipped with a CVR and a FDR. The requirement was implemented in 1961 so that Australian registered aircraft were some of the first to carry CVR's (5).

The International Civil Aviation Organisation (ICAO) publishes standards and Recommended Practices for flight recorders (Annex 6 and Annex 13). In 1986 a panel of specialists significantly updated the international standards for flight recorders to include a requirement for 32 parameter FDR depending upon the size and complexity of the aircraft. Other requirements covered smaller transport aircraft and rotor craft.

In 1995 ICAO convened a Flight Recorder Panel (FLIRECP) to review the flight recorder requirements and develop suitable recommendations, to update the Annexes. It was agreed that there should be common flight recorder requirements for all air transport aircraft above 5,700 kg, MTOW, rather than the current arrangements of differing requirements based on a 27,000 kg limit. An expanded parameter list was suggested for future introduction which reflected the complexity of aircraft operation, the sophistication of the aircraft systems and the use of new technology such as "fly by wire". Under some circumstances the mandatory parameter requirements could exceed one hundred. In conjunction with these developments the panel recommended that the duration of the CVR recording should be extended from 30 minutes to 2 hours (6).

Technical Development of Recorders

The United States Federal Air Regulations stipulate how the flight recorders should be fitted to the aircraft, from which bus they should receive their power, the range, accuracy and recording interval of the parameters to be recorded and the technical standard (TSO) specifying the minimum performance standard (7). The TSO's specify in particular the environmental conditions in which the FDR and CVR shall operate, the impact and penetration resistance, static crush, fire and water protection to ensure that the record can be retrieved and analysed. An important criteria is that the external case must be either bright orange or yellow with strips of reflective tape. This criteria remains unchanged.

The TSO requirements have been developed in the light of accident experience (see Table 1) so that the current flight recorders have to be able to survive accident conditions such as a high intensity fire (1100 C) for one hour, a 10 hour low intensity fire and a 3400 g impact deceleration (8).

TABLE 1
CRASH SURVIVAL REQUIREMENTS

	1965	*1995*
IMPACT	1100g,5ms	3400g, 6.5 ms
PIERCE	500lbs, 10ft	500lbs,10ft (hardened)
FIRE	1100°C, 30 mins	1100°C, 60 min + bake, 10hours
CRUSH	5000lbs, 5 mins	5000lbs, 5 mins
SEA WATER	36 hrs	9ft, 30 days
DEEP SEA	nil	20,000 feet

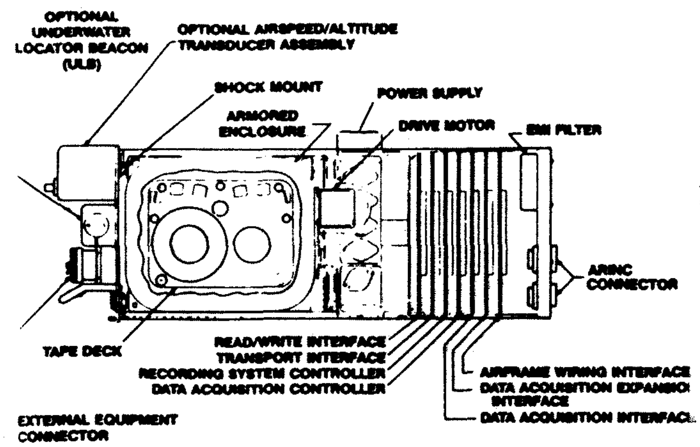
The original flight data recorders introduced from 1957 were of the oscillographic type that engraved the four parameter traces (altitude, airspeed, magnetic heading and vertical acceleration) on metal foil as a function of elapsed time. A binary stylus also recorded radio transmitters (microphone) keying. One type utilised Inconet foil as the recording medium which because of the high melting point of this metal provided the necessary fire protection. The other main type of FDR at that time, utilised aluminium foil as the recording medium. This required thermal protection which was provided in a spherical shell enclosing the recording medium.

The readout of these oscillographic records was extremely time consuming and manpower intensive. The metal foil was loaded on a special readout table and the engravings on the foil measured by examination through a 35-200 power microscope. Each engraving had to be measured in relation to its distance from a reference line and from an arbitrary start time. The X, Y, co-ordinates so developed had then to be converted to parametric information using known calibration tables.

The oscillographic FDR's suffered from two significant disadvantages. The physical size of the metal foil restricted the number of parameters which could be accommodated. The majority of the recorders were of the five parameter type although there were some modules with eight parameters. The second disadvantage was that they were electromechanical devices which required frequent maintenance to ensure that the foil moved evenly and at the nominal speed. As the FDR's aged, the reliability and accuracy of the data deteriorated.

While the three main equipment manufacturers in the United States were producing oscillographic type recorders, there were early models of digital recording devices designed in Europe and Australia and manufactured in Europe and Canada. These devices used digital encoding techniques on to wire or metal tape. The advantages of digital recording devices included greater reliability, less maintenance and ease of replay. These provided the opportunity to record a greater number of parameters at increased frequencies.

FIGURE 2
DIGITAL FLIGHT DATA RECORDER



With the demand for increased parameters primarily to meet the requirements of the wide-body aircraft, the United States equipment manufacturers introduced Digital Flight Data Records (DFDR). The DFDR's were designed to the ARINC characteristic 573 and recorded digital information on crash and fire protected magnetic tape. Whereas the oscillographic type recording had a finite recording duration of approximately 300 hours the DFDR used a continuous loop system to provide 25 hours of recording in accordance with ARINC 573.

Data older than 25 hours is erased and replaced by new data.

The early model FDRs took raw data from the aircraft systems. For example pitot and static pressure was feed directly to connections on the FDR and then converted to airspeed and altitude signals within the FDR. Although there are still some models which have this capability so that they can be fitted to small non-complex conventional aircraft, the majority of recorders are now part of an extensive flight data monitoring and acquisition system within the aircraft electronics architecture. The flight data acquisition units sample the data and send the data to the FDR in a serial format.The format of the data on the magnetic tape is such that each second of data is called a subframe with four subframes per frame. The first part of any subframe is a synchronisation (sync) word which lasts for 1/64 of a second and signals the start of the subframe as well as providing identification for the particular subframe. Each word comprises of 12 bits. The remaining 63 words in each second can be utilised to record 10 or 12 bit variable data and single bit discrete data.

A given word slot in the subframe may contain the same parameter as in the other subframes, or it may contain a different parameter in each of the four subframes, or it may contain the same parameter in every other subframe. In this way a parameter may be recorded with a frequency varying from four times per second to once per 64 seconds. In fact by utilising two evenly spaced word slots, the frequency can be increased to eight samples per second such as that required for vertical acceleration data.

The flexibility of the ARINC 573 characteristics provided the operators and the accident investigators with a major improvement in flight recording. The mandatory parameters could easily be accommodated and the aircraft manufacturers offered operators various additional parameter options. In excess of one hundred variable and discrete parameters could be recorded. Discrete parameters are bi-state data such as microphone keying, autopilot engagement and undercarriage squat switch.

The replay of DFDR tapes is a semi-automatic process using special constructed tape decks and interface equipment. Alternatively the DFDR can be powered-up in a replay mode and the data extracted through the interface equipment. The magnetic tapes are first played on special electronic hardware that amplifies the recorded signal, shapes it, recognises the sync words, and puts the data stream into computer compatible format (the data are recorded on the DFDR tape in a waveshape called Harvard biphase code).

Computer software had to be programmed to match the parameter configuration specified by the operator for particular aircraft type. And the ease of modification of the date format meant that in some instances operators would reconfigure the non-mandatory parameters to meet special aircraft development requirements.

Although there were some technical difficulties with the early model DFDR's these were quickly remedied. DFDR's provided the major recording capability through the 1970's and 1980's. Some countries introduced mandatory requirements to replace the older FDR's with DFDR's because of their improved reliability and accuracy.

With the introduction of "digital" aircraft with "fly by wire" control systems, digital databuses, electronic flight instrumentation ("glass" cockpits) the amount of data available for recording, and the ease with which it could be recorded, demanded additional specifications.

The manufacturers had begun work in solid state recording devices (SSDDR) in the 1980"s and these units became available in

1990. Externally they looked similar to previous models as they had to meet the existing ARINC 573 and 717 characteristics. However, internally they were very different. A typical SSDDR has an armoured memory module containing 24 to 64 megabits of memory in 1 megabit devices. The memory chips are contained in a second internal steel enclosure, surrounded by fire protection material and embedded in a gel to prevent sea water corrosion and to withstand exposure to other materials. The memory life is in excess of 25 years, more than 10,000 write/read cycles. Most units use data compaction to reduce the memory requirements by factors of 2 to 5 depending upon the flight dynamics. For example, only data changes may be recorded with a full parameter (baseline) value captured every 256 seconds.

Extensive BITE is incorporated to continuously monitor all the main functions including a "read after write" data verification. Defects in memory can be transparent, alternate memory locations being used and extra memory provided for. The failure of a complete chip will reduce the total storage time but will not cause loss of data. No scheduled maintenance is required for these new generation recorders and the ULB can have a six year life lithium battery(9).

Their main advantages of solid state recorders, from an aircraft operator perspective, are that they are virtually maintenance free and that the data can be easily extracted. They have reasonably sophisticated bite to warn of a data recording failure memory failure or loss of data stream. They have the recording capacity of the DFDR but use data manipulation or data compression techniques.

Cockpit Voice Recorder

The basic design of Cockpit Voice Recorders has, until very recently, remained unchanged since their introduction thirty years ago. The conventional CVR is a four channel, crash-survival type tape recorder that records the total audio environment on the flight deck. The units use a closed loop recording method so that they only retain the last period of operation. When the first requirement was introduced in Australia it called for a 60 minute recording duration. However, when the United States introduced its requirement five years later, the duration was 30 minutes. Subsequently, the Australian requirement was changed to 30 minutes in the interests of standardisation and reducing costs to the operators.

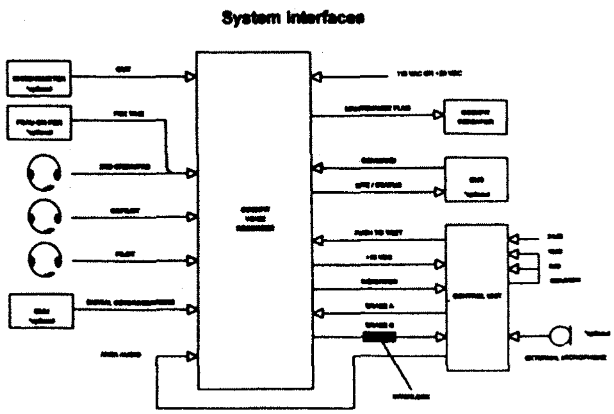
The CVR typically records all the audio signals picked up by the flight crew headset microphones, the captain's on one channel and the first officer's on another channel. An omni-direction cockpit area microphone (CAM) must be mounted remotely usually on the overhead panel to provide the total flight deck audio environment. This is recorded on a third channel. The fourth channel is used for additional flight crew positions and public announcements made by the flight crew to the passengers.

This recording arrangement provides an ideal recording of the flight deck aural environment, with the source of any transmissions or conversation easily determined from the channel on which they are recorded. The requirement to record the flight crew headset microphone was initially introduced in Europe. Previously conversation between the flight crew had to be discerned from the CAM channel. This was less than ideal in most circumstances due to the high ambient noise from airflow, systems and powerplants.

The latest CVR models now utilise solid state technology. When the audio signals are received they are digitised, time coded and compressed before storing in memory. The air safety investigator has to rely on the equipment manufacturer's design to ensure that the audio signals can be regenerated adequately and in correct time sequence.

The benefits of solid state CVR's are that there is almost negligible maintenance and there is improved reliability of the recording system.

FIGURE 3
COCKPIT VOICE RECORDER SYSTEM



Accident Investigation Experience

The first FDR's of the 1960's and early 1970's recorded the basic four flight parameters so that the flight path of the aircraft could be determined. The CVR was instrumental in providing the investigators with information about flight crew actions and responses. Often, why the aircraft achieved the flight path was determined from the CVR.

Depending upon the complexity of the occurrence, the information derived from the flight path and the CVR was sufficient to determine what happened and why it happened. A good example of the CVR providing clues to the cause of an accident was the investigation of a Lockheed L1011 accident near Miami, Florida in December 1972. The CVR record indicated that the flight crew became so preoccupied with a malfunction of the nose landing gear position indicating system that they failed to notice that the auto pilot altitude hold had disconnected, allowing the aircraft to descend and crash.

Not all accident investigations are as straightforward and the FDR, as well as the CVR, becomes critical to the success of the investigation. Unfortunately, the limitation of the earlier standard FDR's has been very evident in two recent accidents.

The Boeing 737 is one of the most popular narrow body aircraft in airline operation. The later models in production today bear the same designation as the first models produced in 1967 but apart from their external appearance have little else in common. Systems, structures, equipment, instrumentation, powerplants, have all been updated. However because of the common designation the later Boeing 737's did not have to have expanded parameter FDR's.

In March 1991 a Boeing 737-200 on a scheduled flight to Colorado Springs, USA was observed to roll inverted and impact the ground short of the runway on the landing approach. The basic five parameter FDR only provided conformation of the observed flight path. The events occurred so quickly that the CVR recording of the flight crew comments did not provide any clues to the cause of the loss of the control. After extensive trials, simulator runs, theoretical calculations, no definite reason for the loss of control could be determined.

In September 1994 a Boeing 737-400 on approach to Pittsburgh, USA, similarly rolled inverted and impacted the ground. In both cases the structural deformation was extreme and the conventional wreckage examination could not determine any reason for the loss of control. Again the CVR did not provide any clues to the occurrence as the flight crew were taken by surprise. The FDR in this second case was a later DFDR model but only recorded eleven parameters(see table 2)

Although this allowed certain possibilities to be discounted, the engines continued to operate normally for example, a critical feature was missing. There was no

TABLE 2
BOEING 737-400 PARAMETER FIT

TIME	PITCH ATTITUDE
ALTITUDE	ROLL ATTITUDE
AIRSPEED	ENGINE THRUST
HEADING	VERTICAL ACCELERATION
TIME OF RADIO TRANSMISSION	
CONTROL COLUMN OR PITCH CONTROL SURFACE	
CONTROL WHEEL OR LATERAL CONTROL SURFACE	

recording of the position of the flight control surfaces so that it was not possible to determine how the aircraft became inverted. After eighteen months and thousands of manhours, the investigation team still have not been able to determine why the accident occurred.

In contrast, a recent accident involving a Boeing 757 aircraft illustrates how the later DFDR and CVR, built to the modern crash survivability criteria, with ULB's, were paramount in providing all the information required for the investigation. On 6 February 1996 a Boeing 757 with 176 passengers and 13 crew departed the Dominican Republic for a flight to Berlin and Frankfurt in Germany. After a night take-off from Puerto Plata, the aircraft was climbing through 7000 feet when the crew called the approach controller to report that they were returning to the airport. The aircraft was observed on radar to descend rapidly and crash into the sea. No other information was given by the flight crew.

This particular aircraft was first registered in 1985 and was equipped with a DFDR, recording 70 parameters(see Table 3) and a CVR.

Both recorders were fitted with ULB's. The United States Navy were asked to assist in locating the wreckage. The ULB's provided a reliable sonar signal which allowed the location to be identified at a depth of 7000 feet, on the edge of a deeper seabed trough.

TABLE 3
BOEING 757 PARAMETER FIT

AIRSPEED ALTITUDE RADIO HEIGHT
LATERAL/LONGITUDINAL/VERTICAL ACCELERATION MACH
PITCH ATTITUDE ROLL ATTITUDE
SIDESLIP/DRIFT VHF TRANSMISSION
ENGINE EPR/THRUST/N1/OIL TEMPERATURE
ELEVATOR/AILERON/RUDDER POSITIONS
PITCH TRIM POSITION/ ANGLE OF ATTACK
CONTROL COLUMN/RUDDER PEDAL POSITION
ALL WARNINGS AND EICAS MESSAGES
UNDERCARRIAGE POSITION/BOGIE TILT
THRUST MANAGEMENT COMPUTER/MODES/STATUS
AUTOPILOT STATUS/MODES ENGAGED
LEADING EDGE/FLAP SELECTION AND POSITION
NAVIGATION INSTRUMENTATION/MARKERS
GPWS/TCAS WARNINGS
AIR DATA COMPUTER SELECTION
INERTIAL NAVIGATION DATA

The next phase was to organise a recovery team with a deep sea submersible capable of descending to depths in excess of 7000 feet. When the recovery ship was on station, the submersible was launched and it quickly homed in on the general area of the wreckage from the ULB signals. Video from the submersible showed the complete destruction of the aircraft with the main identifiable portion being the tail cone with the fin and elevator still attached. The remaining structure had been extensively destroyed with only the wing centre box section identifiable. The flight recorders on the Boeing 757 aircraft are located together above the cabin at the rear of the pressure bulkhead. That area was unidentifiable from the wreckage. However the submersible began specific tracking to the ULB signals and the CVR was easily found laying exposed on the seabed in an area some distance away from the tail cone and wreckage. The bright red colour made it easily discernible against the grey silt background. After capturing the CVR in one of the submersible's mechanical arms the signal from the DFDR ULB was traced to an area of the wreckage.

The DFDR was not visible and the other arm was used to move the wreckage aside. The powerful spotlight on the submersible then picked up a reflection from the reflective tape on the outside of the recorder. The DFDR was then quickly retrieved and the two recorders brought back to the recovery vessel from which they were transported speedily to Washington for reply and analysis. Within 24 hours the data and audio had been replayed and analysed, revealing that the aircraft had experienced a relatively simple problem peculiar to this aircraft and did not indicate a systemic problem affecting other aircraft. The very expensive recovery operation was curtailed without any wreckage having to be recovered and no safety or restrictive action required regarding other aircraft of the same type.

Both recorders had survived the high impact forces although the exterior cases showed evidence of deformation and penetration. They had then withstood immersion in salt water for four weeks at a depth of 7000 feet, and the ULB's had operated providing the key to the location.

The evidence from the CVR indicated that the captain's airspeed indicator (ASI) was giving erroneous readings during the take-off. The DFDR data showed that the centre autopilot was engaged two minutes later. This senses airspeed data from the same source as the captain's ASI and as height increased the speed over-read significantly. The autopilot consequently increased the pitch attitude to reduce speed. The first officer stated that his ASI was reading markedly lower values which were decreasing. The DFDR also indicated that the captain took no action to transfer his air data instrument source (a selection switch monitored by discretes on the DFDR). The recorders graphically recorded the ensuing confusion, the sound of the aircraft stalling and operation of the stick shaker to impact. The DFDR positively showed that the aircraft was out of control for nearly 2 minutes but that the engine and aircraft systems were consistent with the various manoeuvres. The anomalies in the airspeed were consistent with an obstruction in one of the airspeed sensors.

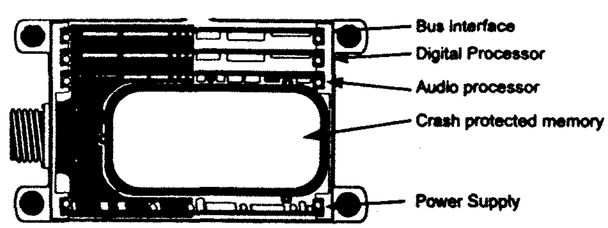
Future Developments

The ICAO Flight Recorder Panel considered several of the developments in recorder technology, and applications which are likely to occur by the end of this century.

The introduction of digital communications as part of the Future Air Navigation System (FANS) has serious implications for the investigator. No longer will communications between the aircraft and the controller be audible. The necessity of recording the content of these digital messages,and the time that they are displayed, was emphasised . The most suitable place would be the CVR as there will be spare memory because of the reduction in aural communications.

Video recording on the flight deck has been discussed for some 15 years. The electronic flight instrumentation has large quantities of numerical data, symbology and display options for the flight crew. Even with the data capabilities of the expanded FDR's it is not possible to record all the possible information. Consequently a video recording of the electronic flight instruments would be a means of retrieving the actual information displayed (11).

FIGURE 4
COMBINED AUDIO/DATA RECORDER



With these developments the flight recording designers and manufacturers are considering a solid state recorder which could accommodate all these sources of data in one unit: flight parameter data, audio data, digital communications, video recording, aircraft systems status, maintenance and system health data.

Conclusions

The main milestones in the development of the civil regulations relating to the crash protected flight data and cockpit voice recorders have been reviewed. In a period of thirty years, the equipment design and technology has evolved from simple oscillographic recording devices to complex solid state recording systems. The simple FDR's allowed the basic flight path of the aircraft to be determined but little else. The modern DFDR's record well in excess of one hundred parameters to provide a record of the various systems, the control inputs and control surfaces. In this way the flight crew actions, the flight management computer interpretation of those actions and the resulting control responses are recorded so that the investigator can examine the total system.

Examples of serious accidents which have not been successfully completed were used to illustrate how the investigator is hampered unless the aircraft is equipped with a comprehensive recording system. A recent accident involving a Boeing 757 was quoted as an example of the paramount importance of the FDR and CVR, their survival of severe impact, of penetration and of deep immersion and the importance of the design criteria for locating the units under water.

The role of flight recording will increase in the future as aircraft become more complex, the system software more sophisticated and technology changes with greater reliance on digital communications.

References

1 Air Crash, The Cause is in The Wreckage, F. Jones, ISBN 0863790941

2 History and Development of Flight Recorders, January 1966, Civil Aeronautics Board BOSP 7.6.1

3 The Status of Flight Recorders in Modern Aircraft, Carol Roberts, Journal of Air Law and Commerce, Vol43 Issue 2,1977

4 The New US Flight Recorder Regulations, D.R.Grossi, Proceedings of teh 15th Symposium "Aircraft Intergrated Monitoring Systems", September 1989

5 Black Boxes, N. Campbell, Asia Pacific Air Safety Journal, Issue 5 October 1993

6 Development of ICAO New Standards and Recommended Practices, P. Mayes, Proceedings of 25th ISASI Annual Seminar, Paris, 1995

7 Flight Data Recorder Readout Experience in Aircraft Accident Investigations 1960-1973, National Transportation Safety Board, NTSB-AAS-75-1

8 Solid State Flight Recorder Evolution, W. Hardman, ISASI Annaul Seminar Proceedings , Canberra, 1991

9 Solid State Flight Data Recorder and its Support Equipment, H. Napfel, ISASI Annaul Seminar Proceedings , Canberra, 1991

10 A New Digital Flight Recorder, F. Earl Kabel, ISASI Forum Winter, 1980

11 Control Cab Video Recorder, W. Schumets, ISASI Forum Winter, 1981

12 Flight International Number 4516 Vol 149, 27 March 1996