

Developments in Flight Recorder Equipment and Analysis

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Neil graduated in 1983, with a Bachelor of Engineering degree (Electronics), from the University of Western Australia. In 1986 he joined the Bureau of Air Safety Investigation as a flight recorder specialist. Neil took leave of absence in 1994-1995 and managed the flight data analysis program for Gulf Air in Bahrain. During 1998 he was a member of the ICAO Flight Recorder Panel that developed changes to ICAO Annex 6. In February 2000, Neil joined the Corporate Safety Department of Cathay Pacific Airways Limited in Hong Kong. During 2001 and 2002 he held the position of Manager Air Safety. In December 2003 he rejoined the Australian Transport Safety Bureau as a Senior Transport Safety Investigator.

1. INTRODUCTION

This paper describes developments in flight recorder equipment and analysis techniques from an Australian perspective. Australia was the first country to require cockpit voice recorders (CVR's) to be fitted to transport aircraft (1 January 1963) and one of the first to require flight data recorders (FDR's) to be fitted.

2. ACCIDENT HISTORY

No recorders were fitted to the aircraft involved in the following accidents. This resulted in a lack of evidence for the investigating team and uncertainty in determining the contributing factors.

26 June 1950 **VH-ANA** **DC-4** **near York, WA**

The aircraft departed Guildford Airport, Perth en route to Adelaide and Melbourne. It crashed some 12 minutes later with the loss of 29 lives. Although the cause of the crash was never truly identified it was suspected that it was due to engine failure caused by an open cross-feed drain valve.

10 June 1960 **VH-TFB** **F-27** **Mackay, Qld**

The TAA Fokker F-27 Friendship crashed into the ocean with the loss of all 29 people onboard. The subsequent board of inquiry was unable to come to any definite conclusions as to the factors underlying the accident and recommended:

“It has proved to be impossible to reach any firm conclusion as to the cause of the accident, there being no survivors of the fatality, there are no means of ascertaining what occurred on the aircraft in the last few minutes of its flight. It would, no doubt, have been enlightening to have a record of any conversation which took place between the Captain and the First Officer during that period and of the readings of the flight instruments up to the moment of impact.”

In 1961, the Federal Government accepted this recommendation with an implementation date of 1 January 1963. The date was later extended two years to 1 January 1965. Recorder reliability issues meant that VH-RMI was still not fitted with recorders when it crashed in 1966.

30 November 1961 VH-TVC Viscount Sydney, NSW

At the height of a severe thunderstorm, with heavy rain, violent winds, thunder and lightning, a Vickers Viscount aircraft crashed into Botany Bay, Sydney. All onboard, four crew and 11 passengers, perished. The Ansett-ANA flight 325 was completing a scheduled return flight from Sydney to Canberra. The flight plan did not allow for an extensive, intense storm cell to their south.

"The cause of the accident was the failure in flight of the starboard outer wing in upward bending due to tensile overloading of the lower spar boom at station 323, probably induced by a combination of manoeuvre and gust loading when the speed of the aircraft was in excess of 260 knots. The circumstances and available evidence carry a strong implication that the in-flight structural failure was preceded by a loss of control with a consequential increase in speed to at least 260 knots. The most probable explanation for the loss of control is that the aircraft entered an area of unexpected turbulence of such severity as to deprive the pilots of full recovery."

The cause of the crash was later established as windshear (downburst) in the storm cell.

22 September 1966 VH-RMI Viscount Winton, Qld

About 150 miles from Longreach, fire was reported in the No. 1 and No. 2 engines. While the aircraft was making an emergency descent, the left wing broke away due to weakening by the fire. After failure of the wing, the plane broke up in mid-air and crashed.

"The means of securing the oil metering unit to the No. 2 cabin blower became ineffective and this led to the initiation of a fire within the blower, which propagated to the wing fuel tank and substantially reduced the strength of the main spar upper boom. It is probable that the separation of the oil metering unit arose from an out-of-balance condition induced by rotor break-up but the source of the rotor break-up could not be determined".

3. DEVELOPMENTS (1968 – 2006)

3.1 Accident:

31 December 1968 VH-RMQ Viscount 720C Port Headland¹

On descent into Port Headland, at an altitude of approximately 7,000 feet, a structural failure of the right wing occurred outboard of the No. 3 engine. Immediately following this failure, some components of the starboard wing struck the starboard tailplane and elevator causing the outboard portions of these two components to fail and the tail section and rear fuselage to separate from the aircraft. All 26 people onboard (4 crew and 22 passengers) perished.

The FDR carried was:

FDR	
Manufacturer:	United Data Control Inc.
Model:	F-542B
Technology:	Analogue (engraving)
Recording medium:	Inconel ² foil
Recording duration:	400 hours
Crashworthiness:	TSO C54 C51
No. of parameters:	Four ³
Readout equipment:	Microscope table

The CVR carried was:

CVR	
Manufacturer:	United Data Control Inc.
Model:	V-412
Technology:	Analogue
Recording medium:	Magnetic tape
Recording duration:	60 minutes
Crashworthiness:	TSO C84
No. of channels:	Four ⁴
Replay equipment:	Tape deck

¹ Accident Investigation Report “Viscount 720C Aircraft VH-RMQ near Port Headland Western Australia 31st December 1968”, Air Safety Investigation Branch, Department of Civil Aviation, September 1969.

² Inconel is an alloy containing nickel and chromium.

³ Pressure altitude, indicated airspeed, magnetic heading and vertical acceleration (load factor) versus time.

⁴ Three crew channels - Captain, First Officer and spare (or public address) - and a channel for the Cockpit Area Microphone.

Both recorders operated correctly and showed that the flight was normal until the aircraft reached 7,000 feet on descent and experienced a catastrophic event that led to a complete loss of control.

The investigation found that the starboard inner wing had failed in upward bending due to fatigue cracking originating within the length of a bushed hole in the flange of the lower spar boom.

Figure 1: FDR from VH-RMQ



3.2 Accident:

10 October 1985 VH-IWJ IAI 1124 Westwind near Sydney⁵

The aircraft was being operated on a night cargo flight from Sydney to Brisbane. The pilot in command intended using the flight to assess the performance of the co-pilot who was being considered for an upgrade. The investigation determined that there was a known malfunction of the rate of turn indicator and simulated failures of other instruments. A loss of control of the aircraft occurred at an altitude of approximately 5,000 feet and the crew did not recover control.

The FDR carried was:

FDR	
Manufacturer:	Fairchild
Model:	5424-501
Technology:	Analogue (engraving)
Recording medium:	Inconel foil
Recording duration:	300 hours
Crashworthiness:	TSO C51a
No. of parameters:	Five ⁶
Readout equipment:	Microscope table

The CVR carried was:

CVR	
Manufacturer:	Fairchild
Model:	A100
Technology:	Analogue
Recording medium:	Magnetic tape
Recording duration:	30 minutes
Crashworthiness:	TSO C84
No. of channels:	Four
Replay equipment:	Tape deck

Both recorders operated correctly during the accident flight and provided valuable evidence for the investigators.

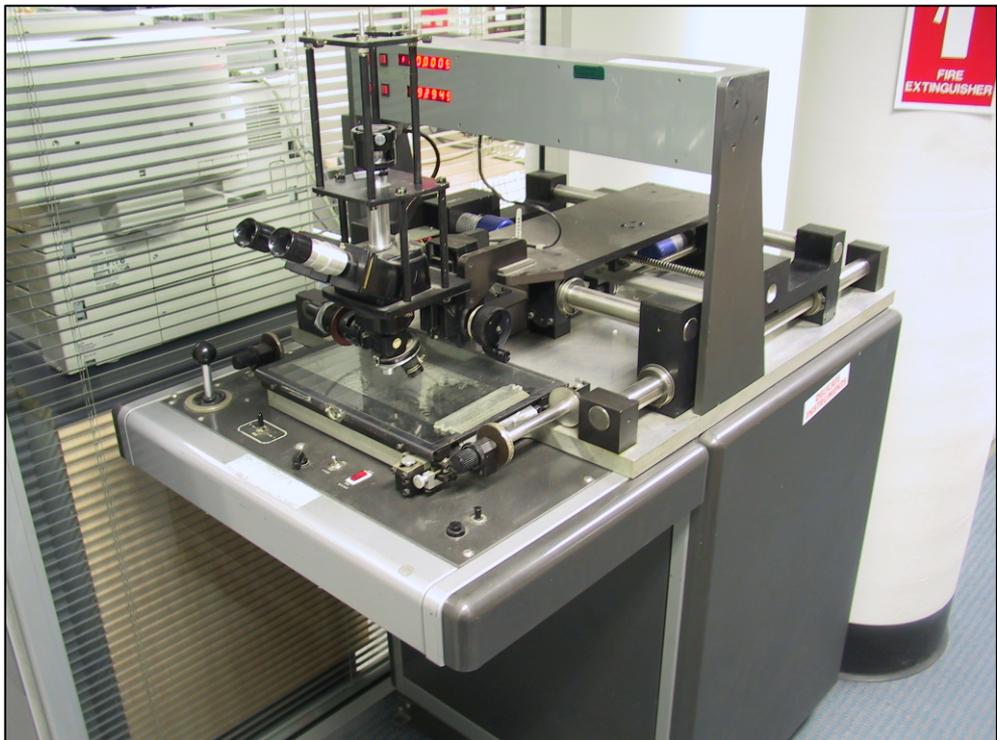
⁵ Aircraft Accident Investigation Report 852-1056, Bureau of Air Safety Investigation, Department of Aviation, October 1986.

⁶ Pressure altitude, indicated airspeed, magnetic heading, vertical acceleration (load factor) and microphone (radio) keying versus time.

Figure 2: FDR from VH-IWJ



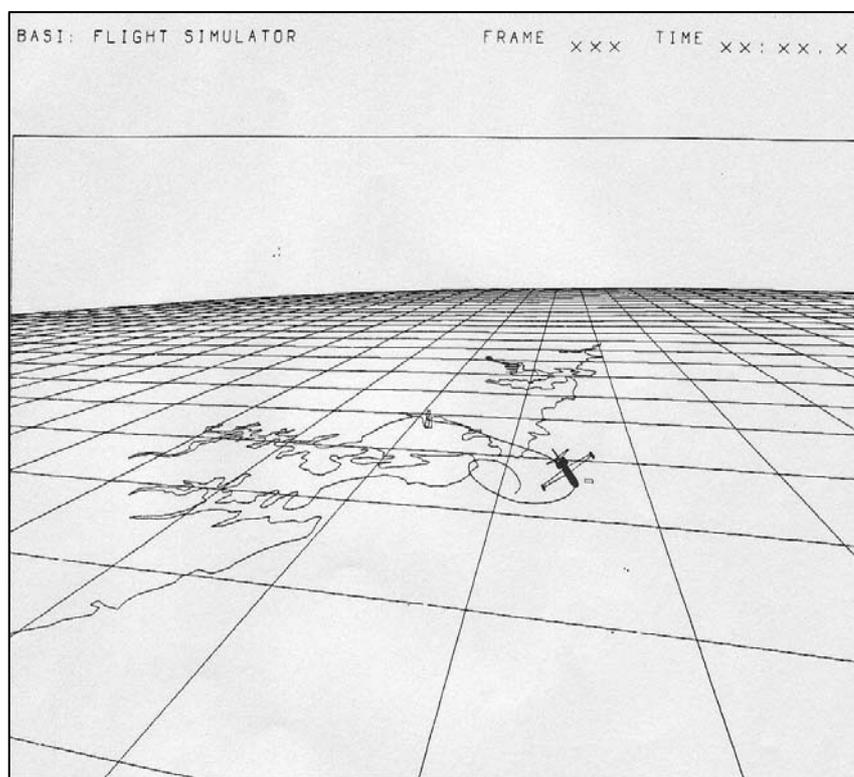
Figure 3: Microscope readout table for analogue (foil) FDR



In 1980 it was proposed⁷ that the Air Safety Investigation Branch⁸ develop a computer graphics system. In 1984, the Bureau of Air Safety Investigation (BASI) introduced its first computer graphics system which made BASI one of the first government accident investigation authorities to use this technology. The system comprised an Evans and Sutherland PS300 monochrome vector graphics workstation hosted by a PDP 11/45 mini-computer. This system could animate a simulated instrument panel, an ILS approach as well as a general 3-dimensional view.

The accident to VH-IWJ was one of the first in Australia to be investigated using this technology.

Figure 4: Sample output from the PS300



⁷ Recorder Research Note 12, P. Mayes, Air Safety Investigation Branch, December 1980.

⁸ In 1982, the Air Safety Investigation Branch (ASIB) was re-organised to become the Bureau of Air Safety Investigation (BASI). On 1 July 1999, the multi-modal Australian Transport Safety Bureau was created by combining BASI with other agencies.

3.3 Serious Incident:

12 August 1991 VH-HYC A320 and HS-TMC DC-10 Sydney⁹

On 12 August 1991, simultaneous runway operations (SIMOPS) were in use at Sydney airport. SIMOPS allowed runways 25 and 34 to be used independently for arriving aircraft.

VH-HYC was making an approach to runway 25 while HS-TMC was making an approach to runway 34. The crew of HS-TMC had been instructed to stop before the flight strip of runway 25. ATC made a “stop immediately” call to HS-TMC and VH-HYC went around from a height of approximately 20 feet. As VH-HYC overflew the runway intersection HS-TMC was encroaching the sealed surface of runway 25. The two aircraft passed in very close proximity at the runway intersection.

The FDR carried by VH-HYC was:

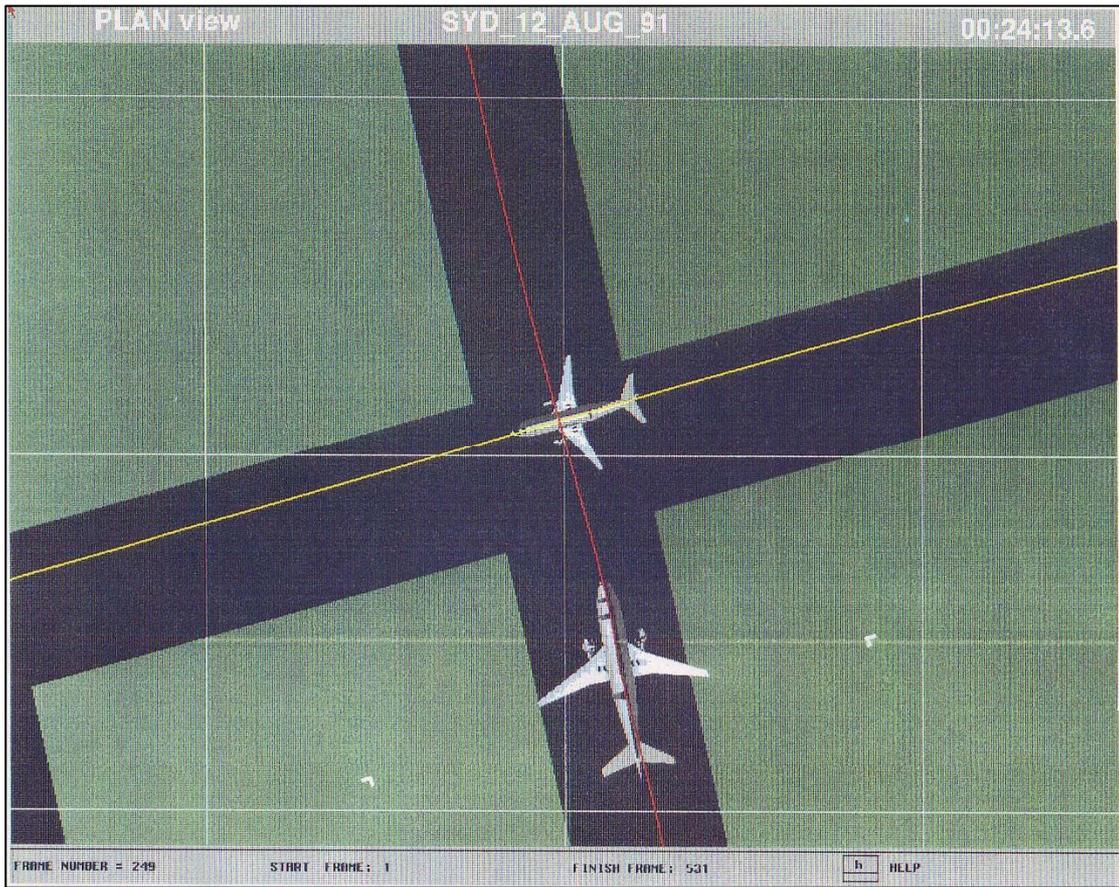
FDR	
Manufacturer:	Sundstrand Data Control
Model:	UFDR ¹⁰
Technology:	Digital
Recording medium:	Magnetic tape
Recording duration:	25 hours
Crashworthiness:	TSO C51a
No. of parameters:	224
Readout equipment:	Teledyne Interface Unit & PDP mini-computer

FDR data from both aircraft was examined and a computer graphics animation of the incident was produced. The computer graphics system used was initially developed by BASI in-house before development was continued by a contractor. The hardware platform was a Silicon Graphics Iris 4D/70 workstation and the software used was the Aircraft Accident Investigation System (AAIS) software. Output from AAIS is shown in Figure 5.

⁹ Special Investigation Report B/916/3032 “Near Collision at Sydney (Kingsford Smith) Airport 12 August 1991”, Bureau of Air Safety Investigation, Department of Transport and Communications, February 1993.

¹⁰ Universal Flight Data Recorder.

Figure 5: Output from AAIS computer graphics system



3.4 Serious Incident:

1 August 2005 9M-MRG Boeing 777 near Perth¹¹

9M-MRG was being operated on a scheduled passenger service from Perth to Kuala Lumpur, Malaysia. The crew reported that they observed a low airspeed warning on the aircraft's Engine Indication and Crew Alerting System when climbing through FL380. At the same time, the aircraft's slip/skid indication deflected to the full right position on the Primary Flight Display (PFD). The PFD speed tape then indicated that the aircraft was approaching the overspeed limit and the stall speed limit simultaneously. The aircraft pitched up and climbed to approximately FL410 and the indicated airspeed decreased from 270 knots to 158 knots. The stall warning and stick shaker devices also activated.

The pilot in command (PIC) reported that he had disconnected the autopilot and lowered the nose of the aircraft. The autothrottle commanded an increase in thrust which the PIC countered by manually moving the thrust levers to the idle position. The aircraft pitched up again and climbed 2,000 ft. The PIC notified air traffic control (ATC) that they could not maintain altitude and requested a descent and radar assistance. The crew was able to verify with ATC the aircraft speed and altitude.

The FDR carried was:

FDR	
Manufacturer:	Honeywell
Model:	SSFDR ¹²
Technology:	Digital
Recording medium:	Flash memory
Recording duration:	25 hours
Crashworthiness:	TSO C124
No. of parameters:	> 1,000
Readout equipment:	PC

¹¹ Interim Factual Report, 200503722, Australian Transport Safety Bureau, 24 March 2006.
http://www.atsb.gov.au/publications/investigation_reports/2005/AAIR/air200503722.aspx

¹² Solid-State Flight Data Recorder.

The CVR carried was:

CVR	
Manufacturer:	Allied Signal
Model:	SSCVR ¹³
Technology:	Digital
Recording medium:	Flash memory
Recording duration:	2 hours
Crashworthiness:	TSO C123
No. of channels:	Four
Replay equipment:	PC

The FDR data indicated that, at the time of the occurrence, unusual and instantaneous acceleration values were recorded in all three planes of movement. The acceleration values were provided by the aircraft's ADIRU¹⁴ and were used by the aircraft's primary flight computer during manual and automatic flight. The primary flight computer compared the information from the ADIRU with the information from the Standby Air Data and Attitude Reference Unit. During the occurrence, this comparison function reduced the severity of the initial pitching motion of the aircraft.

In 1991, a decision was made at BASI to standardize on the computer graphics system being developed at the Canadian Transport Safety Board - the Recovery, Analysis and Presentation system (RAPS). Development of a BASI in-house system ceased. To obtain the necessary performance, RAPS used Hewlett-Packard UNIX workstations which were reliable but expensive.

In 1992, the commercial development of RAPS was taken over by Flightscape Inc. and the software, now called 'Insight', was converted for use on a PC. This allowed advantage to be taken of the rapid increase in performance and low cost of PC hardware. In 2005, the ATSB adopted the use of Insight and flight recorder specialists operate the complete system on their laptops, effectively giving them a portable flight recorder laboratory.

Insight Analysis and Insight Animation were used in the 9M-MRG investigation. A demonstration view, obtained by using Insight Animation, is shown in Figure 6.

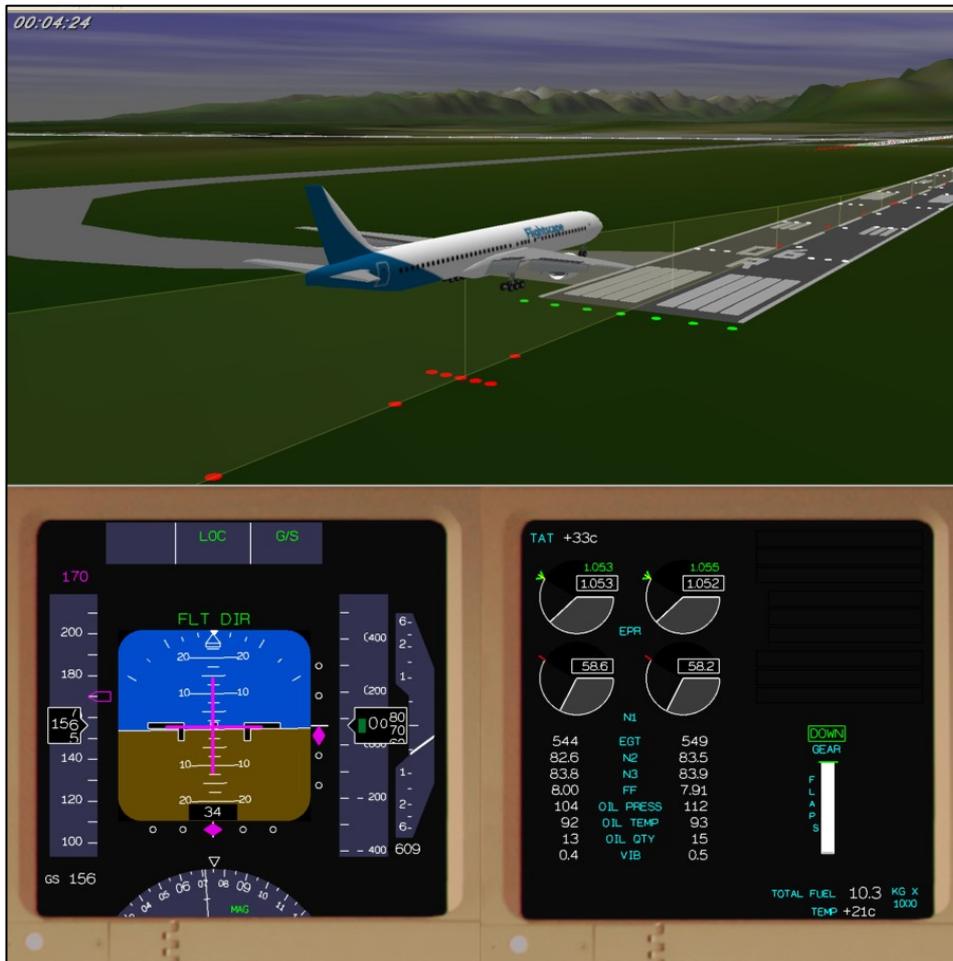
For commonality with several major carriers in the region, the ATSB also uses Teledyne Controls' GRAF¹⁵ and Vision software. This software has proved to be particularly useful for analyzing quick access recorder data.

¹³ Solid-State Cockpit Voice Recorder.

¹⁴ Air Data Inertial Reference Unit.

¹⁵ Ground Replay and Analysis Facility.

Figure 6: Sample output from Insight Animation



4. DEVELOPMENTS IN RECORDER CRASHWORTHINESS

TSO¹⁶:	Recorder:	Date:	Impact:	Fire:
C51	FDR	Aug. 1958	100g for 11 milliseconds	1,100°C for 30 minutes 50% of outside area
C84	CVR	Nov. 1963	100g for 11 milliseconds	1,100°C for 30 minutes 50% of outside area
C51a	FDR	Jan. 1966	1,000g for 5 milliseconds	1,100°C for 30 minutes 50% of outside area
C123	CVR	May 1991	1,700g for 6.5 milliseconds	1,100°C for 30 minutes 100% of outside area 50,000 BTU/hour ----- 260°C for 10 hours
C124	FDR	Feb. 1992	3,400g for 6.5 milliseconds	1,100°C for 30 minutes 100% of outside area 50,000 BTU/hour water calorimeter ----- 260°C for 10 hours
C124a	FDR	Jan. 1996	3,400g for 6.5 milliseconds	1,100°C for 60 minutes 100% of outside area 50,000 BTU/hour water calorimeter ----- 260°C for 10 hours
C123a	CVR	Feb. 1996	3,400g for 6.5 milliseconds	1,100°C for 60 minutes 100% of outside area 50,000 BTU/hour water calorimeter ----- 260°C for 10 hours

¹⁶ Technical Standard Order - issued by the Federal Aviation Administration.

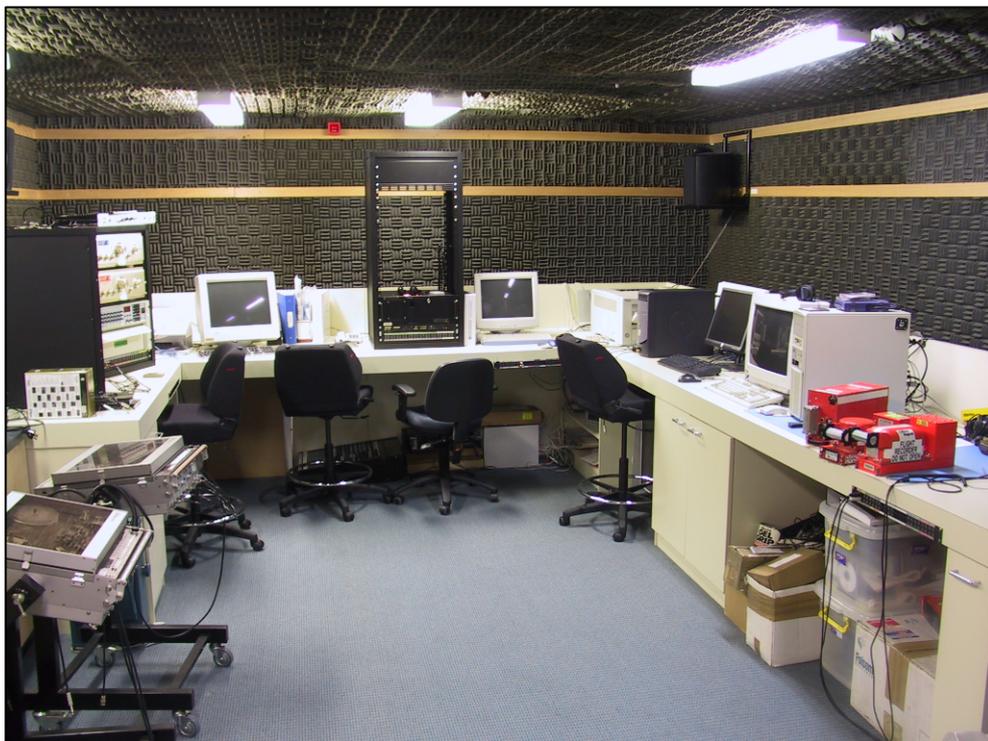
Figure 7: Fire test of a Loral Data Systems recorder, Florida, 1992



Figure 8: Audio Laboratory, Air Safety Investigation Branch, Melbourne, circa 1979



Figure 9: Audio Laboratory, ATSB, Canberra, 2006



5. FUTURE DEVELOPMENTS

5.1 Image Recorders

Image recorders could be used to store:

- External images of the aircraft control surfaces, landing gear and engines
- Cockpit images of complex displays that cannot be fully recorded by the FDR eg. the navigation display and weather radar display
- General images of the cockpit including pilot activity and instruments (a number of cameras would be used to fully record the cockpit environment however only a single recorder would be required)

Image recorders could also be used in smaller aircraft not currently equipped with an FDR or a CVR. In this case the image recorder would be used instead of an FDR or CVR as it would be simpler and cheaper to install than separate recorders.

From the NTSB web-site:

'In its February 1, 2005, annual report to Congress on the Most Wanted recommendations, the Department of Transportation stated that the FAA has no rulemaking underway to mandate the installation of TSO-approved video equipment on aircraft operated under Part 135 (commuter) that do not currently have flight recorders. The report to Congress further states that should an aircraft operator or original equipment manufacturer wish to install a crashworthy video recording system voluntarily, either in the cockpit or in the aircraft cabin, the FAA would work with the applicant to approve such an installation with or without a TSO. The FAA conducted tests of a "proof of concept" video recorder system during June 2005, and is scheduled to publish a final report of the test results and findings by December 2005'.

5.2 Recorder Independent Power Supply (RIPS)

A RIPS provides an independent 10 minute power source for the CVR when aircraft electrical power is lost. The RIPS is designed for use with solid-state CVR's as their power consumption is lower than that of tape-based recorders. The FAA has issued an NPRM¹⁷ which proposes a RIPS for newly manufactured aircraft only.

There are no plans for a RIPS to be required for the FDR, as not only the FDR but all the sensors/systems on the aircraft would also need to be powered for the FDR to record useful data.

¹⁷ Notice of Proposed Rule Making.

5.3 Combi-Recorders

Two combination (CVR/FDR) recorders will eventually replace a separate CVR and FDR. One system should be located as close to the cockpit as practicable and the other as far aft as practicable. Both recording systems should be capable of recording all mandatory data parameters covering the previous 25 hours of operation and all cockpit audio including controller–pilot data link messages for the previous 2 hours of operation. The system located near the cockpit should be provided with an independent power source that is located with the combination recorder, and that automatically engages and provides 10 minutes of operation whenever normal aircraft power ceases, either by normal shutdown or by a loss of power to the bus. The aft system should be powered by the bus that provides the maximum reliability for operation without jeopardizing service to essential or emergency loads, whereas the system near the cockpit should be powered by the bus that provides the second highest reliability for operation without jeopardizing service to essential or emergency loads. Two combi-recorders will maximize the chance that both cockpit audio and flight data are able to be recovered after an accident.

6. SUMMARY

The advent of digital electronics in the 1960's led to major changes in flight data acquisition, flight data recorders and ground-based replay and analysis systems. With the first generation of analogue recorders, each parameter was separately wired to the FDR and separately recorded. This inevitably limited, to about 10, the maximum number of parameters that could be recorded.

With the digital revolution, aircraft now use databuses which the FDR system can tap into, to obtain access to 1,000's of parameters.

Progress with CVR's was less dramatic, with 30 minute tape units eventually being superseded by 2 hour solid-state units. These CVR's now have the capability to record non-voice ATC messages eg. CPDLC¹⁸ transmissions.

World-wide experience showed that CVR audio and FDR data was sometimes unable to be recovered following an accident, often due to fire damage when magnetic tape was the recording medium.

In the 1990's, with the introduction of solid-state recorders using flash memory as the recording medium, recorder crashworthiness standards were significantly improved. This is now reflected in excellent survival rates of the data stored by solid-state recorders.

¹⁸ Controller-Pilot Data Link Communications.