

FUTURE VIDEO ACCIDENT RECORDER

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This Paper was presented at the National Transportation Safety Board International Symposium on Transportation Recorders, on May 5th 1999, at Arlington, Virginia, USA

KEYWORDS

Inter-modal
Video
Accident
Recorder

FOREWORD

This paper examines the viability and use of video camera systems for accident investigation. While the examples used, and the details explored, are applied to commercial aircraft, the same logic reads across to all public transportation, where safety of passengers is paramount. Specific recent interest from ferry operators, inter-city rail operators, and school bus operators shows that future accident investigations will be heavily dependent on information gathered and recorded by video means.

INTRODUCTION

In March 1999, the National Transportation Safety Board issued a Safety Recommendation, which highlighted its earlier commitment to monitoring the progress of the use of video recording in the cockpit, following an air accident in 1989. The Recommendation goes on to emphasise the work being carried out by Eurocae and ICAO FLIRECP/2 concerning video recordings, and notes the commitment of FLIRECP/2 to the introduction of video recordings in an appropriate and agreed format.

These conclusions only serve to reflect the case put by the United Kingdom Air Accidents Investigation Branch in a position paper of 14th June 1996.

As the technology has matured, trials of various systems have been carried out, but no clear mandate for a system has so far been given. This paper shows how recent developments in Digital Video Recording technology can be used in the aerospace environment to achieve the aims of air accident investigators.

A system consisting of five internal cockpit mounted cameras, and three external cameras is suggested. Using digital control methods, the update rate and recorded resolution of individual cameras can be varied to make the best use of the available recording medium.

The paper goes on to discuss the reasoning behind digital video recording, its advantages over tape based recording, and to compare various video compression techniques.

The paper goes on to suggest how such a system may be used as part of a future "Aircraft Recorder Server", in which Audio, Data and Video are all recorded in a single "Black Box".

AIRBORNE CAMERA SYSTEMS

Fire at Manchester - August 1985. On 22nd August 1985, a British Airtours 737 was on a take off roll from Manchester Airport when an engine fire caused the pilot to abort. Not realising the extent of the fire, he followed standard procedures to exit the runway, as he did so turning the flaming wing upwind fanning the flames onto the fuselage. The resulting fire caused the deaths of 55 passengers and crew.

The Air Accidents Investigation Branch (AAIB) of the United Kingdom Department of Transport concluded in their report (AAIB 8/88) that “Research should be undertaken into methods of providing the flight deck crew with an external view of the aircraft, enabling them to assess the nature and extent of external damage and fires”

Accident at Kegworth - January 1989. On 8 January 1989, a British Midlands 737 had an engine failure during flight. As the crew, unlike the passengers, were unable to see the traces of physical damage on the engine itself, they carried out various procedures to identify which engine had a problem. For various technical and operational reasons, they throttled back the healthy engine, and made their approach to East Midlands Airport on their failed engine. The accident just short of the runway cost 47 passengers their lives.

The AAIB report on the accident (AAIB 4/90) stated that “The CAA should expedite their current research into methods of providing flight deck crews with visual information on the status of their aircraft by means of external and internal closed circuit television monitoring.”

The Benefits of Improved Vision. In 1991, in Jeddah, a DC-8 had a tyre burst on take-off roll. Unaware of the fire, the pilot retracted the burning undercarriage into the wheels well, causing the total loss of the aircraft with 260 passengers and crew.

In a similar incident in 1986, a wheel well fire caused a fire warning shortly after take off from Heathrow. The pilot of the departing aircraft was warned of the extent of the fire by the pilot of an aircraft following up, allowing him to return to land with no casualties despite extensive damage to the aircraft.

CAA and Other Work. Prompted by the AAIB report, the United Kingdom Ministry of Defence Royal Aerospace Establishment, Farnborough carried out a successful “Proof of Concept” flight (March 21, 1989) to show that external cameras fitted to a BAC 1-11 would prove useful to the pilot, and would be capable of operating in the environment.

In 1989 British Airways, funded by the UK CAA, carried out a trial installation of two cameras on a Boeing 747, the results of which were published as CAA Paper 95001. This report also covered a funded study by DRA Farnborough into “A Human Factors Investigation into the Use of Airborne External Video Camera Systems”, and a Safety Benefit Study carried out by the College of Aeronautics at Cranfield, now Cranfield University. While acknowledging the potential safety benefits brought by video cameras in several of the analysed categories, the CAA concluded that, given the technology at the time, they could not take steps towards mandating external viewing systems.

RECENT DEVELOPMENTS IN THE INDUSTRY

Glass Cockpits Traditionally, Air Accident investigators have been able to rely on data “stored” by instruments jammed at the point of impact, following an accident. However, modern “Glass Cockpit” displays have no such “memory” and provide the investigator with little in the way of evidence to show their status leading up to, or at the time of, an air accident. This has seriously reduced the amount of information available for post accident analysis.

FANS. Recent moves in aviation have further impeded the accident investigator. The adoption of the “Future Air Navigation System” (FANS) would mean that uplinked information from Air Traffic Controllers will in future be carried out by datalink rather than voice. While operationally there are many advantages, the adoption of FANS severely reduces the amount of useful information available to the accident investigator from the Cockpit Voice Recorder.

Cockpit Environment Recorder. It is our contention that much of the above information could be restored for post accident use by eventually replacing the Cockpit Voice Recorder with a combined cockpit voice and video camera system recording the complete “Cockpit Environment”. The discussion of the structure of the combi recorder is dealt with in the section of this paper entitled “The Future Flight Recorder”.

The video camera positions suggested for this system are: Captain's main instruments display, covered by camera located outboard and behind the pilot; Co-pilot's main instruments display, covered by camera located outboard and behind the pilot; General flight crew activity, covered by “fish eye” lensed camera in roof panel; External “Fin” mounted camera, showing the overall attitude of the aircraft, damage to control surfaces and engines; Underbelly forward looking, viewing the nosegear; Underbelly rearward looking, viewing the maingear. In addition it may be useful to have a further two cameras in the cockpit covering the central console, and the overhead panel. The exact locations of the cameras will be specific to the aircraft type, and must be established through trials.

TECHNOLOGY

Aerospace Standards.

To withstand the harsh aerospace environment, all components need to be designed and manufactured specifically for use in that environment. Taking standard off the shelf cameras and recorders designed for the office environment and using them in the air, while economically attractive, will result in early problems and failures. Specifically, externally mounted cameras need to be small, light, and reliable using solid state electronic shuttered light control, thermostatically controlled heaters for de-misting and de-icing, and aerodynamically shaped housings to allow the flow of air to remove water droplets.

The Video Camera.

The worldwide use of video cameras for buildings and area security is now well established, with thousands of cameras being installed weekly. This mature technology is now leading to highly reliable solid state CCD camera sensors, at ever-cheaper prices and in ever-smaller physical sizes.

Camera observation has now become an accepted part of modern life. The modern businessman uses camera technology to conduct “video conferencing” with international offices. Mostly, then, we have come to accept the presence of cameras in our daily lives, and are no longer intimidated by the idea that we are being recorded going about our business.

Indeed, most of us welcome the increased security afforded by town centre police surveillance cameras, and point of sale cameras which check that we are who we say we are, every year preventing millions of pounds in fraudulent transactions. In many instances, video tapes are used for training de-briefing (for example in line-pilot’s simulators), and can also be used to confirm that the correct actions were taken by staff, for example showing that procedures were correctly followed when in dispute. Taken together, the advent and introduction of video cameras into any workplace, including the cockpit, should not be feared, but should be welcomed.

Resolution. One of the major parameters to be considered in the choice of video camera is the required resolution of the recorded image. Whilst modern image enhancement techniques can re-emphasise video data obscured by errors in lighting, and even errors in focusing, it must not replace data which was not originally captured by the video system due to poor sensor resolution. To do so would bring the reliability of the data extracted into question.

The sizes of aircraft instruments, and the text and graphics displayed on them is well defined, mostly by reference to the “Design Eye Position”, which is the position of the average pilot within cockpit.

The minimum requirement of the video for accident investigation needs in the cockpit is to identify a graphical pointer (defined in ARP4103 as a minimum of 0.1 inches (2.54mm)), which could then be simulated on a representative instrument to obtain the reading. This would imply that a single “standard” 400 TV lines per picture height resolution camera could detect such a pointer over an area of 677 x 508mm.

If reading text on the instrument panel is required, this results in a far more strenuous set of criteria. The sizes of text are shown below as Table 2 (SAE ARP4102)

Experimentally it has been found that to read text, 10 TV lines are needed even in good laboratory conditions. Assuming that the camera can be located at the same distance from the instrument panel as the Design Eye Position, and given a “standard” video camera with a resolution of 400 TV lines per picture height, this means that to be able to read a 5mm high character, a single camera will be able to cover only 300 x 225 mm on the instrument panel.

Text Category	Angular Subtension at Pilots Design Eye Position
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Primary	20' of arc = 0.33°
Secondary/Non Essential	15' of arc = 0.25°
Minor	12' of arc = 0.20°
Fixed, Continuously Available	10' of arc = 0.17°

Table 2

Colour. Where detection of alarm signals is concerned, colour is an essential part of the message, and the use of a colour sensor is justified. However, colour CCD sensors have considerably lower resolution than monochrome sensors, and their use must be treated with some caution.

Lighting. Modern monochrome CCD cameras are capable of operating from full moonlight (0.1 lux) to full sunlight (100,000 lux), by automatic electronic shuttering, which makes them ideal for use in the cockpit environment, where they will automatically adapt to the wide range of conditions which may prevail. However, as they react to the average light level across the scene, they are not so effective where part of their field of view might be the darkened instrument panel, and another part may be the bright windshield. Therefore careful positioning, and possibly masking of certain parts of the field of view, may be necessary.

THE VIDEO RECORDER.

Solid State Recording vs Tape. Tape based systems have traditionally been used for video recording for flight trials and other airborne work. When considered for air accident investigation uses, the medium has serious shortcomings.

Wear. In a system in use 24 hours a day, the requirement for maintenance to replace worn tapes is relatively high, resulting in high "cost of ownership" for the airline. A solid state digital system needs no such maintenance.

Quality. With a high frequency, wide bandwidth signal like video, the quality of recording on tape systems soon deteriorates with usage, most experts recommending that a VCR cassette be used no more than 10 times. A digital system, using flash memory with an expected life of 200,000 write cycles, would reduce this maintenance to a minimum.

Flexibility. Perhaps the biggest advantage of digital systems over tape based systems, however, is the ability to rapidly access a particular image or sequence of images. A tape system is essentially a serial device, where a user has to start at the beginning and progress through the recording until reaching the required sequence of images. With a digitally controlled system, a sequence of images can be accessed easily either by time, or alarm. This could mean that an alarm could be noted by the digital system, for example: on a fire alarm; pilot initiated alarm; when the aircraft altitude falls

below 10,000 feet; or whatever the air accident investigators require. Then this section of recording could be easily accessed during analysis.

Further to this, uniquely in a digital recording system, the alarm action can cause a change in the way that the recorder works. For example, this could mean that as the aircraft descends prior to landing, the recorder starts to record at higher resolution or with a faster update rate.

Under normal circumstances, the recording will overwrite once the medium is full, after say half an hour of recording. Again, given a digital alarmed system, it would be simple to program the recorder to preserve the recording say one minute prior to, and one minute following an alarm, thus ensuring that vital information is not overwritten however long the flight continues after the incident.

These parameters, and others, will be discussed by Eurocae Working Group 50, prior to the publishing of the promised Minimum Operating Performance Specification (MOPS).

VIDEO MULTIPLEXING

In order to avoid multiple recorders, it is essential in any multi-camera video system to convert the various camera inputs to a single video signal. This is achieved by "Video Multiplexing", which takes one picture (field) from the first video input, and follows it with a field from the next input, a field from the third input, and so on. If one camera input is more important than another is, then more fields can be taken from that input channel, or that channel can be returned to more often. If the incoming video signals are "genlocked" that is synchronised to a single master video clock then it is possible to switch between the video channels at field rate. In an aircraft environment, running extra genlock cables to each camera position will build extra weight and therefore running cost into the system, and it is usually sufficient to "slip" a field from time to time to achieve the multiplexing of unsynchronised signals. In practice higher reliability will be expected if up to 4 fields are recorded from each channel at a time.

VIDEO COMPRESSION

Essential Parameters. To make the best use of any given volume of digital recording medium, it is essential to use one of several video compression algorithms. For accident investigation usage, it is essential that the chosen method records information which can be relied upon, and in which each picture "stands alone" containing within its data file all the information necessary for the reconstruction of the picture. Also, the chosen method must be able to operate in "real time", that is that compression rates must be able to cope with a number of pictures per second.

JPEG vs MPEG. The two most successful video compression methods suitable for real time video compression are JPEG, defined by the Joint Photographic Experts Group, and MPEG, defined by the Motion Picture Experts Group. MPEG systems are designed to be used for compression of motion pictures, and rely on the storage of moderately compressed “Intra Pictures” every 15th frame, then Forward Predicted “P-Pictures”, storing only the change vectors of parts of the pictures, and finally Bi-directional “B-Pictures” which are generated estimation pictures averaging between the I-Pictures and the B-Pictures. This technique gives excellent compression of static scenes, generating larger files, hence using more of the available storage medium where there is movement within the picture. This is just at the moment where our interest in the picture is greatest. The reliability of these pictures is not high; for example a car moving quickly away from a traffic light will appear to take the white stop line along with it for a few frames. Discerning what happened in an accident situation with this sort of evidence would at the very best be unconvincing. Furthermore, since in subsequent pictures all that is stored is changes to the I-Picture, the possible loss of that I-Picture should there be recording medium damage in an accident, would mean that a whole stream of data is rendered meaningless. JPEG addresses each incoming video field as a separate picture, compressing with a predictable, pre-settable, compression rate, leading to a predictable file size. Overall a compression ratio of about 12:1, giving a file size for a colour picture of about 20 kB, will produce a quality of reproduced image about equal to that from an SVHS video recorder, adequate for most requirements. The incoming video signal is digitised and subjected to a 2 Dimensional Discrete Cosine function, applied to each cell of 8 x 8 pixels (picture elements). The output is quantized at the preset Q level, a higher Q leading to a smaller file size but a loss of high frequency information, hence detail. This quantization results in a data file consisting of runs of value numbers, and long runs of zero’s, and can be further compressed by merely storing the numbers of zero’s in any given run (Zero Run Length Coding). The resultant files are then further compressed by the use of a “Lookup Table” of frequently encountered patterns (Huffman Coding).

The resultant recording is effectively to turn the video sequence into a series of still pictures, showing the fine detail of the scene, more akin to using a 35mm camera with autowind, than to traditional movie film photography. It has been found in various military and commercial security systems that an update rate using this technique as slow as one frame every four seconds is adequate update to track incidents.

Given the requirements for our video compression techniques stated above, the best choice is a JPEG based algorithm.

THE FUTURE AIR ACCIDENT RECORDER

The above thinking has led to the development of a video based Accident Recorder, now in its prototype form.

Future Air Accident Recorders are likely to be ‘combi’ units, recording audio, data and video in a single “Black Box” recorder. This recorder will be digital solid state,

for the reasons already discussed, and will need to satisfy the recording requirements for all air accident needs. This will mean that an installed dual redundant system will allow the total destruction of one of the recorders, without affecting the ability of the air accident investigators to do their work.

THE "AIRCRAFT RECORDER SERVER"

The last couple of years have seen an explosion in the development of information systems. Specifically the growth of the Internet has led to the sudden and dramatic development of transmittal and recording systems and techniques. This has necessitated the differences between the digital transmission of data, audio and video signals being almost eliminated.

New accident recorders will take advantage of these developments, by becoming "server" machines. Data, audio and video will be converted to digital signals at source (that is at the DAU for data, at the microphone control unit for audio, and at the camera site for video). The serial data can then be transmitted through the airframe and recorded by a "dumb" box, which merely acts as a sponge to all data, which it sees. A standard software protocol such as TCP-IP, and hardware Ethernet, which is widely used for all Internet transactions can be employed, and the community can benefit from advances and developments in the wider engineering world. The advantage of this approach is that the technology dealing with the acquisition of the original data is the same as that dealing with the digitisation, compression and transmission, leaving the technical issues with the sensing equipment manufacturer, and leaving the way open for future enhancements. The "Aircraft Recorder Server" would establish the Recorder as the Ethernet "hub". This would allow twisted pair transmission at up to 100Mb rates, and would allow any number of new "nodes" to be added, to expand the system in the future.

The use of industry standard techniques will allow the transmission of data between the "Server" and the terminal, to be used as an accident preventative just as "Quick Access Recorders" are used at present. In the future, data will be transmitted from the aircraft in flight to the ground such that maintenance issues can be addressed long before the aircraft lands.

CONCLUSION

The history of aviation accident investigation gives strong arguments for the use of cockpit and external video cameras. The component parts for the systems, video cameras, and multiplexing digital video recorders now exist, and are in everyday use in ground based security systems. The development of the combined "Aircraft Recorder Server", in conjunction with recommendations from Eurocae Working Group 50, will provide future air accident investigators with an invaluable new source of evidence.

BIOGRAPHY

Mike Horne BEng CEng MIEE is Managing Director of AD Aerospace Ltd. After qualifying from the University of Bradford with an honours degree in Electrical and Electronic Engineering, and a Student Apprenticeship with Marconi Avionics in 1983, he has worked extensively in video camera systems for a wide variety of purposes from missile guidance and fire control, to pipe inspection and commercial security. His work has included image intensified and thermal imaging systems. In 1995 he joined the successful video security systems company, Dedicated Microcomputers to form DM Aerospace, which later split off as an independent company AD Aerospace, specialising in the design and manufacture of video systems for aerospace. During his time at the company, Mike has overseen the development of the first "Digital Video Network Server" compatible with aerospace requirements. This is now being offered to the world's airlines, and a spin off product to the School Bus market. Mike has two children, Greg aged one, and Dennis aged two months.