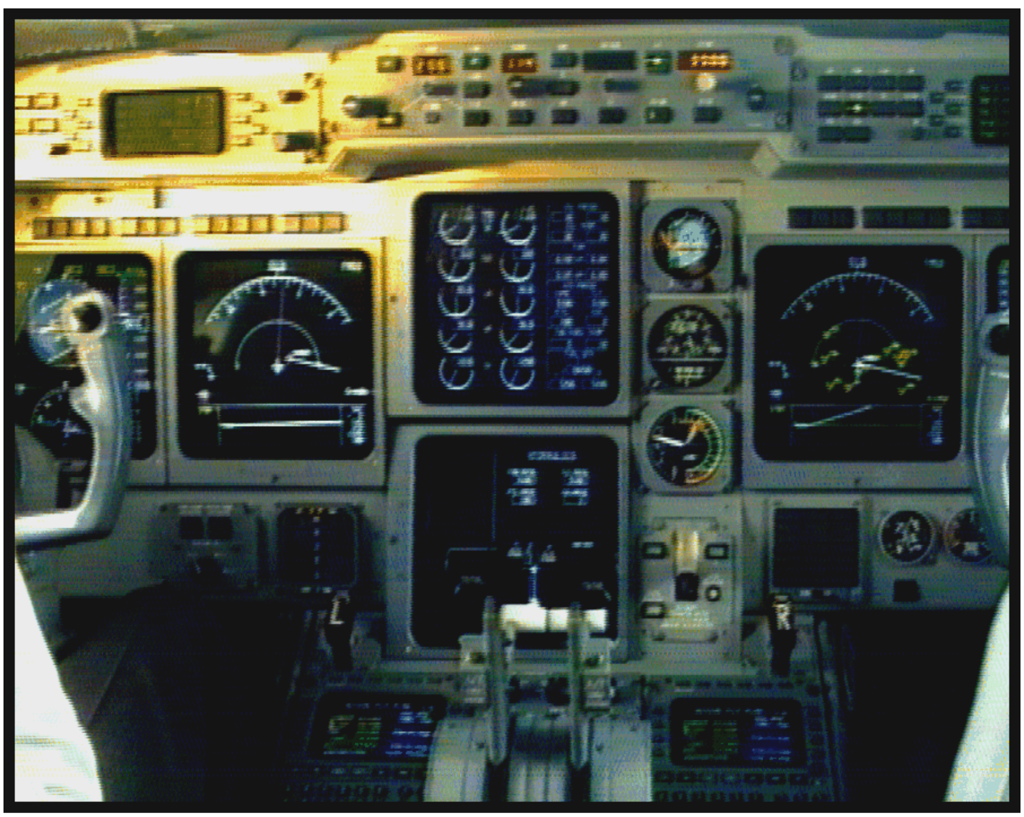
Flightdeck Video Recording

The Acquisition of Video Data

M.A. Horne BEng CEng MIEE
Technical Manager
DM Aerospace



The Flightdeck of a Gulfstream G4.
Frame captured from a video camera source

Executive Summary

In recent years several air accident reports have pointed to the advantages which might be gained by the use of closed circuit television (CCTV) cameras on commercial aircraft, by allowing the pilot to see, in either real time or replayed time, the results of an in-flight incident.

The recent move towards the reception of Air Traffic Control messages via a digital datalink direct into the cockpit has prompted EUROCAE working group WG50 to investigate the use of video cameras. These would be used to record pilot reaction and the cockpit environment, augmenting the coverage of the Cockpit Voice Recorder (CVR). This paper investigates the acquisition of data from the cockpit using video camera techniques.

To fully monitor and record the cockpit environment, five internal cameras are required; one for the primary displays of each pilot; one for the overhead switch panel; one for the central console; and a fifth wide angle camera showing general cockpit environment.

The relevant information can be gathered using aerospace standard solid state Charge Coupled Device (CCD) cameras, providing that the angles and fields of view, and locations of the cameras, are carefully chosen.

The data can then be compressed, recorded, downloaded to a crashproof medium as digital data, and simultaneously be made available for the pilot either in real time, or with simple replay facility.

All the technology required is currently available in commercial security systems using proprietary Digital Video Storage and Transmission (DVST) techniques.

1. Introduction

1.1 History

Following the fire on a British Airtours Boeing 737-236 on 22 August 1985 in which 55 passengers and crew died, the United Kingdom Department of Transport Air Accident Investigation Branch recommended in their report *(Reference 6)* 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"*

This desire was repeated after the crash of a British Midlands 737-400, in which 47 passengers died, on the approach to East Midlands airport on 8th January 1989 *(Reference 7)*.

Following the crash of an El Al Boeing 747 in Amsterdam in 1992, the Netherlands Aviation Safety Board included in their recommendations *(Reference 8)* that work following the accident should:

> *" Investigate the advantages of installation cameras for external inspection of the airplane from the flightdeck"*

Prompted by these findings, the United Kingdom Ministry of Defence Royal Aerospace Establishment, Farnborough carried out a "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. British Airways, funded by the UK CAA, carried out a trial installation of two cameras on a Boeing 747. At the same time a UK company carried out installations on Lockheed Jetstar, Citation II and Gulfstream IV aircraft. The Gulfstream installation is still operating successfully 5 years after commissioning.
A US company have several installed systems employing both internally and externally mounted cameras, for use in both cargo hold security and passenger entertainment roles.

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, and the "Big Brother" state, where remote observers watch every move in shopping malls, car parks and around buildings is now a reality. 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.

The cockpit environment is one area where CCD cameras have not yet penetrated. However, as a result of the adoption of complex data oriented systems such as the Future Air Navigation System (FANS), information previously available to air accident investigators from the CVR is being lost. As a solution to this, consideration of the use of video cameras to monitor and record an airliner flightdeck is being put forward.

The possible uses of video camera monitoring of multiple aircraft parameters on a single multiplexed video channel is also being considered as a way of expanding the number of parameters recorded on the FDR on older aircraft types.

1.2 Scope

This paper will concentrate on the use of cameras within the cockpit environment, furthermore will deal primarily with the acquisition of relevant images by the camera sensors specifically for use by air accident investigators. Fairchild (*Reference 9)*, have already published a report looking at the methods of digitally recording such images using various compression technologies, and this paper will go on to expand on the Fairchild findings, introducing Dedicated Microcomputers' state of the art Digital Video Storage and Transmission (DVST) video compression techniques. This system is currently in use throughout the world in many high level security applications.

1.3 Questionnaire

A questionnaire is available to allow those interested to express their opinions as to the use and viability of Flightdeck Video Acquisition and Recording. The results will be published once analysed.

2. Air Accident Investigation Requirements

2.1 Requirements

So what images actually need to be recorded to satisfy the air accident investigators that they have a true picture of the cockpit environment?

In order to determine the sequence of events leading up to an accident, the investigator currently has a variety of sources of information available to them. These include; the Cockpit Voice Recorder (CVR); the Flight Data Recorder (FDR); Radar plots; Radio Transmission (RT) recordings; Witness statements; and Physical evidence at the crash site.

When investigating serious incidents, as now required by Annex 13 of the Chicago Convention, the investigator has all of the above plus first hand reports from the aircraft's crew.

Thus a very detailed picture of events can be established. However, the lack of direct evidence relating to both crew activity and instrument indications can lead to an incomplete understanding of the events leading up to an accident, which at best leads to problems in determining its cause and at worst could lead to wrong conclusions being drawn from the evidence that is available. A good example of this was the accident investigation into the crash of a COPA 737 in South America. This gap in the data available to accident investigators could be filled by the use of flight deck mounted cameras.

2.2 Camera Locations

Various trials over the past few years have shown that such an approach is not only feasible but also practical. For recording the flight deck of a typical commercial transport, the ideal fit would be 5 cameras located and configured to capture the following data:

1 & 2	Pilots' main instruments display.	Covered by 2 cameras, one located outboard of each pilot's seat.
3	The central console, with the main engine controls.	Covered by a single camera mounted in the roof panel
4	The overhead panel containing systems controls and indicators.	Covered by a single camera mounted in the control console.
5	General flight crew activity	Covered by a "fish-eye" lensed camera mounted in the roof panel

If economics, or space considerations do not allow the fitting of all five cameras, then a reduced set of three (leaving out cameras 3 and 4 above) would allow retrieval of most of the relevant information.

Either a full or partial view of what the pilots are able to see through the windscreen may be of value to the accident investigator. Such a view would enable assessment of light levels, amounts of cloud, visibility, icing and the precise moment at which the approach or runway lights became visible to the pilot.

2.3 Pilot Issues

The question of recording crew activity is contentious because of the various national laws covering the disclosure of such potentially sensitive information. It is not intended to cover these aspects in this paper but rather to concentrate on the benefits of such a system to the accident investigator.

It may be important to the accuracy of the final investigative accident report as to whether the crew had followed check-lists precisely, or whether they had followed laid down procedures. Failure in these areas cannot always be detected using the information currently available to investigators.

Even if the FDR indicates that certain information is available to the pilot, it cannot be assumed that the pilot was in a position to absorb that information for a variety of reasons. He may have been prevented from observing an event by an incident that did not manifest itself on the CVR or RT recording. For example a minor distraction, attention to paperwork, navigation charts or even temporary obstruction of the relevant instrument.

In the event of mis-selection of controls, the manner and circumstances of that selection can only be fully understood if the actual selection can be seen. Many accident reports have cited high flight deck work load as a causal or contributing factor - the magnitude of this workload can only be fully assessed if a visual record of the events is available..

If concern is expressed about recognisably showing the pilot, it would be possible to establish camera positions for a particular cockpit layout, which would show crew activity, but would not allow the pilot to be easily recognised. Alternatively, it would be possible, as with the CVR, to arrange that the recording is erased when the parking brake is applied.

2.4 Update rate

Traditionally, the air accident investigator has made great use of a single “snap shot”, using the positions of mechanical dials and instruments frozen on impact, to show the state of the aircraft immediately before the accident.

Modern digital video recording technology can provide the investigator with some quarter of a million “snap shots” throughout the flight, showing the cockpit environment at take off, and climb out, as well as at any alarm stages. By reviewing the recording, he can go through incidents as they happen, up to the final moments of the flight.

Because of the demands on the capacity of the recording medium in the FDR, some parameters which are considered to be of low importance are sampled at very low rates, less than once in 60 seconds in some cases. It could be the case that parameters that were considered to be of little relevance at the design stage can become very relevant in the case of an accident investigation. In the absence of a direct visual record, the investigator has an incomplete picture of what information was actually available to the flight deck crew.

2.5 Recording Duration

From an accident investigation stand point the ideal would be that the output of all cameras would be recorded for the whole of the flight from engine start to shut down. However, update rates and recording capacities make this ideal difficult to achieve for longer flights, and the condition would be far more severe than is imposed on, for example, the CVR, which covers a maximum of the last 2 hours of flight. When deciding priorities for recording capacity, it is essential that the landing phase should be given most weight followed by the take-off and then the cruise phase. This is in inverse relationship to the probability of accident. A digital recording medium can have the update rate dynamically altered during differing flight phases, and so is preferred in this respect.

In this way, the recording of a flight can be built up such that the take-off phase is always retained, but the memory is then recycled to allow as a minimum the last two hours of flight, plus the approach and landing phases, to be retained.

The flexibility of the digital recording system makes it possible to achieve whatever flight profile is required by the certifying bodies, at pre-defined update rates which may be different for each flight phase.

3. Camera Parameters

3.1 Detection and Recognition

3.1.1 Resolution of the Eye

Theoretically, the eye can resolve about 30 seconds of arc *(Burle Electro Optics Handbook, Reference 2).* That means that in perfect conditions you should be able to distinguish between two black lines 0.1mm thick and 0.1mm apart at 1m distance. Under laboratory conditions, the resolution of a normal eye is more like 50 seconds of arc, allowing distinguishable lines 0.25mm thick and 0.25mm apart, again at 1m distance. In a more practical situation, with lower than perfect contrast ratio, and ordinary clutter, between 6 and 12 minutes of arc are required before positive detection can be confirmed. This is equivalent to spotting a 3mm insect at arms length.

3.1.2 Military Experience

The resolution necessary for Detection, Orientation, Recognition and Identification of various military targets has been experimentally found to be as shown in Table 1, below. The units are "line pairs" which are equivalent to the equally spaced black/white bars used in 3.1.1 above *(Burle Electro Optics Handbook, Reference 2).*

Task	Line Resolution per Target Minimum Dimension
Detection	1.0 +/- 0.25 line pairs
Orientation	1.4 +/- 0.35 line pairs
Recognition	4.0 +/- 0.8 line pairs
Identification	6.4 +/- 1.5 line pairs

Table 1 - Line Resolution Requirements

3.2 Camera Resolution

Camera Resolution is normally measured in "TV lines per picture height". A "CCIR" (Monochrome UK standard) picture contains 625 lines vertically, of which 585 give active, useful video signals. Because of the interlace of the two fields making up the picture, the vertical resolution of a TV camera is usually of the order of 350 TV lines. In the horizontal direction, the resolution varies widely, depending on the sensor chip used for the specific camera, the number of picture elements (pixels) used by the manufacturer, and the amount of electronic post-processing employed. A high resolution monochrome camera may have 768 horizontal pixels per line, which will give a resolution of about 550 TV lines per picture height.
A colour camera will show markedly lower resolution due to the constraints put on by the masking of the colour filters. A good colour camera will give 450 TV lines per picture height horizontal resolution.
The EIA television system used in the US only uses 525 vertical TV lines, of which 485 are active. The resolution is therefore reduced accordingly.

For the purposes of the remainder of this document we will assume that the resolution of a medium resolution, "standard" CCD camera is 400 lines x 400 lines, to simplify the working. It should not be forgotten that this is a simplification, and that further work will be required to calculate the actual performance of a system, based on the actual camera resolutions used.

3.3 Reading Text

Recommended sizes of text are given in Table 2, below *(SAE ARP4102, Reference 3)*

Text Category	Angular subtension at the pilots eye position
Primary	20' of arc = 0.33º
Secondary/Non Essential	15' of arc = 0.25º
Minor	12' of arc = 0.20º
Fixed, Continuously Available	10' of arc = 0.17º

Table 2 - Text Subtension at Pilots Eye Position

Experimentally, it has been found that, to read text (rather than detect that text is present) 10 TV lines are needed, that is that it is the equivalent of "Recognition", in 3.1 above. This is the limit in good laboratory viewing conditions, which will not be the case in a normal cockpit environment. However, it is expected that in the case of the air accident investigator needing to extract information from a picture, video enhancement techniques will be used, so that this ideal figure is still valid.

As the height of text recommended to be used on cockpit displays is only defined in terms of angular subtensions from the Design Eye Position, a certain number of assumptions will have to be made to come up with conclusions as to the viability of reading text through a cockpit video camera system.

Taking the text heights into consideration (and assuming that only "Primary" data is essential to be read by the video camera system), then assuming that the camera is at the same approximate distance from the displays as the Pilots Design Eye position, the maximum angle of view of the camera will be:

$$^{400}\!/_{10} \text{ TV lines x 0.33 degrees } = 13.2 \text{ degrees.}$$

If the camera is further away than the Design Eye position, then a correspondingly longer focal length lens will be required . If we take the example of a height for the character on the display of 5mm, then this gives the total viewed area on the display surface, of 300 x 225 mm, which immediately implies that the camera is dedicated to the primary flight control displays of a single pilot. This, taken with the angle of view of the camera gives a location of the camera 1.14m from the display, so that a camera 1.14 metres from the display, with a field of view of 13.2º will be able to read characters 5mm high over an area the size of the pilot's primary instruments.

3.4 Reading Graphical Displays

All that is required to read a graphical representation of a conventional instrument is that the position of the pointer relative to the graduation is detected.
From Figure 1 below, the pointer measuring 0.1 inches (2.54mm) is the minimum graphic which needs to be detected. *(SAE ARP4103, Reference 4)*

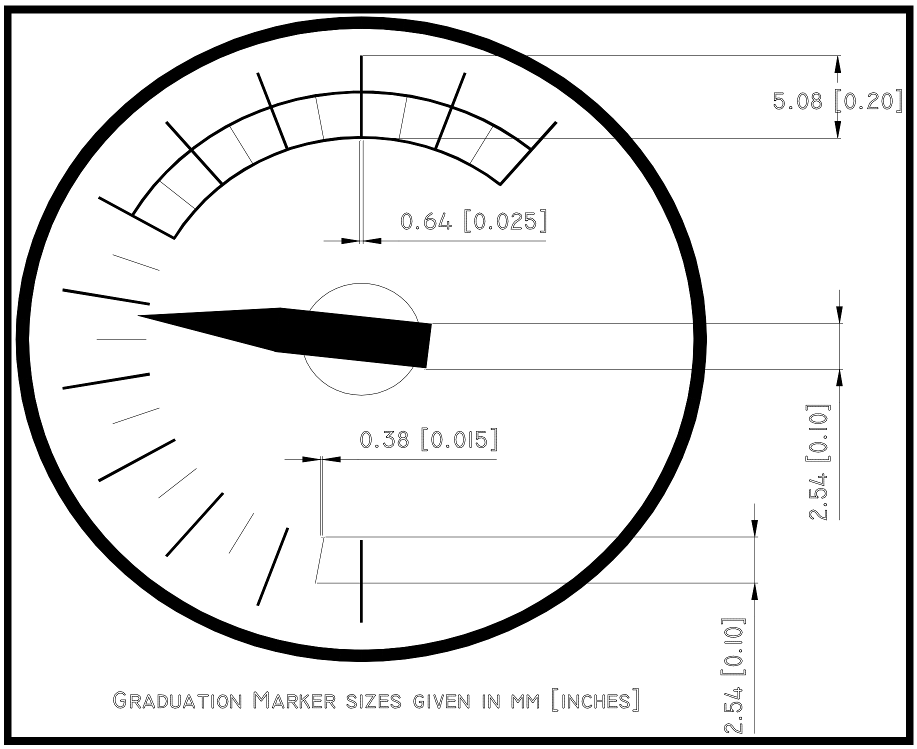


Figure 1 - Instrument Graphics

Carrying out the same calculation as above, with the Detection criteria of 2 lines (1.0 line pairs) substituted, we have that the minimum field of view is

$$\frac{400}{2} \times 2.54 \text{ mm} = 508\text{mm}.$$

Therefore, using the 4:3 aspect ratio of the camera, the camera would be able to cover 677 x 508mm.

Comparing this figure with that for reading a 5mm text, above, it can be seen that the camera could cover twice the display area, if it were only to correctly record graphical images.

3.5 Lighting

Modern monochrome CCD cameras are capable of operating in lighting conditions from full sun to an illumination of 0.1 lux (approximately 0.01 foot candles), by automatic electronic shuttering (no mechanically moving parts). This means that they are ideally suited to working in the cockpit environment, and will automatically adapt to the conditions. The standard electronic shuttering is, however, controlled by the average light level received over the whole picture. Therefore, if part of the picture is viewing the displays, and part is viewing out of the windscreen, then the electronic compensation will mean that the picture is darker than necessary for optimum viewing of the displays. Care should therefore be taken in the positioning of the cameras, and masking or extra control of the circuitry should be considered if the intrusion of external lighting through the windscreen is unavoidable, or is desired to give additional information about the ambient conditions.

The dial markings on avionic instruments are luminous with an intensity of 0.50 +/- 0.25 foot lamberts, with the pointer at least 20% greater than this *(SAE ARP4103, Reference 4).* Experimentation in a cockpit under night conditions should be undertaken as to the optimum control circuit to ensure that these are clearly visible and do not “bloom” out making them difficult to read.

Greater sensitivity can be achieved by electronic amplification, where the signal is forced to 1.0V peak to peak, or by image intensification using military style intensifier tubes. Each of these options have their own problems, which are outside the scope of this paper.

3.6 Colour

Ideally, recordings should be made in colour, as colour is extensively used in modern glass cockpits to distinguish different levels of priority information. Certainly, where detection of alarm signals is concerned, where colour is an essential part of the message *(SAE ARP4102, Reference 3),* the use of a colour sensor is justified.

Colour CCD cameras are limited in their sensitivity to around 5 lux (approximately 0.5 foot candles), with light control still being achieved by electronic shuttering. Their lower sensitivity makes the viewing of instruments at night more difficult, and therefore colour sensors should only be selected where a specific need for colour images is determined.

Colour CCD cameras also have considerably lower resolution, so while there may be advantage to choosing a colour sensor, the use must be treated with some caution.

3.7 Refresh Rate

A UK standard CCIR CCD image is built up over an exposure time of 20ms (16.6ms for US standard EIA), then the sensor is cleared down, ready for the next “exposure”. This “refresh rate” of 1/50 second (1/60 second EIA) can cause beating effects with the refresh rates of glass cockpit displays and seven segment LED panels (refreshed at 1/60 second). This is the effect which can be seen when TV screens are shown on a TV programme or movie. The effect is particularly noticeable when single frames are recorded, and the integration of the eye is taken out of the equation..

In order to eliminate these problems, it may be necessary to integrate over a few video frames, to “even out” the beating effects. This is easily achieved with a digital recording system.

Further experimentation is necessary with installed systems to assess the extent of this problem, and to evaluate the number of frames of integration which will be necessary to eliminate the effect.

4. Recording

4.1 Accident Reporting Requirements

To be of use in incident reporting, the recording mechanism and medium need to be robust enough to withstand the shocks and vibration associated with in flight incidents. To be of benefit to the accident investigators in the analysis of the reconstructed video following an accident, the recorded data needs to be easily recoverable, and "frame independent" such that if only a portion of the video data is sufficiently unharmed to be of use, then a full and useful frame of information can be extracted.

4.2 Experience from Industry

Various forms of video compression have been tried within the CCTV industry over the last few years which are discussed elsewhere (*Fairchild paper, Reference 9*). MPEG techniques compress the digitised video signal by storing only the changes between frames. Although MPEG gives a greater compression ratio when the scene is mainly static, the reliance on preceding frames in order to reconstruct a given "still", and the blurring of quickly moving objects caused by quantisation of the picture, make the technology unsuitable for air accident investigation.

JPEG is now the standard technique used by the majority of the CCTV manufacturers, and the reconstructed pictures have been court room tested, and found to give a reliable reproduction of the stored scene.

4.3 JPEG Technology

JPEG technology effectively turns the video sequence into a series of still pictures, showing the fine detail of the scene over a long period by "Time Division Multiplexing" (TDM).
The effect is more akin to using a 35mm camera with autowind, than to traditional movie film photography. Security systems for major military, and high priority civil targets are now using this technology widely, coupled with "Time Lapse" video recorders. A typical system securing a large site may consist of 16 cameras being recorded 24 hours a day, at "12 fields" update rate, giving a video frame recorded from each of the cameras every 4 seconds, to allow 24 hours to be fitted on a standard 2 hour videotape. This has been found to give adequate update to track incidents.

4.4 Real Time Replay

Some accident investigation authorities have recommended that external CCTV be fitted to public transport aircraft as an accident prevention aid with the secondary use as an accident investigation tool. This was one of the recommendations leading from the UK AAIB report into the Air Accident at Kegworth *(Reference 7),* and the Netherlands Aviation Safety Board report on the Air Accident in Amsterdam *(Reference 8).*

This implies that the recording technique must allow replay to be simultaneous with recording. This necessitates the use of "random access" memory media, such as solid state storage devices, and hard drives. Use of a hard drive as a primary recorder, with the data further output to a crash proof storage medium (see Figure 2), would allow the flight crew to replay at much faster update rates, for a much greater duration direct from the hard drive, without disturbing the recording essential for accident investigation.

4.5 The Workings of a Digital Video Recorder.

The new generation of digital video recorders, being led by Dedicated Micros with "Digital Video Storage & Transmission" (DVST) technology, is revolutionising the security industry by getting rid of the traditional "drop out" problems experienced with metal oxide video tapes following wear. Digital storage, using either hard drive or solid state memory, allows random access leading to the ability to replay at the same time as continuously recording.

The incoming video camera signals are first field multiplexed. That is, that a single video sequence is constructed from a number of camera inputs, by interleaving a single field from each camera in turn.

The single video waveform is now digitised, and compressed using a modification of JPEG techniques. The digital video signal is field independent, that is that all the data necessary to re-construct a single video field is available within that field, with no reliance on previous fields. This is important should the data only be partially recoverable after a aircraft crash.

Table 2 below shows the approximate size of the data records per field, dependant on the quality of restored video required. The compression factor can be programmed in, or can vary through the flight dependant on flight phase.

Picture Quality	Field Data Size (Kbytes)
Medium Quality Monochrome	10
High Quality Monochrome	15
High Quality Colour	20

Table 2 - Field Data Sizes

The digital data is then stored in solid state memory devices, or hard drive, and also output in serial form to a crash proof medium (See Figure 2). The current "state of the art" is that 4 frames per second can be recorded from a time division sequence of images.

The storage capability of digital media is rising all the time. Currently available on the market are 9GB hard drives, or, using solid state Flash Memory, up to 896MB. Practically, a 128MB flash memory module would be capable of storing 5000-6000 high resolution images, which could represent recording 4 cameras for 20 minutes, each at an update rate of once per second.

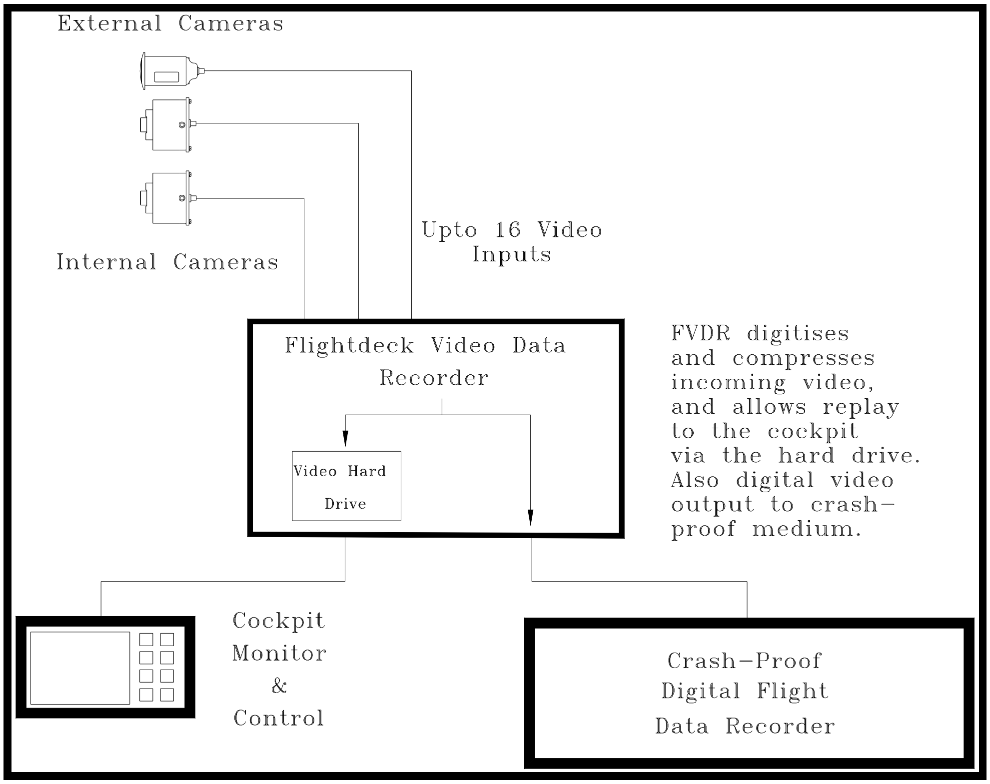


Figure 2 - Crash Proof Flightdeck Video Data Recorder

4.6 Interface to Digital Flight Data Recorder.

Once the video is converted to digital form, the recording of the signal becomes a mechanical task, just like recording any other digital parameter aboard the aircraft. However, the amount of information to be stored is quite large, and the limitation is the cost and availability of large Flash Memory devices, together with the access speed required for the data transfer. Therefore it seems likely at present, that the Flightdeck Video Data Recorder will be a separate item from the DFDR, although using a duplicate crash proofed and certified flash memory block. This also eases the certification route for the new unit, as it will not interfere with standard mandatory equipment in any way.

5. Conclusions

5.1 The technology exists today to carry out whatever video acquisition and recording tasks are required by accident investigators, to fully record the flightdeck environment. This technology is in use worldwide, day to day in the CCTV security industry. It is widely tested, courtroom proven, and highly reliable.

5.2 By using selected video cameras, modified and ruggedised to meet the harsh environment demanded by the aerospace industry (such as the DM Aerospace "FlightVu" series); and carefully positioning them as determined through trials involving air accident investigators, such a system can be assembled. Current work suggests that a series of five cameras in the cockpit would be ideal to fully document the flightdeck environment, although a sub-set of three would give investigators most of the information they require.

5.3 While reading text using a camera is possible, this would imply a camera specific to each pilot's primary flight instruments. More effective usage of the medium may be able to be achieved by reading graphical images, and assuming that the content of a text messages is recorded elsewhere, although it will probably be possible to decide which message was being displayed at any time by analysing lengths of words and phrases.

5.4 By using digital recording techniques, such as the Dedicated Micros DVST technology, simultaneous record and replay can be achieved, allowing the pilot to replay an earlier incident while in flight.

5.5 Use of the DVST technology makes the task of interfacing a video signal to a modern digital FDR simple, the only obstacles being the volume of information to be stored, and the high data transfer rates.

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