Civil Aviation Authority

CAP 762

CAA Research Project

The Effectiveness of Image Recorder Systems in Accident Investigations

Safety Regulation Group

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The Effectiveness of Image Recorder Systems in Accident Investigations

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Executive Summary

1 The CAA initiated this research to determine whether flight deck image recording systems would provide useful additional information for accident investigations.

The principle of the research was to install a Flight Data Recorder (FDR), a Cockpit Voice Recorder (CVR) and an image recording system on a commercial full flight simulator and have a flight crew "fly" some predefined scenarios that were designed to lead to serious incidents.

2 Once the scenarios had been flown, the results were analysed in two stages. During the first stage, the German Air Accident Investigation Agency (BFU) analysed the FDR/CVR data without access to the image recorder data and the French Air Accident Investigation Agency (BEA) analysed the image recorder data without access to the FDR/CVR data. The second stage of the analysis involved both BFU and BEA being given access to the data that had previously been withheld to determine whether their conclusions changed. The accident investigators that conducted these investigations had no prior knowledge of the incident scenarios.

The resulting reports were then analysed by the CAA to determine whether image recorders did provide useful additional information.

3 The results of the research were mixed. Although image recorder systems do provide some benefits, this research has not found them to be as effective as has been postulated by some accident investigation agencies.

The research indicated that the benefits of image recorders are:

a) They may enable investigators to see whether flight deck instruments have gone blank;

b) They will, under certain circumstances, allow investigators to see smoke in the flight deck; and

c) They may enable investigators to see if a flight crew member tried and failed to resolve a problem, resulting in no record in the traditional "black box" recorder.

4 The results of the research and the associated literature review on the detection of stress and workload indicate that the disadvantages of image recorders are likely to be:

a) If inappropriately installed, they can pose a significant and potentially detrimental intrusion in to flight crew privacy. However, it should be noted that this research has shown that image recording systems can gather large amounts of data that may assist accident investigation, without providing explicit identification of the flight crew;

b) The behaviour of a flight crew may be affected by the knowledge that they are on camera;

c) Installing them will incur cost and weight penalties;

d) Protecting the data generated by them from inappropriate use and access may require changes to the data protection legislation that currently applies to flight recorders, both in the UK and abroad; and

e) Use of image recorders in isolation could be actively misleading.

5 In conclusion, the research indicates that image recording systems can, if properly installed and appropriately analysed together with conventional recording systems, provide additional information that would assist in accident investigation.

The extent of the benefits provided and whether they can be justified in relation to the cost will need to be the subject of further research and a detailed regulatory impact assessment.

Background/Introduction

1 Several accidents and incidents in the recent past have indicated a possible need for the provision of flight deck image recording systems. The most significant of these accidents have been those where the accident investigation agencies have found it impossible to determine the exact nature of the events that led to the accident. In many of these accidents/incidents the investigators suspect that the causes stemmed from a series of human factors related events (e.g. distractions, errors) but they have been unable to substantiate this using the flight recorder data currently available to them. They have, therefore, postulated that flight deck image recorders would assist in this kind of situation.

2 Although the accident investigation agencies believe benefits could be obtained from flight deck image recording (for example see UK AAIB report N30LT 6/12/03), it has, so far, been difficult to define exactly what information they could provide that is additional to the information provided by FDRs and CVRs.

3 While flight deck image recording systems may be able to provide additional information, flight crews have expressed the concern that these systems would constitute a significant invasion of their privacy. As a result of this concern, the pilot associations require assurance that the benefits to accident investigation of the provision of such equipment would justify the potential invasion of privacy.

4 The purpose of this research project is was to compare the data provided by flight deck image recording against the data provided by FDRs and CVRs and determine what, if any, additional information is provided.

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Participants

The following people and organisations supported this trial:

- Mr. Peter Sheppard from UK AAIB and Captains David Harrison and Frank Epstein from BALPA drafted the accident scenarios for use on the trial.
- Messrs. Mike Horne and Gus Parker from AD Aerospace provided the cameras for the trial and supported the camera installation and full flight simulator trials.
- Captain Malcolm Terry and First Officers James Taylor and Sam Whatmough from BALPA flew the simulated accident scenarios.
- M. Philippe Plantin de Hugues from BEA (France) and Herr. Axel Thiel from BFU replayed and analysed the recorder data.
- GECAT Engineering and Flight Training provided the simulator and simulator support.

These people also supported assessment meetings as appropriate.

The CAA is grateful to these people and their organisations for their invaluable support during this trial.

In addition to support from external organisations, the author also received help and support from many individuals within the CAA. The author would like to express their thanks for this.

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Chapter 1 Methodology

1 Introduction

The following details the five stages of the project.

1.1 Stage 1

Stage one consisted of two parallel tasks:

1.1.1 Task 1: Camera installation work with camera manufacturer and BALPA representative.

This task had two main purposes:

a) Determine the appropriate camera locations for the trial; and

b) Determine whether it is possible to use camera locations that provide adequate views of the instruments and flight controls while minimising the extent to which flight crew are visible to protect flight crew privacy as far as possible.

The camera installation trial was also used to ensure that the other recording functions operated correctly.

This work was performed by a BALPA representative and the camera manufacturer with assistance from the CAA.

A Boeing 737 simulator was used for both the camera installation work and the flight trials. The main reason for this was that the volunteer flight crew were all type rated for the 737 and, since the 737 cockpit arrangement is fairly typical of a modern commercial aeroplane, the results would have wide applicability.

1.1.2 Task 2: Draft series of representative accident scenarios.

A series of situations in terms of aircraft failures, weather and terrain that could lead to an accident were necessary to generate the required image data and FDR/CVR data. Clearly the scenarios should not be designed such that they favoured one or other outcome (i.e. for or against image recording).

The UK AAIB performed this work in conjunction with representatives from BALPA. It was agreed that the BALPA representative present at this meeting should **not** be the same person as the BALPA representative who would be 'flying' the accident scenarios. This was to avoid the trial’s flight crew having any prior knowledge of the scenarios as it was felt that the flight deck environment should be as realistic as possible during the flight simulator trials.

1.2 Stage 2

Stage 2 of the trial was a scenario evaluation meeting at Aviation House, Gatwick. The CAA, the UK AAIB, BALPA, GECAT Simulators and the camera manufacturer attended this meeting.

The purpose of the meeting was to evaluate the proposed scenarios and determine the following:

a) Whether the scenarios covered a broad enough range of accident types to avoid skewing the result of the trial;

b) Whether there were any health and safety issues related to the planned scenarios;

c) Whether it was possible to replicate the accident scenarios with the simulator equipment available; and

d) Whether the proposed scenarios posed any additional un-foreseen difficulties.

The flight crew that were to fly the scenarios mentioned in Stage 1 were not present at this meeting.

The representatives from BEA and BFU (who would be replaying the flight recorders after the full flight simulator trial) and the trial's flight crew were excluded from this meeting to avoid influencing their findings.

1.3 **Stage 3**

Stage 3 of the trial was to fly the agreed scenarios.

The purpose of this was to provide voice, parameter and image data related to the agreed scenarios for further assessment.

It was agreed that the flight crew would be debriefed on the actual events associated with each scenario as soon as they had completed their reports. This was intended to reduce the stress associated with flying a series of accident scenarios.

1.4 **Stage 4**

1.4.1 Stage 4 of the trial was the replay of the flight recorders.

This work was carried out in two parts by two different investigation agencies.

The purpose of this stage was to generate separate accident investigation reports that would enable the assessment of what additional information is provided by flight deck image recording systems.

The success of this stage of the trial was dependent on the total isolation of the two recorder assessments. To achieve this, BFU and BEA agreed that they would not communicate with each other about the accident/incident scenarios until the wash-up meeting at the end of the trial.

1.4.1.1 Part One of the process was for BFU (Germany) to replay the FDR and CVR and BEA (France) to replay the image recorder data. At the end of this process it was agreed that each of them would produce an interim report on the causes of the accidents/incidents associated with each of the scenarios.

1.4.1.2 Part Two of this process was to provide the FDR and CVR data to BEA for analysis and the image recorder data to BFU for analysis. At the end of these analyses, BFU and BEA each agreed to submit a further set of accident investigation reports to supplement their original findings.

1.4.2 Within the limitations defined above, the purpose of this was to replicate, as closely as possible, the normal accident investigation process using flight recorders. It was felt that this would provide valuable additional information for this research.

1.5 **Stage 5**

1.5.1 Stage 5 of the trial was a 'wash-up meeting' that was attended by the CAA, all three investigation agencies, the camera manufacturer and BALPA representatives, including as many representatives of the flight crew as possible.

1.5.2 The purpose of this meeting was to:

a) Present the analyses of the flight recorders and establish what information was gained from each and how;

b) Determine exactly how much additional information was gained from the image recording system;

c) Establish whether or not cameras can be located so as to protect pilot privacy without compromising the benefit to accident investigation;

d) Establish the limitations of the proposed system; and

e) Establish the limitations of the trial's output.

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Chapter 2 Details of Stage 1 - Camera Installation and Scenario Development

Stage 1 of this trial (determination of equipment functionality and camera installation) was successfully completed and the results of these two processes are given below, with references to appendices where appropriate.

1 Determination of Equipment Functionality

The primary purpose of stage Stage 1 (camera installation) was to install and test the image recording system. However, as the simulator was not equipped with a CVR or an FDR, stage Stage 1 was also used to determine whether the other flight recorder equipment that had been installed in the simulator for the purposes of this research functioned correctly. The results of these checks are shown below:

1.1 CVR

The simulator was not equipped with a CVR and so one had to be installed in preparation for this research.

There were some initial problems with the CVR (it was not correctly installed at the start of the camera installation trial and so did not initially record anything).

This problem was overcome and the AAIB agreed that the audio recordings of the trial flights were acceptable.

1.2 FDR

The simulator generates a large number of parameters that are mainly used in assessing flight crew performance during flight crew training.

The simulator generated parameters were assessed to determine whether they were equivalent to those required by the current operational rules relating to flight data recorders.

Although the recording rates were somewhat faster than required in most cases, it was established that the simulator was capable of generating information that was equivalent to that which would be recorded on an FDR.

This was discussed with the AAIB who agreed that the output was suitably representative. Based on this, it was decided that there was no need to install an FDR.

2 Camera Installation

2.1 Overview of Installation Trial Attendees

The camera installation trial took place on the 5th of August 2002 and was supported by the following people and organisations:

- GECAT Engineering and Flight Training
- Captain Malcolm Terry, the Flying Captain for the full flight simulator trials
- AD Aerospace, the supplier of the image recording system
- The UK AAIB
- The CAA Research Team

2.2 Purpose of Installation Trial

The camera installation trial had three main purposes:

a) To determine the best location for each of the cameras associated with the image recording system;

b) To install the CVR and Image Recorder and to establish the equivalence of data recorded from the simulator to the current operational rules for flight data recorders installed in large transport aircraft; and

c) To determine whether it is possible to record a general area view of the flight deck without providing explicitly identifying images of the flight crew.

2.3 Result of Camera Installation trial

2.3.1 Number of Cameras

The image recording trial used five cameras.

Four of the cameras were used to record the flight deck instrument panels and to generate a composite general area view.

A fifth camera was used to provide a single general area view. The accident investigators were instructed that this view was only to be used as a last resort in the event that the four instrument panel cameras did not provide sufficient information. This was to allow evaluation of whether the combination of instrument panel cameras would provide a composite general area view.

There was no camera looking directly up at the overhead panel.

2.3.2 EUROCAE ED-112

The image recording system was required to be set up to be as close as possible to the specifications provided in EUROCAE ED-112 (Minimum Operational Performance Specification For Crash Protected Flight Recorder Systems). This document was published in March 2003.

The extracts from EUROCAE ED-112 that are relevant to this research are reproduced in Appendix 8.

2.3.3 Camera Locations and Rationale

In addition to the requirement to match EUROCAE ED-112 as closely as possible, the camera locations were selected to obtain the best views of the instrument panels without providing identifying images of the flight crew.

The selected camera locations provided views of all instrument panels with the exception of the overhead panel and the aft electronics panel.

The cameras were located as shown in figure 1.

The Boeing 737 flight deck layout is shown in Appendix 7.

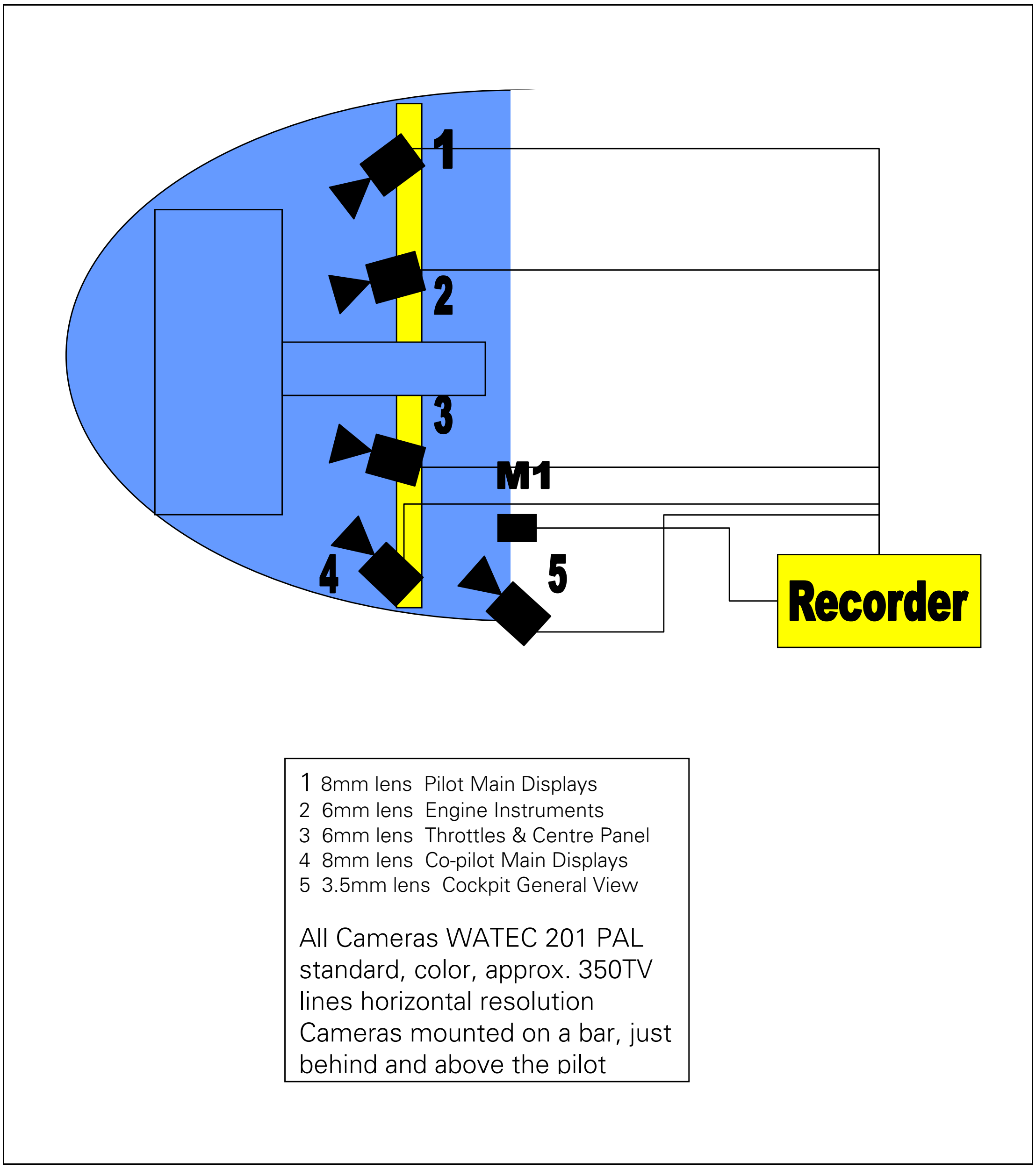

Figure 1 Flight Deck Camera Layout.

The selected camera angles/locations resulted in the following types of image:

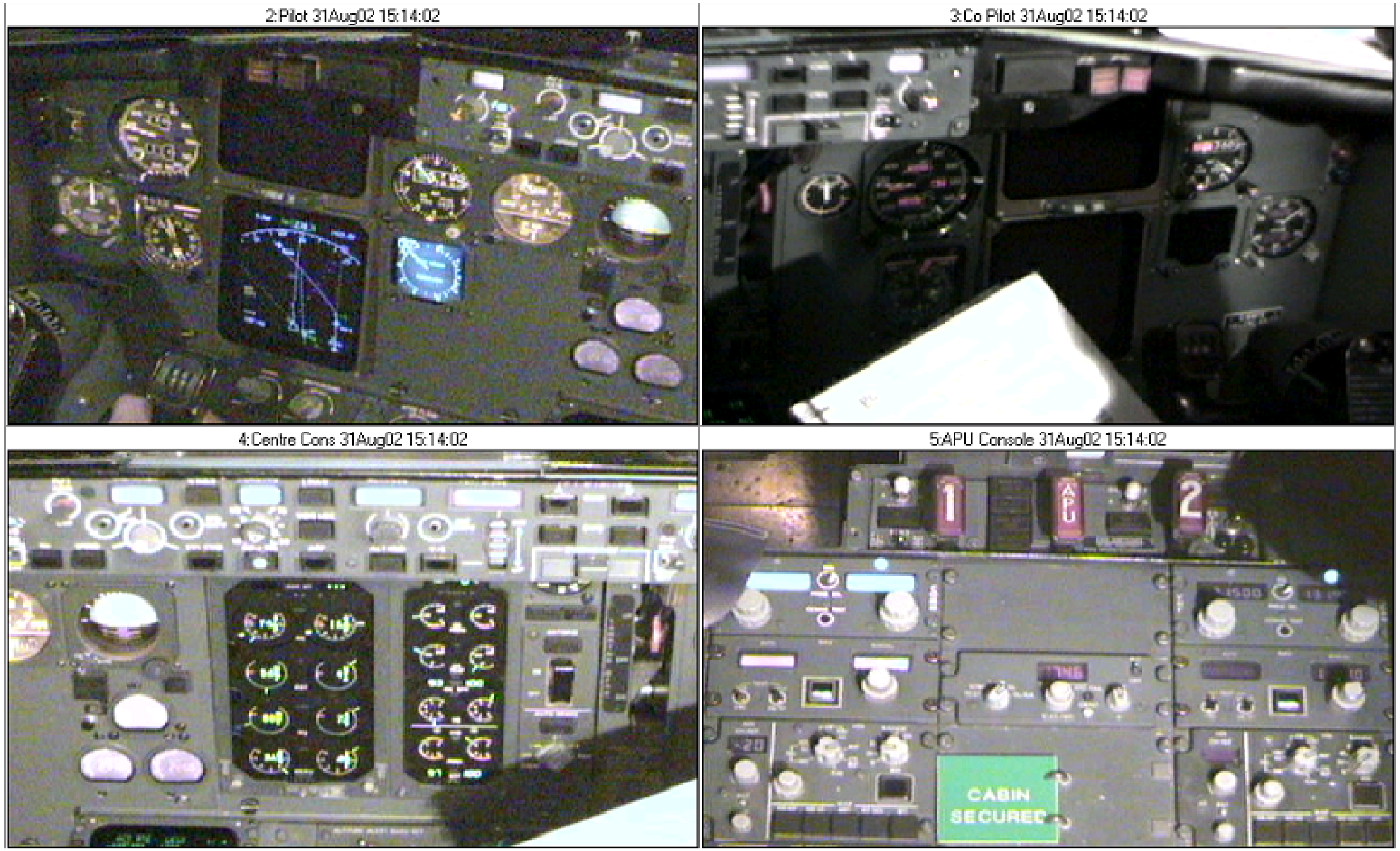

Figure 2 Images Supplied by Camera Views

After reviewing the images presented it was agreed that they provided sufficient coverage of the flight deck instruments to allow the investigators to attempt an analysis of the accident scenarios. As previously stated, the camera installation did include one "typical" general area view which the investigators were instructed to use ***only if they could not gain the information in any other way*** as this camera did allow flight crew to be identified.

2.4 Image Splicing for General Area Views

2.4.1 The CAA was aware that intrusion of pilot privacy was a major issue in the debates around flight deck image recording, particularly with respect to general flight deck area views. Various international working groups (e.g. the International Society for Air Safety Investigators (ISASI), EUROCAE Working Group 50 and the Joint Aviation Authorities Flight Recorder Study Group) had spent considerable time discussing different ways in which this problem could be addressed, including data encryption and image distortion.

Although it was agreed that some form of data encryption would be useful, the different discussions concluded that it was not a complete solution to the problem.

The discussions on image distortion concluded that this methodology could not be used, as it was not technically feasible to avoid accidentally distorting images of the flight deck instruments while trying to distort the explicitly identifying images of the crew.

To address this issue, the CAA proposed a new use of existing image processing technology.

2.4.2 The CAA proposed that the general flight deck area view should be generated using two corner-located cameras instead of one centrally located camera.

It was further proposed that the cameras be located such that their viewing angle excluded the head and shoulders of the crew member they were directed towards (while in the normal seated position), whilst providing as great a general view of the flight deck as possible.

The subsequent post-processing exercise would then 'stitch' the two sets of image data together, providing a view of the general flight deck area that was equivalent to that which would be produced by a single centrally located camera, without providing explicitly identifying images of the crew.

It was also felt that this dual camera location would make it easier to avoid identifying images of the crew as they moved around the flight deck, although it was accepted by all parties that if the crew walk directly towards the camera, it would be impossible to avoid recording an explicitly identifying image.

2.4.3 The CAA proposal was tested during the camera installation trial and it was concluded that it did have the potential to provide a general area view without the level of intrusion implied by the use of a single camera.

2.5 Interim Conclusions Regarding Equipment Installation

2.5.1 Equipment Installation

The camera installation trial allowed the team to confirm that the proposed equipment installations, including camera locations and viewing angles, would ensure that the simulator setup allowed accurate recording of accident data.

2.5.2 **Rear Facing Cameras and General Area View**

The camera installation trial also gave the team the chance to re-create previously reported events that could, potentially, have contributed to accidents/incidents and determine whether these events would be detected using a forward facing camera set up.

No rear facing cameras were used during this research trial.

2.5.2.1 The purpose of the experiments was to determine whether the proposed combination of camera views would detect these events without the use of a rear facing camera or a general area view. The events under consideration were:

a) Aggressive intrusion in the flight deck (e.g. from a passenger/terrorist);

b) Flight crew members changing seats;

c) Non-flight crew members being invited to fly the aircraft;

d) More than one person in any flight deck seat;

e) Inter-flight crew aggression; and

f) Physical incapacitation of the flight crew.

2.5.2.2 Two types of camera set up were used:

a) A combination of cameras that provided a combined view of the flight deck but did not provide a single general area view; and

b) A single camera providing a general area view.

2.5.2.3 In all cases of aggression (including inter-flight crew aggression) the image recorder provided a clear view of the situation from the combined camera set up without the need to revert to the view provided by the general area view. This was largely because the camera angles were such that:

a) Anyone attacking the flight crew from behind would be seen; and

b) If a member of the flight crew were to wield a weapon, either the weapon would be seen or the action itself would result in a sufficiently different pattern of behaviour on behalf of the aggressor and their victim that it could be picked up by an image recorder.

The image recorder also provided clear views of anyone changing seats in the flight deck and the camera angle was such that, should the seat be occupied by more than one person, that too would be visible.

2.5.2.4 It should be noted that, even though no rear facing cameras were used in the research trial, the investigators did not report any information deficiencies resulting from the absence of a rear facing camera.

2.5.2.5 The assessment of whether an image recorder could pick up information about physical incapacitation of the flight crew required the evaluation of two different issues:

a) A member of the flight crew becoming incapacitated and falling forwards on to the control column; and

b) A member of the flight crew becoming incapacitated and falling backwards in their seat.

In the first instance the cameras provided a clear image of the flight crew because they had fallen forwards from their normal seated position and in to the view of the instrument panel.

The second case was not so clear cut. Because the camera angles were designed to avoid identifying images of the flight crew whilst in their normal seated positions, they did not provide direct information about flight crew incapacitation. However, during the normal course of flying, flight crew are seen to move their hands over the instruments, thus providing evidence that they are not physically incapacitated. The inference of this is that the absence of movement for a prolonged period (e.g. several minutes) would provide evidence to suggest the physical incapacitation of a member of the flight crew.

NOTE: This assessment was limited to physical incapacitation of the flight crew as image recorders are unlikely to be able to provide information on any other form of flight crew incapacitation.

2.5.3 **General**

The following interim conclusions can be drawn from the camera installation trial:

a) The single general area view camera that has been proposed by various international working groups (e.g. the International Society for Air Safety Investigators (ISASI) and EUROCAE Working Group 50), has caused much debate, particularly with respect to potential intrusions of flight crew privacy. This camera can be adequately replaced with a set of multiple cameras with carefully selected viewing angles.

b) Information relating to the following issues can be obtained without the use of a rear facing camera:

   i) Aggressive intrusion in the flight deck (e.g. from a passenger/terrorist);

   ii) Flight crew members changing seats;

   iii) Non-flight crew members being invited to fly the aircraft;

   iv) More than one person in any flight deck seat;

   v) Inter-flight crew aggression; and

   vi) Physical incapacitation of the flight crew.

3 Derivation of Scenarios, Rationale and Authors

3.1 The scenarios were drafted jointly by the AAIB and two BALPA Training Captains.

The rationale behind each of the scenarios was that it should be:

a) Safe for the flight crew concerned;

b) Representative of "typical" accidents/incidents;

c) Not skewed in either direction (i.e. for or against image recording); and

d) Practical to implement on the simulator provided.

The main intent of each of the scenarios was that it should increment the mental and physical workload of the flight crew to the point where it would be reasonable to expect mistakes to occur.

3.2 The BALPA Training Captains had wide experience of both training flight crew and contributing to accident investigations. This, combined with the experience of the AAIB, resulted in a set of scenarios that the evaluation team believed would provide valid data for this research.

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Chapter 3 Details of Stage 2 - Scenario Evaluation

Stage 2 of the trial (scenario evaluation) was completed successfully and the details are provided below. However, before the scenario evaluation could commence, the meeting attendees (see paragraph 2.1) were made aware of some trial limitations that were known at the start of this research. These are also provided here.

1 Trial Limitations Known at Start

1.1 The CAA was aware of the following limitations of this trial prior to commencing their research:

a) Simulators are not capable of providing genuine light conditions and, therefore, the effects of changes in ambient light on a flight deck image recorder could not be established during this trial. This issue was discussed and, since it was not the purpose of this trial to develop camera technology, it was agreed that this limitation was acceptable;

b) The simulator provided could not accurately represent parts of the aircraft becoming detached and so scenarios including events like this were not possible. However, as there are many other common contributory factors for accidents, this was not considered to be a significant limitation; and

c) The simulator provided was not equipped with a CVR. This meant that a CVR needed to be temporarily installed resulting in a non-standard equipment installation. This did not have a significant effect on the outcome of the trial.

1.2 The flight crew were aware that they were flying accident scenarios, even though they did not know precisely what was going to happen. This will have resulted in the flight crew being at a heightened state of awareness. It is not known exactly how this affected their responses to the scenario events but, as this research was intended to assess the effectivity of the equipment and not the ability of the flight crew, this was not considered to be a significant concern.

2 Scenario Evaluation

2.1 Who Evaluated the Scenarios

The four proposed scenarios were evaluated by a team made up of:

- The CAA Project Leader
- Two BALPA Training captains
- A CAA Training Captain
- A representative of the AAIB

The team was selected based on their experience with the 737 and assisting with accident investigations. They were also required to be independent of the flight crew who would actually fly the scenarios.

The intent of the meeting was to ensure that proposed scenarios met the objectives set out in paragraph 4 of the Introduction and to discuss any practical difficulties that they might entail.

2.2 This meeting took place at Aviation House, Gatwick in August 2002.

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Chapter 4 Details of Stage 3 - Flying the Scenarios

1 Two flight crews were used to fly the scenarios agreed during Stage 2. Both flight crews had the same Captain but each crew had a different First Officer.

2 The scenario requirements that were drafted in Stage 1 (Camera Installation & Scenario Drafting) of the research were only intended to be basic descriptions of the required events that were intended to be expanded in detail before being run on a simulator.

3 When the full flight simulator trials were actually run, the skill of the flight crew often precluded the originally planned set of events from resulting in any significant incidents or accidents and so further embellishments were added during the full flight simulator trials to ensure that useful data was obtained.

4 Care was taken to ensure that these additional embellishments did not result in either a significant deviation from the original intent of each scenario or a skewed set of data.

5 The overviews of scenarios one to four are provided in Chapter 5 of this report and the details of what was actually flown are provided in Appendices 1 to 4.

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Chapter 5 Details of Stage 4 - Analysis of Incident Data

1 General

1.1 The scenario plan information provided in italics below is a direct quote from the scenario proposals supplied as a result of the scenario evaluation meeting.

1.2 The proposals contain suggested events that were deemed to be representative of "typical accidents/incidents".

As these were only proposals, some of the scenarios were altered subtly during the simulator "flights".

The exact details of what occurred during each scenario are provided in the "Debrief From Simulator Operator" sections of Appendices 1 to 4.

1.3 The analysis information that follows is the CAA analysis of all submitted accident data; flight crew ASRs, BFU's accident reports and BEA's accident reports.

2 Scenario 1

2.1 Scenario Plan

2.1.1 *At Maximum Take Off Weight (MTOW), a run down engine failure during an early turn on a SID probably associated with the first power reduction before flap retraction is complete and on the inside engine (of the turn). Associated with frequency changes on RT and possibly turbulence or weather problems there is usually a long delay to recognition. Using an airfield with a declared emergency turn for terrain clearance in the opposite direction to the SID, such as Glasgow 05 for southbound jet traffic, introduces very significant crew workload and CRM requirements to achieve success. A variety of further reasonable problems can then sustain the workload and complications throughout the approach even to the point of baulked approach.*

- *Start condition: Glasgow Airport, MTOW, engines off parked*
- *Flight plan for a South Departure for London Heathrow (LHR) from Runway 05*
- *Weather: 5km Visibility, 500ft cloud base, no rain, wind 030/15kts*
- *Engine flameout during early turn onto SID (2 NM DME)*
- *Frequency changes, turbulence and weather problems en-route to delay recognition of the engine failure*
- *Auxiliary Power Unit (APU) will not start resulting in electrical load shedding*
- *Further reasonable problems to maintain workload*
- *Microburst*

2.2 Analysis of Accident Data for Scenario 1

2.2.1 The initial accident reports from BEA and BFU were analysed in detail. The analysis of the **interim** reports addressed the following issues:

a) The Flight Crew ASR;

b) Failure Of The APU Starter;

c) Autopilot Failures;

d) Loss of Hydraulics and the Effect on Flight Crew Workload;

e) Turbulence;

f) Cabin Crew Distractions;

g) Minor Discrepancies; and

h) Summary Of Information Gained From Initial Reports.

2.2.2 The analysis of the **final** reports addressed the additional issues listed below:

a) Did an Analysis of the Complete Data Set Result in Opinion Changes?

b) Limitations Imposed by the Supplied Data;

c) Comparison of BFU and BEA Analyses of Image Data;

d) The BFU's General Comment on the Usefulness of Image Data; and

e) BEA's CVR Analysis.

NOTE: Each of these issues is discussed in the CAA Analysis sections of Appendix 1.

2.3 Summary of CAA Analysis for Scenario 1

2.3.1 There were some surprising omissions from both sets of analyses, notably the apparent APU Starter and Autopilot A failures. Equally, although both sets of analyses contained sufficient data to infer an excessive physical workload, neither made specific reference to this (the issue of mental workload is not discussed here, as it would be difficult to make useful conclusions relating to an investigator's ability to detect this based on flight recorder data).

2.3.2 The analyses of this scenario show that image data can provide the following information that is additional to data provided by FDR and CVR:

a) Actual adherence of the crew to checklist procedures; and

b) Crew actions not recorded by CVR or FDR (e.g. some checklist actions and most forms of silent communication).

2.3.3 It can also be seen that image data can provide substantiation for information provided by the other recorders (e.g. the image recorder provided evidence of severe turbulence which confirmed the CVR's recording of crew discussions relating to turbulence). In some cases this will provide the accident investigator with a means of balancing the image recorder's view of a situation with a crew's view of a situation (i.e. was the turbulence actually severe?).

2.3.4 There may be other means to cross validate FDR and CVR data but, in cases where this data only implies a set of events, any form of cross validation must be considered a possible means of achieving resolution.

The analyses of this scenario data also shows that the image data cannot provide certain types of information (e.g. status of systems which have no display and the level of verbal communication between the crew). These types of data still need to be obtained from the FDR and CVR.

NOTE: The accident data, interim and final reports supplied by BEA and BFU and the detailed CAA analysis of these data are located in Appendix 1.

3 Scenario 2

3.1 Scenario Plan

3.1.1 *A tyre failure at or during rotate, again with a heavy aircraft, operating above the maximum landing weight which achieves hydraulic damage to the gear and flap primary system. Usually achieves a gear retraction and partial flap retraction before total loss stops operations and requires alternate operations for subsequent movement of either. It takes a carefully co-ordinated return to achieve success which can then be complicated by any number of relatively minor problems such as weather, on board medical or oven/galley fire. The original cause of unknown gear damage will often be forgotten, leading to landing roll problems, such as multiple wheel failure on the one gear.*

- *Start Condition: Geneva Airport, MTOW and above maximum landing weight, engines off parked*
- *Weather; 5km Visibility, 500ft cloudbase, wind 10kts down the runway*
- *Flight plan for departure to Heathrow (LHR) either runway okay*
- *Tyre failure at rotation all tyres on one side*
- *Total hydraulic fluid loss from both A and B systems gear retraction okay and partial flap*
- *Aircraft operated in manual reversion*
- *Rear galley fire during subsequent return*
- *If landing rolls looks okay - collapse landing gear*

3.2 Analysis of Accident Data for Scenario 2

3.2.1 The initial accident reports from BEA and BFU were analysed in detail. The analysis of the **interim** reports addressed the following issues:

a) The Tyre Burst;

b) The Effect of the Tyre Burst on the Landing Sequence;

c) Loss of Hydraulics and the Effect on Flight Crew Workload;

d) The Fire;

e) The Thrust Reversers; and

f) Summary of Information Gained from Initial Reports.

3.2.2 The analysis of the **final** reports addressed the additional issues listed below:

a) Did an Analysis of the Complete Data Set Result in Opinion Changes?

b) Limitations Imposed by the Supplied Data;

c) Comparison of BFU and BEA Analyses of Image Data;

d) General Image Recorder Issues:

i) The BFU's General Comment on the Usefulness of Image Data;

ii) Failed Mitigation Attempts;

iii) Comparison of Analysis Approaches; and

e) Issues Raised during the Analysis of Initial Reports.

NOTE: Each of these issues is discussed in the CAA Analysis sections of Appendix 2.

3.3 **Summary of CAA Analysis for Scenario 2**

3.3.1 Neither of the accident reports correctly determined the initial cause of the problems (i.e. the tyre burst). As previously discussed, this was a largely predictable outcome, the only element of surprise being that neither of the CVR analyses mentioned any flight crew discussion about a 'rumbling noise'.

3.3.2 There were some differences between the reports. The BEA reports highlighted system issues that the BFU reports did not - this was particularly true with respect to the two image data analyses. The BFU reports provided information about what the crew were doing that was absent from the BEA analyses - an example of this is the pre-flight checks.

3.3.3 The differing analyses of the image data clearly show that the investigator's focus or 'slant' has a definite effect on the amount useful information that can be obtained from an image recorder.

While this is almost certainly true for any other kind of flight recorder data too, it may be especially true for image recorders. This is because an image recorder contains a roughly equal combination of information about 'what happened' and 'why it happened', whereas an FDR usually contains more information about 'what happened' and a CVR usually contains more information about 'why it happened'.

It is true to say that both FDRs and CVRs will contain both types of information but possibly not in as greatly a combined manner as an image recorder.

3.3.4 Although this scenario demonstrates some of the advantages of an image recording system (e.g. the ability to see what alerts were displayed to the flight crew) it also clearly shows that the scope of these benefits does have limits. Some of those limits are due to system constraints, such as the absence of audio information, and some of those limits are due to the way in which the data is analysed.

This scenario does show that it would be possible to determine that a flight crew tried and failed to achieve one or more physical tasks. This means that it may be possible to determine that a flight crew were unable to perform necessary mitigating actions rather than simply failing to take them.

It is surprising that the image data was not used to demonstrate that the flight crew were subjected to an excessive physical workload. Although this information could have been inferred from the FDR and CVR data, one of the previous assumptions about image data was that it would be able to show excessive physical workload. Neither the analysis of this scenario, nor the analysis of scenario 1, appears to support that theory.

This scenario shows that there are several occasions when the image data provides substantiation for the FDR and/or CVR data. One example of this is that the FDR and CVR analyses report that the hydraulics had failed and the BEA image data analysis also references complete loss of hydraulic pressure. As previously discussed, data that corroborates the FDR and CVR information can be very useful in cases when determining probable cause is difficult.

Once again, it is possible to see that there are some forms of information that can only be obtained from the FDR (e.g. the centre-line deviation and associated rudder input) and some which can only be obtained from the CVR (e.g. the Captain's discussions with the cabin crew).

It is also interesting to note that this scenario shows that there are some forms of information that cannot be obtained using any type of flight recorder (e.g. what the flight crew are looking at). Although this infers that there is 'missing information' it is probable that there would be some form of crew response to what they are looking at, either in the form of physical actions or crew discussion. This being so, the 'missing information' may well have little effect on the determination of probable cause.

NOTE: The accident data, interim and final reports supplied by BEA and BFU and the detailed CAA analysis of these data are located in Appendix 2.

4 Scenario 3

4.1 Scenario Plan

4.1.1 *ATIS:* *Geneva, "A", Runway 23, 180/22 CAVOK 35/20 1002, Thunderstorms in the vicinity.*

Performance: *MTOW for runway*

Exercise: *Engine fire, shortly after Vr. Fire not extinguished by the fire bottles. Crew probably decide to return and land as soon as possible (ie. overweight). If necessary encouraged by the cabin crew who call on the interphone to remind the captain that smoke and flames are visible (wing fire?) and passengers are extremely panicky. On approach/finals, aircraft encounters a windshear warning and/or microburst (Simulation does have microburst and windshear). Depending on the severity of the microburst (that has been selected) the aircraft may crash (it is very heavy), continue to a landing or go-around. If the latter course is taken then another microburst may be encountered.*

- *Start condition Geneva Airport, Maximum Take Off Weight, engines off, parked*
- *Weather CAVOK with thunderstorms wind 180/220 knots QNH 1002*
- *Plan for departure on runway 23 to LHR*
- *Initiate heavy rain on take off*
- *Engine fire shortly after Vr*
- *Fire not extinguished by bottles*
- *Cabin crew inform Captain that smoke and flames are visible from engine and the passengers are panicking.*
- *Cabin crew inform Captain that wing appears to be on fire and the passengers are panicking*
- *Windshear and microburst on approach (50% microburst)*
- *If go around flown initiate a 100% microburst on next approach*

4.2 Analysis of Accident Data for Scenario 3

4.2.1 The initial accident reports from BEA and BFU were analysed in detail. The analysis of the **interim** reports addressed the following issues:

a) The Flight Crew ASR;

b) The Engine Fire;

c) The Hydraulics Systems;

d) Lack Of ILS; and

e) Summary of Information Gained from Initial Reports.

4.2.2 The analysis of the **final** reports addressed the additional issues listed below:

a) Did an Analysis of the Complete Data Set Result in Opinion Changes?

b) Limitations Imposed by the Supplied Data;

c) Comparison of BFU and BEA Analyses of Image Data:

i) Checklists;

ii) Hydraulics Warning;

iii) Loss of Instruments;

d) The BFU's General Comment on the Usefulness of Image Data;

e) Passenger Unrest; and

f) Loss of ILS.

NOTE: Each of these issues is discussed in the CAA Analysis sections of Appendix 3.

4.3 Summary of CAA Analysis for Scenario 3

Once again there were differences in emphasis between the BEA and BFU analysis of the image data. The conclusions that may be drawn from this are noted in the analysis of scenario 2.

This scenario shows that there are several occasions when the image data provides substantiation for the FDR and/or CVR data. One example of this is that the FDR and CVR analyses report that an electrical system had failed and the BEA image data analysis corroborates this.

As previously discussed, data that corroborates the FDR and CVR information can be very useful in cases when determining probable cause is difficult.

NOTE: The accident data, interim and final reports supplied by BEA and BFU and the detailed CAA analysis of these data are located in Appendix 3.

5 Scenario 4

5.1 Scenario Plan

5.1.1 *Aircraft at a light take-off weight and cg on the aft limit. Strong gusty wind with crosswind on limit for landing. Just after V1 high vibration on upwind engine (use fan blade loss on sim to create vibration) followed by rundown soon after Vr which is accompanied by loss of left and right primary displays for about two seconds, if EFIS equipped aeroplane. Severe turbulence on approach after return with landing baulked by preceding aircraft having problem and being slow to clear runway. Go-around has to be flown from about decision height. On second approach, same severe turbulence with significant wind shear in the flare.*

- *Start condition - Glasgow airport, light take off weight, engines off, parked*
- *Flight plan for a South Departure for LHR from Runway 05*
- *Weather; 5km Visibility, 500ft cloud base, no rain, wind 90? (crosswind limit)*
- *Engine fan blade loss just after V1*
- *Loss of Captain and first officer’s flight displays*
- *Severe turbulence on approach*
- *Go around due to traffic on runway*
- *Second approach with same severe turbulence with significant wind shear in flare*

5.2 Analysis of Accident Data for Scenario 4

5.2.1 The initial accident reports from BEA and BFU were analysed in detail. The analysis of the *interim* reports addressed the following issues:

a) The Flight Crew ASRs;

b) Smoke in the Flight Deck;

c) Loss of the First Officer's Displays;

d) Failure of the APU Starter;

e) Failure of Auto Electric Transfer;

f) Loss of Captain's Glasses; and

g) Summary of Information gained from Initial Reports.

5.2.2 The analysis of the *final* reports addressed the additional issues listed below:

a) Did an Analysis of the Complete Data Set Result in Opinion Changes?

b) Limitations Imposed By The Supplied Data;

c) Comparison Of BFU and BEA Analyses Of Image Data; and

d) The BFU's General Comment on the Usefulness Of Image Data.

NOTE: Each of these issues is discussed in the CAA Analysis sections of Appendix 4.

5.3 Summary Of CAA Analysis For Scenario 4

5.3.1 The analyses of this scenario reinforce the results of the previous analyses, particularly with respect to the uses of the different types of flight recorder.

In addition to this, these analyses make four other significant points.

5.3.2 Firstly, if image data is analysed in isolation from other recorder data, it could be actively misleading. This leads to the conclusion that proposals to use image recorders as a replacement for an FDR and/or CVR should be carefully considered to ensure that any investigations that may be based on a single image recorder do not result in spurious findings.

5.3.3 Secondly, the analyses of this scenario would seem to support the theory that image recorder data could show that information that was recorded on the FDR was not displayed to the flight crew. As this may lead to a reduction in the number of accidents that are deemed to result from pilot error, it is significant result.

5.3.4 Thirdly, the initial analyses of this scenario would appear to indicate that an image recorder is not guaranteed to detect smoke in the flight deck, even if it is visible to the crew. This is because the smoke may be generated outside the camera field of view. However, it is fair to say that, if the smoke is sufficiently dense to be seen, and it is generated within the camera field of view, the camera system will record it. Whether or not the investigators see it will depend upon how dense the smoke is and whether another source of information has led them to look for it.

This implies that one of the main proposed uses of image recorders cannot necessarily be achieved.

5.3.5 Finally, the analyses of these scenarios strongly suggest that the order in which flight recorder data types are analysed can have a direct effect on the result of the analysis. Although this would appear to be due to a set of human factors relating to accident investigation, it is a point that should be carefully considered when debating the use of any type of flight recorder, including image recorders.

NOTE: The accident data, interim and final reports supplied by BEA and BFU and the detailed CAA analysis of these data are located in Appendix 4.

Chapter 6 Details Of Stage 5 - Wash Up Meeting

1 Who Attended The Wash Up Meeting

1.1 This meeting was attended by:

- The CAA Project Leader
- Members of the flight crew that flew the scenarios
- AAIB
- BEA
- BFU
- BALPA Training Captains
- The camera manufacturer

1.2 The meeting was hosted by the CAA and its purpose was to review the flight crew, BEA and BFU reports and the CAA analysis of those reports. The review was intended to:

a) Compare and contrast the reports generated after the event against the actual events programmed in to the simulator;

b) Gain an understanding of each party's view of the events;

c) Discuss the questions and possible anomalies identified in the CAA's analysis; and

d) Identify any errors or contentious points in the CAA's analysis.

2 Conclusions Reached During Wash Up Meeting

2.1 The Flight Crew Discussions

2.1.1 The flight crew were debriefed immediately after flying each scenario so they were familiar with the actual programmed events and, as previously discussed, their ASRs were typically accurate.

Any immediately obvious anomalies were discussed with them during the debrief sessions and so the main source of discussion with the flight crew was the CAA questions that were raised during the detailed analysis of the reports.

Most of the CAA flight crew questions related to the limited amount of flight deck discussion for certain events.

In almost all cases, the reason for the absence of discussion was quite simple. Both members of the flight crew could clearly see what was going on, they knew exactly what each was required to do next and so there was no need for discussion.

2.1.2 This is a significant conclusion as far as CVR and image recorder analysis goes. It makes it very clear that highly trained flight crews frequently have no need to discuss events that occur in the flight deck.

This means that, in some cases, the CVR may contain very little information about what the flight crew are doing or facing.

Although no flight recorder could capture purely mental activities, it is possible that image recorders could capture some of the silent communication (e.g. hand gestures) that occurs on the flight deck, thus providing a little more information to the investigator.

Where the absence of discussion was not due to a lack of need for discussion, the root cause was because the flight crew had not been aware of the events. This was either due to a range of human factors associated with the workloads they were handling or to simulator glitches.

2.2 Investigator Discussions

BEA and BFU had been isolated from all other members of the research team during their analysis of the flight recorder data. As a result, this meeting was their first opportunity to gain an understanding of what events had actually been programmed in to the simulator and how close their accident reports had been to the programmed events.

The discussions with the investigators fell in to two categories:

a) Discussion of the different ways to analyse image recorder data and the possible impact of using different approaches; and

b) Discussion of the identified anomalies in their reports.

2.2.1 Differing Approaches To Image Data Analysis

BEA and BFU agreed that they had approached the image data in two different ways.

2.2.1.1 The discussion on this subject concluded that this was reasonable as there is currently no guidance related to analysing image data and the rules of this research project did not specify how data should be analysed.

It was agreed that both approaches had their strengths and their weaknesses and that a combination of both approaches may have yielded better results.

The particular areas where a combined approach would have been beneficial related to time periods such as pre-flight checks and the use of checklists during emergencies.

The issue of image data being actively mis-leading was also discussed. The investigators agreed that there were cases where they had been misled by the data.

They also agreed that there were situations where, had they not been in possession of other information (i.e. CVR and FDR), they would have been misled by the image data.

2.2.1.2 As a direct result of these discussions, all members of the research team agreed on the following points:

a) Image data should not be used as a sole source of accident data; and

b) Guidance needs to be drafted for the analysis of image data.

2.2.1.3 The direct development of guidance material for accident investigation is outside the scope of this research, however, it is recommended that, at the very least, any proposed guidance covers:

a) The sources of material/data that should be used to corroborate image data;

b) Proposed approaches to analysing that data (i.e. a combination of analysing flight crew activity and system status); and

c) The ways in which image data can be misleading.

2.2.2 Discussion Of Identified Anomalies

There was considerable discussion of the accident report anomalies that the CAA analysis identified.

Some of the discrepancies could be explained by the fact that image data can be misleading, as discussed above. However, there were anomalies that could not be attributed to this.

Some of the discrepancies were due to the order in which the data was analysed, e.g. BFU noted smoke in the flight during their analysis of the image data where BEA did not. After discussion, it was concluded that this was almost certainly due to the fact that BFU had listened to the CVR first and already knew that there was smoke on the flight deck, whereas BEA analysed the image data first and did not know to look for it.

Some of the discrepancies appeared to be direct mistakes that could not be properly explained during the wash up meeting.

This understandably concerned those present at the meeting and it was agreed that the AAIB would act as an independent arbiter and investigate the causes for the mistakes.

NOTE: The details of this investigation are provided in Chapter 7 paragraph 2 of this report.

2.3 CAA Analysis

The CAA analysis did not raise any significant areas of contention, however, there was considerable discussion relating to two main topics:

a) Smoke; and

b) Human factors in the flight deck.

2.3.1 Smoke

The main source of the debate about smoke was the discrepancy between the BEA report and the BFU report. BFU reported that there was smoke in the flight deck; BEA did not.

The relevant section of image recorder data was investigated at length by both the CAA project leader (during the CAA's analysis) and the whole of the project team during the wash up meeting.

The results of the various investigations were inconclusive. It is possible that the image data shows the smoke but the team agreed that it was difficult to see the smoke and be sure that it was smoke (some patterns were found in the image data that could have been smoke or could have been shifts in lighting).

The final conclusion of this was that image recorder systems would record the presence of smoke as long as it was in the field of view of a camera. However, the ability of an investigator to see the smoke would depend on how dense it is and whether other data had led them to expect to see smoke.

2.3.2 Flight Crew Activities, the Flight Deck Environment and Associated Human Factors

One of postulated benefits of image data was that it would provide a lot of information about human factors in the flight deck.

The wash up meeting spent considerable time analysing the CAA's data to determine whether this had actually been proved.

The analysis covered the following basic issues:

a) Flight Crew Distraction;

b) Flight Deck Intrusion/Aggression;

c) Flight Crew Incapacitation;

d) Flight Crew Work Load;

e) Failed Mitigation Attempts; and

f) Blanked Displays & Misleading Information.

2.3.2.1 **Flight Crew Distraction**

It was agreed that, because image recorder data is not supported by sound, the ability of an image recorder to indicate that a flight crew has been distracted is dependent upon the crew's physical reaction to the distraction.

If the source of the distraction was not visible to the cameras (e.g. an aural interrupt via the intercom system or an event external to the flight deck) an image recorder would only be able to indicate that a distraction had occurred if the flight crew exhibit a physical reaction to the distraction (e.g. turning to face the source of the distraction).

In the absence of a physical reaction, an image recorder would provide very little information relating to distractions outside the view of the system cameras.

The wash up meeting also concluded that the lack of supporting aural data from an image recorder would make determining the scale of a distraction that occurs outside the view of the system cameras very difficult.

If the crew exhibit a physical reaction to the distracting event, a camera would show this but it would not be possible to differentiate between trivial events (e.g. offers of food to the crew) and potentially hazardous events (e.g. galley fires).

The conclusion was that, with the exception of flight deck intrusion/aggression, which are discussed below, image recorders could only provide limited information relating to flight crew distraction.

In order to gain a complete understanding of any distractions the flight crew may have been subjected to, image recorder data should need to be supported by CVR data.

2.3.2.2 **Flight Deck Intrusion/Aggression**

The discussions that occurred during the wash up meeting concluded that an appropriate combination of sensibly located, forward facing cameras should be able to detect:

a) Anyone attacking the flight crew, even from behind;

b) A member of the flight crew wielding a weapon;

c) Flight deck intrusions that affect the ability of the flight crew to control the aircraft, including unauthorised access to flight controls; or

d) Members of the flight crew swapping places.

During this research, the research team was provided with a list of specific forms of flight deck intrusion/aggression that investigators believed could result in hazardous, or even catastrophic events.

It was agreed that the research data indicated image recorder systems would be capable of detecting each of these without the need for rear facing cameras.

2.3.2.3 Flight Crew Incapacitation

The wash up meeting agreed that an image recorder system would be capable of showing that a member of the flight crew had become incapacitated and fallen forwards on to the flight controls.

There was some discussion about an image recorder's ability to detect that a member of the flight crew had become incapacitated if they fell backwards against their seat.

The attendees of the wash up meeting discussed the images captured by the image recorder and agreed that, under normal circumstances, a flight crew is rarely inactive for extended periods of time.

It was also agreed that it was unlikely that one member of the flight crew would be considerably more active than the other(s).

Based on this, it was concluded that, should an image recorder show an extended lack of activity from a member of the flight crew, it would be reasonable for an investigator to conclude that the individual was incapacitated.

2.3.2.4 Flight Crew Workload

Flight crew workload can split in to two categories; mental activities and physical activities. Based upon the results of this research (see appendices 1-4) the team concentrated its discussion on physical workload.

Image data can provide corroborative evidence that demonstrates the number of events (e.g. system failures) that a flight crew are faced with. Note that functioning FDRs and CVRs will also contribute information about system failures and flight deck events.

Additionally, an image recorder could provide information that indicates how physically hard the flight crew have to work.

However, whether this information can be used to conclude that flight crew workload was a contributing factor to an accident or incident depends upon a set of basic human factors:

a) Every individual has a different ability to cope with physical work loads;

b) Minor physical injuries (e.g. strained limbs) can have an affect on an individual's ability to manage their physical workload;

c) An individual's mental state can have an affect on their ability to manage their physical workload;

d) The level of an individual's experience can affect their ability to manage their physical workload; and

e) The investigator will view the data based on their impression of what too much work looks like, which may not necessarily be representative of a flight crew's impression of what is too much work.

After much discussion, the team concluded that image recorders could provide information relating to the physical workload of a flight crew. However, it was also agreed that this information would not necessarily be identified by an accident/ incident investigation.

Although the conclusion would be valid without additional training, there are known indicators of stress (both physical and mental) that investigators could use as part of their analysis of image recorder data.

NOTE: These are discussed in Chapter 7, paragraph 1 of this report.

2.3.2.5 **Failed Mitigation Attempts**

The research data highlighted one unexpected benefit of image recorders.

The data indicates that an image recorder can show when a flight crew have attempted a mitigating action and failed to achieve it (e.g. trying and failing to deploy thrust reversers).

It was agreed that this was information that would not be available from an FDR and, unless the flight crew discussed the failure, was unlikely to be available from a CVR.

It was further agreed that information such as this could reduce the number of accidents/incidents where flight crew error is stated as a contribution to the event.

2.3.2.6 **Blanked Displays and Misleading Information**

The research showed that displays being lost/blanked would be evident from an image recording.

In low lighting conditions, there is a perceptible drop in the ambient light. and a blanked screen is sufficiently different from its surroundings to show up.

Although the limitations imposed on the research mean that this could not be tested in bright light, the difference in appearance may be sufficient to show that a screen has been lost, even if the drop in ambient light is not perceptible.

There have been a number of accidents where investigators have been unable to understand why flight crew failed to react to information that the FDR implied was available. One possible explanation was that the displays had been lost and the flight crew simply never saw the information.

Image recorders will enable investigators to determine whether this was the case.

Another possible explanation is that the information displayed to the crew was different to that recorded on the FDR.

There are a number of possible reasons for this, including data corruption or the effects of filtering prior to recording on an FDR.

If the resolution of the data stored on an image recorder is sufficient, accident investigators may be able to determine whether the crew saw the same information that was recorded on the FDR.

3 Additional Work Resulting from the Wash Up Meeting

3.1 The wash up meeting identified three areas of investigation that the research had yet to address. These were:

a) An investigation in to the causes of the errors in both the BEA and BFU analyses;

b) The practical issues associated with installing image recorder systems; and

c) The issues associated with the small statistical sample used in this research.

It was agreed that each of these issues would be addressed and the report re-submitted to the research team prior to the research being completed.

3.2 During the wash up meeting the CAA noted that they had not yet had time to discuss their findings with a human factors specialist. It was agreed that this too would be covered in the 'additional work' phase.

Each of the identified issues is discussed below in Chapter 7 of this report.

Additional human factors analysis is covered in Chapter 7 paragraph 1, the analysis of BEA and BFU errors is discussed in Chapter 7, paragraph 2, Chapter 7, paragraph 3 addresses the practical implementation issues and Chapter 7, paragraph 4 the small statistical sample.

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Chapter 7 Results of Additional Work

1 Additional Human Factors Investigation into Responses to Stress

1.1 It is not possible to determine how stressed a person is by looking at their face, and, although in some cases it can be possible to determine it by listening to their voice, it is very difficult. However, human beings do display predictable behavioural patterns in response to stress and/or high workload.

1.2 The predictable patterns fall in to seven categories, listed below. Each of these are discussed in Appendix 10, together with an assessment of whether an accident investigator could detect them using image recorder data.

a) Task Mis-Management;

b) Narrowing Of Focus / Loss Of Perception;

c) Solving Simple Problems;

d) Ignoring The Problems;

e) Inability To Re-Assess Situational Data;

f) "It's Always Worked Before!"; and

g) Effect Of Cameras On Crew Stress Levels.

1.3 It should be noted that detection of any of the behavioural patterns listed above is dependent on a forward facing image recorder system (i.e. one whose cameras point from the rear of the flight deck to the front of the flight deck). This is because detection of these behaviour patterns relies on looking at physical actions performed by the crew together with the relevant flight deck instruments they are interacting with. Views such as these could not sensibly be gained from rear facing cameras.

2 Analysis of Errors in BEA and BFU Analyses

2.1 The analysis of the initial accident investigation reports generated for this research showed that mistakes had been made in the analysis of the image data. This was obviously a source of concern, particularly since image data is so compelling, and it raised a number of questions:

a) Why were the mistakes made?

b) Did the limitations of the trial have any bearing on the mistakes that were made?

c) Did the mistakes indicate a need for additional training to be developed to address issues related to the analysis of image recorder data?

As the correct interpretation of image data is as important as the correct installation to the effectiveness of this system, the CAA agreed to investigate the issue.

2.2 The first two questions were answered with a two part exercise.

2.2.1 Firstly, the CAA investigated the guidance available relating to Accident Investigation (ICAO Annexe 13 and ICAO Document 6920 "Manual of Aircraft Accident Investigation")). The analysis of these two documents made it clear that the limitations of the trial had imposed difficulties on the BFU and BEA that may well have contributed toward the mistakes that were made. The most notable of these limitations were:

a) The inability to consult with other investigators (imposed to ensure that the results weren't skewed);

b) The absence of other aircraft information (e.g. items of structural material); and

c) The use of single person teams (used to avoid overloading departments that were already very busy).

As the CAA does not lead accident investigations, the second part of the analysis of questions 1 and 2 was a request that the UK AAIB (who had no part in the investigation of the data) act as an independent arbiter to analyse why the mistakes were made. Their conclusion was that the mistakes were a direct result of the limitations imposed as a result of the trial. They felt that most of the errors would have been picked up and corrected as part of the multi-person cross checks required by ICAO for a normal investigation.

NOTE: The AAIB's report on this issue can be found in Appendix 6 of this report.

2.2.2 While this was a re-assuring result, it still left the question as to whether the use of image recording systems would necessitate further training for investigators. Analysis of other findings of this research leads to the conclusion that additional training must be required. This training would, at a minimum, have to address:

a) The analysis of stress related behaviour patterns and associated human factors;

b) The use of image recorder data in conjunction with other flight recorders and accident data; and

c) The relevance of other accidents and incidents to flight crew perceived experience.

In addition, the investigators would need to fully understand the flight deck layout of any aircraft they were looking at.

2.3 The analysis of the accident reports also led to one other, very significant finding; image recorder data, when used on its own can be directly and detrimentally misleading.

Although this research imposed the stand-alone investigation of image data, it should be standard accident investigation procedure that all evidence should be corroborated as far as possible, whether or not it comes from a flight recorder.

This practice should mitigate against possible mis-interpretations of image data.

3 Practical Implementation Issues

3.1 Practical Issues Associated with Installing Image Recorder Systems on Aircraft

3.1.1 Several aircraft flight decks were inspected as part of this research and some images of an A320 flight deck are included at the bottom of this section (see figure 3 and 4) to illustrate possible camera locations for an image recording system.

3.1.2 The layout of an aircraft flight deck varies based on a number of factors, the most significant of which are the aircraft type, the type variant and the individual modifications made by the operator of the aircraft. The effect of this is that there are many possible flight deck layouts, which makes it very difficult to provide a definitive assessment of where image recorders could be installed on all aircraft currently being operated. However, this research has highlighted a number of issues that would need to be considered when designing an image recorder installation, irrespective of the flight deck layout.

3.1.3 The ability to install image recorder systems in real aircraft is primarily dependent upon the following issues:

a) The number of cameras required;

b) The available space in the overhead panel; and

c) The space and weight implications of an additional recorder, or the cost implications of a combined recorder.

3.1.4 It would be possible to install image recorder systems in most aircraft. However, it should be noted that this research has not conducted any regulatory (cost) impact assessment for image recorders as this is outside the scope of this project.

3.1.5 It would be possible to add image recorder systems to aircraft designs but the following issues should be carefully considered:

a) The cameras will need to be removable to facilitate maintenance but, once in place, should be fixed to prevent anyone altering their viewing angle. It should be noted that this check may be required on a regular basis;

b) A means of demonstrating that the system is functioning correctly, and that the cameras are recording appropriate images of the flight deck will be required; and

c) The design will need to address all the issues associated with adding a further recording system (plus cameras) to the essential bus.

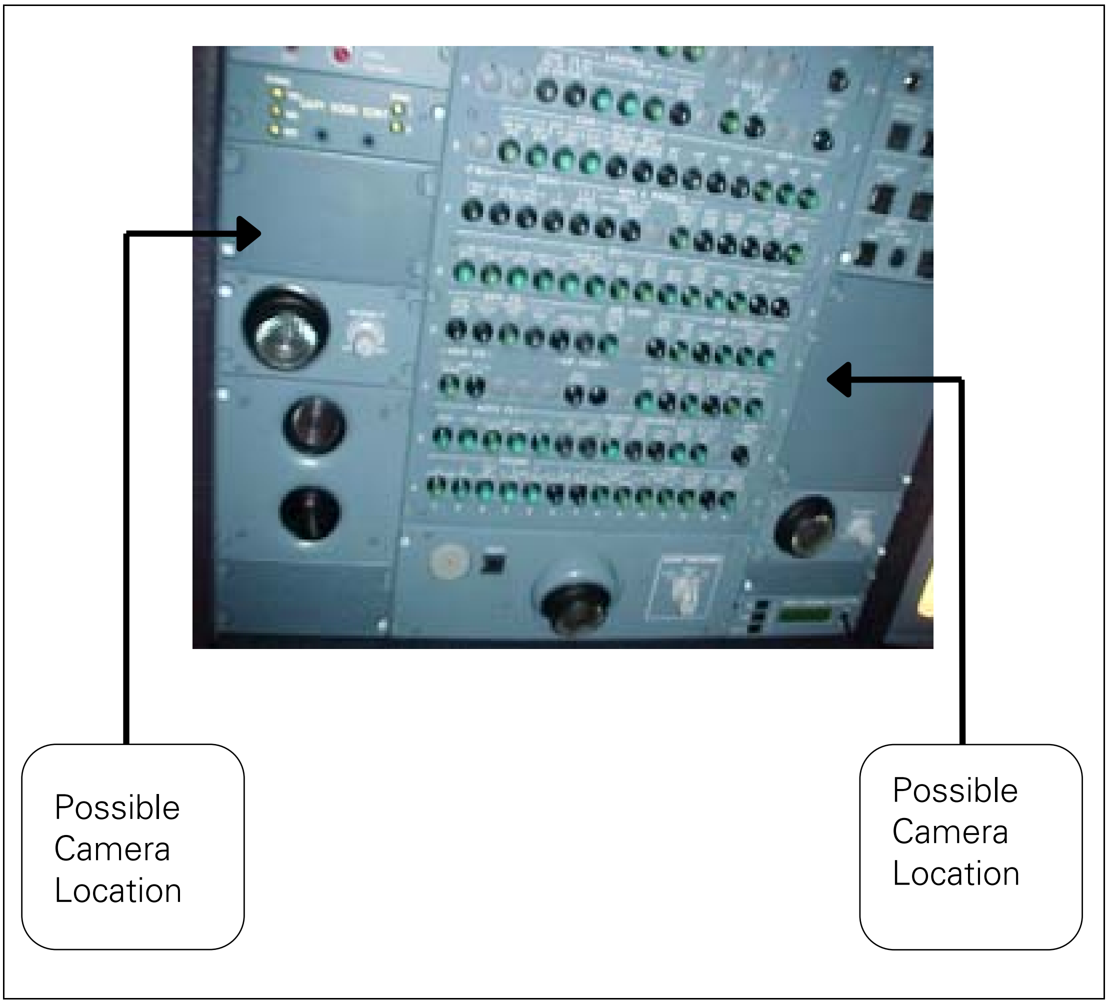

Figure 3 A320 Flight Deck Picture - Overhead Panel View 1 - From the Rear of the Flight Deck Looking Forward

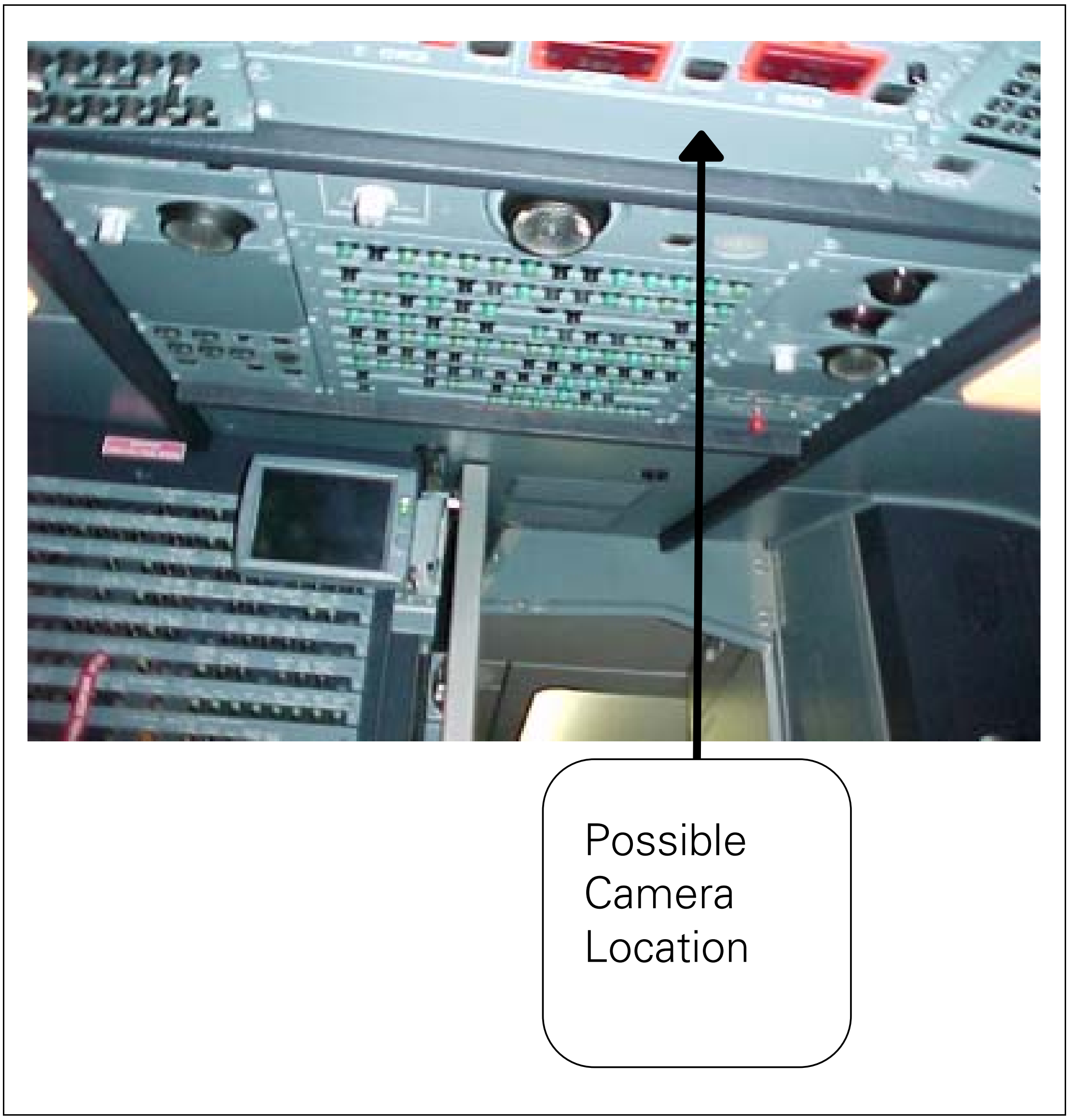

Figure 4 Over Head Panel View 2 - From the Front of the Flight Deck Looking Backward

4 Small Statistical Sample

4.1 The final wash up meeting highlighted the concern that this research, whilst providing valid conclusions, was based upon a small statistical sample (i.e. the four accident scenarios). It was suggested that evaluating the published accident reports from 2002 to determine whether the research conclusions still held true would increase the size of the statistical sample.

Although this was a good point, the CAA concluded that they did not have sufficient expertise to perform this analysis.

4.2 It is recommended that specialists in accident investigation perform this analysis.

Chapter 8 Conclusions

1 Advantages of Image Recording Systems

1.1 Ability to Detect Blanked Displays

This research has shown that image recorder systems can provide clear evidence of the failure of aircraft electronic displays.

It has also been shown that image recorder systems provide images of sufficient resolution to enable investigators to identify both missing data and data fail flags.

This implies that the use of flight deck image recording systems could enable a more comprehensive investigation to be made which may eliminate pilot error as an attributable cause.

This research has also shown that, in addition to identifying failed displays, image recording systems may provide some information as to whether the data displayed to the flight crew is the same as that recorded on the FDR. However, the effectiveness of image recording systems in this area will depend on the resolution of the images provided.

1.2 Ability to Detect Failed Flight Crew Actions

This research has shown that image recording systems can provide information about unsuccessful attempts to resolve problems. This is a potential use of image recorders that has not been discussed before.

FDRs and CVRs can only provide certain types of data. FDRs can only record system status (i.e. what was done and what was not done). They cannot provide information about actions that did not occur.

CVRs can only provide information on flight crew discussions and aircraft environmental noise.

One of the major issues faced by accident investigators is that commercial flight crews frequently act in unison without the need for discussion. This can be particularly true when the flight crew workload is very high.

A clear example of this occurred when the First Officer's displays failed during one of the scenarios. Although the image recorder showed that this had happened, the flight crew did not discuss it at all.

This research also showed that flight crews can sometimes attempt to solve a problem and fail to do so without any audible discussion. If their workload is particularly high they may well resort to visual communication (e.g. looking or pointing) rather than actually saying anything.

If there is no audible discussion relating to a failed attempt to solve a problem and the attempt does not result in a change in environmental noise, the CVR will not provide any information to supplement the lack of FDR information.

This absence of data could result in the flight crew being censured for not taking appropriate action when, in fact, they tried but were unable to do so.

Image recording systems have been shown to be capable of providing information about failed attempts to solve problems. Knowledge of failed mitigation attempts may provide an entirely different focus to an investigation and eliminate the possibility of "crew error due to inaction" being quoted as an attributable cause.

1.3 Ability to See What the Crew are Doing and thus Detect Symptoms of Stress

Although it may be possible to determine that the flight crew is under stress from the CVR, it may not be possible to determine the cause of the stress (i.e. the crew could be stressed due to workload, communication difficulties, simple concern about the situation they are in, system malfunctions etc).

It has been suggested that image data could provide further information about the possible causes of flight crew stress.

Other research has shown that an individual's response to stress is dependent upon their personality, any external factors that they may be subject to and previous experience of similar or related circumstances.

Based on this, it is not possible to state that an individual's facial or verbal expressions are always accurate indicators of the level of stress they have been subjected to.

In addition, this research has confirmed that the interpretation of verbal information (i.e. tone of voice, language used) is subjective and depends upon the investigator(s) involved.

Despite this, there are several known behavioural patterns associated with stress and this research has found that image recorders could provide data relating to these.

This would allow investigators to make an initial assessment as to whether a flight crew was exhibiting the physical manifestations of stress or high workload.

It should, however, be noted that additional training would be required to enable investigators to analyse this human factors data and come to sensible conclusions.

It should also be noted that careful analysis of other supporting information would be required before any final conclusions on crew stress/workload could be drawn. Closer co-ordination between the accident investigation agencies and pilot associations would assist this process.

NOTE: The installation of ICAO Type 1a. Flight Data Recorders will enable the recording and subsequent analysis of input forces applied to the main flight controls. This will provide accident investigators with further indications of physical workload of the flight crew.

1.4 Ability to Corroborate Information Provided by Other Recorders

This research has shown that image recorder systems could provide information that corroborates the findings suggested by other recorders.

An example of this would be the failure of an aircraft system. The FDR may show that a system appears to have failed, however, the lack of data from that system may be due to a wire breaking between the system and the FDR.

Image recorders could provide investigators with a means to check whether there were flight deck indications of the failure.

1.5 Ability to Record Significant Amounts of Data from Flight Panels without the need for Additional Cabling, Associated Weight and Cost Disadvantages

This research has shown that a set of carefully located forward facing cameras could provide a good view of the flight deck displays.

If the resolution of the image was good enough, it is possible that this could provide significant amounts of additional information, without the need for expensive modifications to the FDR system.

However, this finding should be treated with caution.

It is known that the light level in the flight deck can affect the quality of an image, although this research has not managed to establish the extent of that effect.

The light level in a flight deck can change significantly, especially during a long distance flight. This means that the quality of a flight deck image may also change significantly during a long distance flight.

2 Disadvantages of Image Recording Systems

2.1 Intrusion of Privacy

2.1.1 Misuse

Considerable information exists to show that CVR data has been misused.

This misuse has taken a number of forms, including the contents of the CVR being inappropriately broadcast on public media.

If image recorders are to be used for accident investigation, the issues of misuse and data protection will have to be addressed.

Some technical means, such as multi key encryption, have already been discussed within international working groups, e.g. EUROCAE WG-50, but it should be noted that these will need to be supported by adequate legal measures.

When looking at the necessary legal protection of image recorder data, the following should be considered:

a) The current laws of subpoena can, to one extent or another, overcome all data protection laws that apply to flight recorder data; and

b) If this issue is to be resolved the laws relating to the protection and interpretation of image recorder data may need to be re-addressed.

2.1.2 Misinterpretation

Image data can be easily misinterpreted and, since it is also very compelling, it can be difficult to realise that a misinterpretation has occurred.

Unfortunately, the misinterpretation of image data could have serious consequences, which could include either delaying an investigation or promoting an incorrect conclusion during an investigation.

If image recording is to be seriously considered as an accident investigation tool, the issues associated with misinterpretation must be resolved.

The results of this research show that training is a vital aspect of resolving these issues.

It may also be advisable to restrict the interpretation of image data to those who are demonstrably qualified to perform the task.

2.2 Information can be Misleading

This research has shown that image recorder data can be mis-leading, particularly if it is analysed in isolation (see the incident analyses in Appendices 1-4).

Based on this, the conclusion of this research is that, as far as practicable, evidence from image recorders should be corroborated with other sources of data, be they from other flight recordings or engineering evidence. This is true of all information gathered during an investigation and this research has shown that image recordings are at least as likely to be misinterpreted as other sources of data when used in isolation.

It should be standard accident investigation procedure to ensure that all evidence is corroborated as far as possible, whether or not it comes from a flight recorder.

2.3 Cameras can become an Additional Source of Stress

Other research projects (e.g. Chapter 10, referenced document 7) have shown that there is psychological evidence that monitoring people whilst they perform complex tasks has a negative effect on their ability to perform those tasks.

These research projects also show evidence that people perceive having images of their faces and facial expressions recorded to be more personally intrusive than just having their voice recorded. This means that a person's reaction to cameras recording images of their face and facial expressions is likely to be more pronounced.

Although people can eventually get used to cameras in normal situations (Refer to Chapter 10, referenced document 8), discussions with the author of referenced document 8, indicated that their consciousness of the cameras is likely to be re-awakened if something happens to disrupt "normality". This implies that same thing could occur should an emergency situation arise.

The established facts relating to the effect of monitoring would appear to be particularly true if people believe that their actions will be evaluated afterwards. The effect of this is pronounced if the camera is angled towards the person's face.

This results in the conclusion that cameras can affect the way in which flight crews address situations, and their effect is potentially detrimental should they be rear facing.

Since this research has already concluded that rear facing cameras provide very little, if any, useful information for accident investigation, this additional finding leads to the conclusion that the active prohibition of rear facing cameras should be carefully considered.

However, this research has also shown that forward facing cameras can provide information that may be useful for accident investigation and the review of the additional literature referenced in this section indicates this form of camera layout may be less stressful.

2.4 Cost

This research has been limited to establishing the potential effectiveness of image recorder systems. As such it does not include a regulatory impact analysis of the costs likely to be incurred by the installation and maintenance of such systems.

3 Ability to Fulfil Initially Postulated Benefits

3.1 Workload and Stress

Image recorders will be able to provide some indications of the workload and stress a flight crew have been subjected to but their ability to do this is nowhere near as wide ranging as has been postulated.

The image recorder system will only be able to provide indications that a flight crew are exhibiting the physical manifestations of stress. These indications will have to be supported by considerable additional investigation.

It should also be noted that accident investigators will need additional training in human factors analysis to be able to get any benefit from this data.

Finally, whatever data is provided by the image recorder, an accident investigator's determination of excessive workload will depend upon what their individual perception of excessive workload is.

3.2 Detection Of Smoke

This research has shown that if there is smoke in the flight deck and it is in the view of the cameras, an image recorder will record the presence of smoke. However, depending upon the smoke density this may not always be readily apparent to an investigator.

4 Ability to Exclude Explicitly Identifying Images of the Flight Crew

This research has shown that it is possible to avoid recording explicitly identifying images of the flight crew if a combination of appropriately angled, forward facing cameras is used.

Further, although several experiments were conducted, this research has not identified any information relating to passenger and flight crew behaviour/interaction that cannot be gained using forward facing cameras.

Forward facing cameras may not provide views of centre panels or aft and overhead control panels but it is believed that images of these can be obtained using additional cameras directed away from the filght crew.

As explicitly identifying images are one of the major sources of contention surrounding this issue, it seems reasonable that any identified means of avoiding them should be used.

5 Additional Limitations Identified As Part Of The Trial

The analysis of the scenario data identified two additional limitations of the trial.

Both BFU and BEA were kind enough to perform the investigations of the scenarios flown as part of this research but resource limitations meant that they were only able to perform a single person investigation.

As discussed in Chapters 5 and 6 of this report, the limited team sizes and resultant inability to confer and discuss led to certain errors in their analyses.

The AAIB analysed the identified errors and noted that they were mainly due to this problem (see Appendix 6 of this report).

Secondly, the camera angles used in the trial did not provide a view of the overhead panels. There were cases where this meant that the investigators were unable to check whether some alert lights were illuminated.

It is believed that this situation could be resolved with the installation of additional cameras.

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Chapter 9 Recommendations

1 This research has demonstrated that image recording systems can provide additional information that would assist in accident investigation.

The extent of the benefits provided and whether they can be justified in relation to the cost (in both financial and personal privacy terms) will need to be the subject of further research and a carefully prepared regulatory impact assessment.

However, this research has highlighted a number of issues which have resulted in the recommendations discussed in the following paragraphs.

1.1 **No Rear Facing Cameras**

The prohibition of rear facing cameras should be carefully considered, based on the following:

a) They provide no additional information relating to crew's stress levels or workload;

b) There is psychological evidence (Chapter 10, reference document 7) that they have a negative effect on performance; and

c) There is psychological evidence that images of the face are considered to be a more personal intrusion and therefore have a more pronounced effect (Chapter 10, reference document 8).

1.2 **No Explicitly Identifying Views**

Explicitly identifying views of flight crews are not needed in order to gain useful information about accidents and incidents.

A general area view of the flight deck can generally be obtained without showing the head and shoulders of the flight crew while in their normal seated positions.

Finally, the crew identities are already available to the investigators and, should the flight crew change places for any reason, the camera arrangement suggested by this research will show this, as long as the event takes place while the camera is recording.

1.3 **Interpretation of Image Recorder Data must only be Performed by those Specifically trained in Analysing Image Recordings.**

As images can be especially compelling and this research has shown that image data can be misleading, even when analysed by specialists in accident investigation, it is recommended that the analysis and interpretation of image data should only be performed by those specifically trained in this discipline.

It is further recommended that accident investigators, pilot associations, and dedicated human factors specialists should jointly develop this training.

If this training were to result in an accredited joint investigation agency/pilot association qualification, it would be easier to establish the credentials of anyone proposing an interpretation of image recorder data.

1.4 **Increased Co-ordination between Investigation Agencies and Pilot Associations during Investigations.**

This research has identified that, with regard to the analysis of image recordings, accident investigators would benefit from closer co-ordination with flight crews, particularly when investigating information such as perceived knowledge.

It is recommended that the accident investigation community and pilot associations discuss the best means to gather this information.

1.5 **Training**

This research highlighted the need for additional training with respect to specific image recorder issues.

This training should be made available for all organisations involved in the analysis of image recording data.

As a minimum, the training should address the following issues:

a) The benefits & disadvantages of image recorders;

b) Image recorder data must not be used as a single source of information;

c) The limitations of image recorder technology;

d) The need for extensive knowledge of flight deck layout;

e) The need for knowledge of crew background; and

f) The need for detailed understanding of human factors analysis.

1.6 **No Single Recorder Source**

This research has identified that the data produced by any type of flight recorder can be misleading when used in isolation. This is particularly true for image recorder systems.

It should be standard accident investigation procedure that all sources of evidence are corroborated as far as possible.

1.7 **A Regulatory Impact Assessment (RIA) should focus on this report plus input from Pilot Associations and Investigators**

As this research was dedicated to determining whether image recorders can provide useful additional information, it did not address any of the aspects of a regulatory impact analysis.

It is recommended that a further regulatory impact analysis be performed that, as a minimum, addresses the following issues:

a) Protection of flight crew privacy;

b) Installation issues;

c) Maintenance issues (including those associated with maintaining camera angles subsequent to maintenance - this may require similar evidence to that required by reference document 9);

d) Replay issues (including the control of replays); and

e) Possible legislation issues associated with data protection.

Chapter 10 References

1 EUROCAE ED-112 *Minimum Operation Performance Specification for Crash Protected Flight Recorders* Published By EUROCAE in March 2003

2 ICAO Annex 13

3 *Manual of Aircraft Accident Investigation* ICAO Document 6920

4 737 Maintenance Manual Courtesy of Boeing Aircraft Corps

5 *Flightdeck Image Recording on Commercial Aircraft* - ISASI presentation Paper by Pippa Moore of UK CAA - August 2003

6 *Flightdeck Image Recording on Commercial Aircraft* - ISASI Presentation Paper by Mike Horne of AD Aerospace - August 2003

7 *Social Facilitation* by R.B. Zajonc- published in 1965 in *Science2*, issue 149, pages 269-274

8 *Invivo or Invitro: Some Effects of Laboratory Environments with Particular Reference to the Psychophysiology* by Gale A Baker S - Published in "Foundations Of Psychosomatics" 1891

9 CAA Specification 11 *Cockpit Voice Recorder Systems*

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Appendix 1 Investigation Data for Scenario 1

NOTE: All quoted material (e.g. Flight Crew ASRs and Investigation Reports) are shown in italics.

1 Debrief From Simulator Operator

Starting Conditions *Autopilot B u/s on departure* *Autopilot CWS B u/s on departure* *APU Starter u/s*	 *Declared to flight crew* *Declared to flight crew* *Not declared i.e. dormant*
Amended turn no later than 2 DME	*-ATC Pre T/O 13:35*
Taxi at	*13:32*
Take Off	*13:37*
Engine flameout No 1 (LH Engine) in left hand turn	*13:38*
Cobblestones after airborne	
Autopilot A fails	*13:43*
Moderate turbulence - occasionally severe	
Loud bang - cabin crew injury reported	
Right Vector turn	*13:47*
Initiate approach and descent	
Severe injury to cabin crew - doctor requested	*13:49*
Turbulence reduced to light	*13:52*
75% Microburst	
Moderate Thunderstorm	
Variable wind (0kts to 50kts) - tail wind	*13:54*
GPWS "Sink Rate Warning	*"*
Landing	*13:56*
Simulator Recorded 'Crash' Rate of Descent.	

2 Flight Crew ASR

Departed 05 Glasgow (GLA) early (1000 ft above ground level left turn at ATC request). Passing 2500 ft no. 1 engine ran down. Engine fire checklist carried out. Level acceleration at 2700 ft to clean up. Climbed 6000 ft and continued with SID.

SCCM advised that rear cabin crew member had been injured, suspected leg fracture. Radar vectors to ILS 05 GLA for 15 degree flap. Overweight landing.

Moderate to severe turbulence above 1000 ft throughout flight.

3 Initial BFU Analysis Based on FDR and CVR Data

3.1 Flight Plan Data

Date:	*31st August 2002*
Time:	*13:32*
Departure Airport:	*Glasgow*
Departure Runway:	*05*
Captain's Name:	*Malcolm Terry*
First Officer's Name:	*Sam Whatmough*
Deferred Engineering Defects:	*Auto Pilot B, CWS B*
Cloud Base at Take Off:	*500 ft*
Visibility:	*5 km*
Landing Airport:	*Glasgow*
Landing Runway:	*05*
Cloud Base at Landing:	*500 ft*
Visibility:	*5 km*

3.2 Scenario Description from FDR Parameters

The time reference was derived from the recorded parameter "Relative Time", starting at 0s and ending at 1562.300s.

Taxi and take off were found to be under normal conditions.

Rel. Time: 433s: During climb at a "Pressure Altitude" (1013) of 3004ft shortly after setting the "A/T Speed Reference" to 220kt, engine No. 1 ran down rapidly.

Indicating parameters:	*N1 Eng_1 RPM* *EPR* *EGT* *Fuel Flow*
Calibrated Airspeed:	*180kt.*

After engine rundown several discrete warning parameters were activated:

Master Caution
Hyd Warning
Eng Warning
Elec Warning

The thrust lever of engine 1 was removed to 0 42s after N1 has reached a low constant value. At the same time EPR of engine 1 is 0.

During engine rundown the aircraft changed heading from 50° to 345° in a short time and an indicated bank angle up to 26°. While the aircraft was moving with the maximum indicated bank angle, the flaps were removed from 5° to 2°.

During the flight the "Calibrated Airspeed" looked rather "noisy", there were a lot of aileron movements and corresponding bank angle changes.

During the approach phase and after setting the flaps to 5° and then to 15° the roll movements of the aircraft were stabilised.

The aircraft was established on localizer and glide slope to runway 05.

2s after "A/C on Ground" indication, the reverser lever of engine 2 was set to 25° which caused a "Master Caution", "Hyd Warning" and "Flt Control Warning". The "Calibrated Airspeed" in this situation was 157kt. During the deceleration down to a "Calibrated Airspeed" of about 11kt, the aircraft changed its heading periodically until it came to a stop.

3.3 Scenario Description from CVR

The CVR Transcript is more descriptive. Only important parts are reported in detail.

The best impression about the scenario is delivered by the CVR. The crew handled the arising problems (as far as it could be understood) in accordance with the checklists and in a professional manner.

Immediately before touch down the warnings "sink rate" and "pull up" could be heard.

3.4 Conclusion

In this incident scenario engine No. 1 ran down shortly after take off at Rel. Time 433s.

The reason for the engine run down could not be retrieved from FDR parameters and/ or the CVR.

The CVR delivered additional information about a health problem of a passenger and a cabin crew member. The crew handled the emergency situation in a professional manner and as far as could be heard using the emergency checklists.

The aircraft landed safely.

3.5 BFU CVR Analysis

Partial CVR transcript Session 1

Rel. Time		
CVR(min:s)	*FDR(s)*	
->05:48	*->337*	*[Flight preparation]*
05:48	*337*	*tk(?) one is ready for departure*

06:14	*363*	*Power set*
06:19	*368*	*Eighty knots*
06:31	*380*	*Rotate*
06:37	*386*	*Positive climb*
06:38	*387*	*Gear up please*
06:39	*388*	*Gear up*
07:22	*431*	*[Sound of engine rundown]*
07:24	*433*	*Engine failure*
07:26	*435*	*[Conversation and handling noise]*
08:02	*482*	*...engine failure on number one engine...*
08:05	*485*	*Okay, I confirm that's number one engine...*
08:09	*489*	*[Conversation, several checks and handling noise]*
09:58	*587*	*tk(?) one, we have an engine failure on the number one engine ...*
10:24	*613*	*Pan, pan, pan, pan, pan, pan......*
10:53	*642*	*You have control (control handed over to F/O)*
10:57	*646*	*[Several checks]*
11:26	*675*	*Number one isolation valve ...*
11:32	*681*	*...so it's closed...*
12:02	*711*	*APU ?global? start*
12:06	*715*	*Fuel balance*
12:15	*724*	*[Loud bang]*
12:17	*726*	*What was that?*
12:18	*727*	*Lightning strike?...*
12:20	*729*	*No idea*
12:34	*743*	*[Conversation, several checks, handling noise]*
13:00	*769*	*[Cabin attendant reports problem with a passenger]*
14:37	*866*	*... Heading one nina zero, tk(?) one*
14:42	*871*	*... Radar heading one eight zero, tk(?) one*
14:47	*876*	*[Conversation, checks]*
16:30	*925*	*... One engine ?? off landing checklist*
15:53	*942*	*tk(?) one right radar heading north ...*
16:02	*951*	*2500, QNH nina zero(?), tk(?) one*

16:10	*959*	*[Conversation]*
17:19	*1028*	*It'll be a flaps 15 landing ...*
17:41	*1050*	*[Conversation with cabin attendant about a health problem of a passenger]*
18:05	*1074*	*Cabin attendant: The cabin is secured*
18:32	*1101*	*Zero five three is the inbound track*
19:06	*1135*	*[Morse code "DCS" = Dean Cross]*
19:21	*1150*	*[Morse code "IUU" = ILS RWY 05]*
19:22	*1151*	*tk(?) one right zero six five, thank you, full established*
19:25	*1154*	*[Ground controller informed about an injured passenger and crew member]*
19:55	*1184*	*tk(?) one, three fif, 3000 and now established on the ILS localizer*
20:05	*1194*	*Flaps one? Flaps one selected*
21:17	*1266*	*All right, let's go over this, ahh ...*
21:22	*1231*	*Go around procedure?*
21:24	*1233*	*[Several checks and preparation for landing]*
22:11	*1320*	*And limit the bank angle to 15 degrees ...*
22:28	*1337*	*Minima for Glasgow is twenty ...(unreadable)*
22:42	*1351*	*[Several checks]*
23:49	*1358*	*Landing checklist is complete*
24:53	*1482*	*tk(?) one, we land zero five*
25:00	*1489*	*PIC: Okay, I have control*
25:12	*1501*	*"Sink rate, pull up, ... sink rate"*
25:18	*1507*	*[Touch down], reverse*
25:36	*1525*	*Seventy(sixty?) knots*
25:56	*1545*	*{End of CVR recording}*

3.6 BFU FDR Traces For Scenario 1

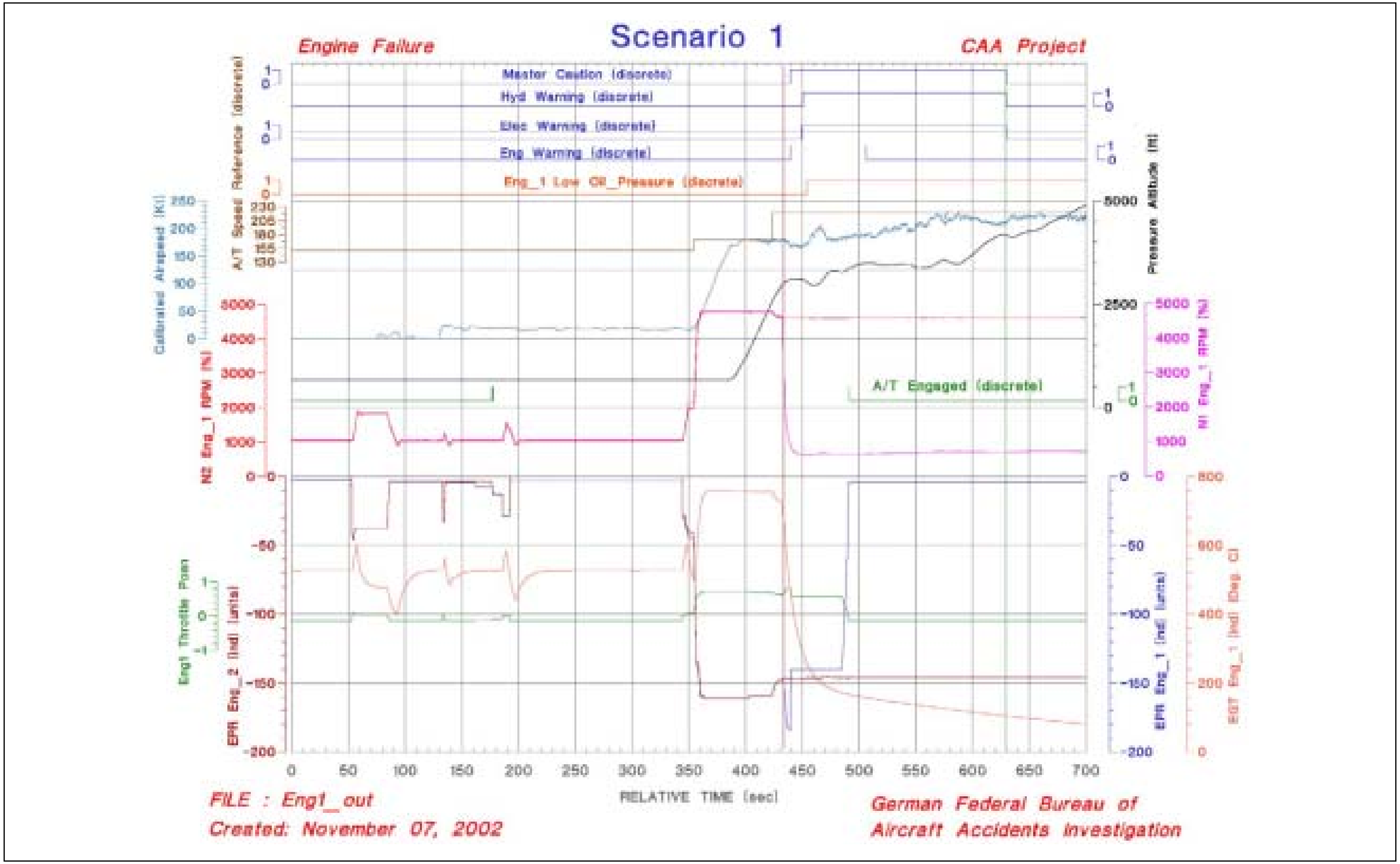

Figure 5 Data Analysis for Scenario 1 - BFU FDR Trace 1

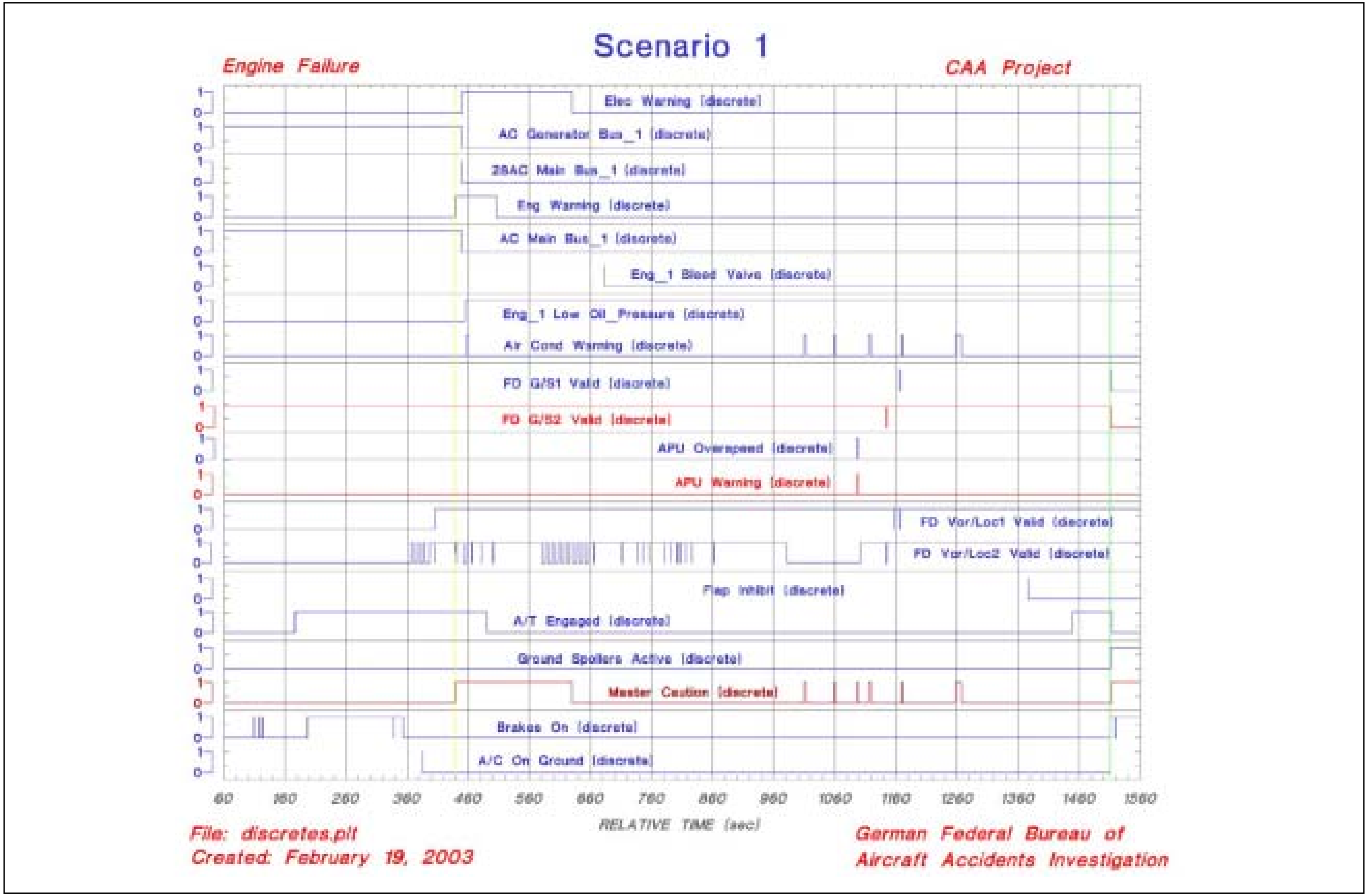

Figure 6 Data Analysis for Scenario 1 - BFU FDR Trace 2

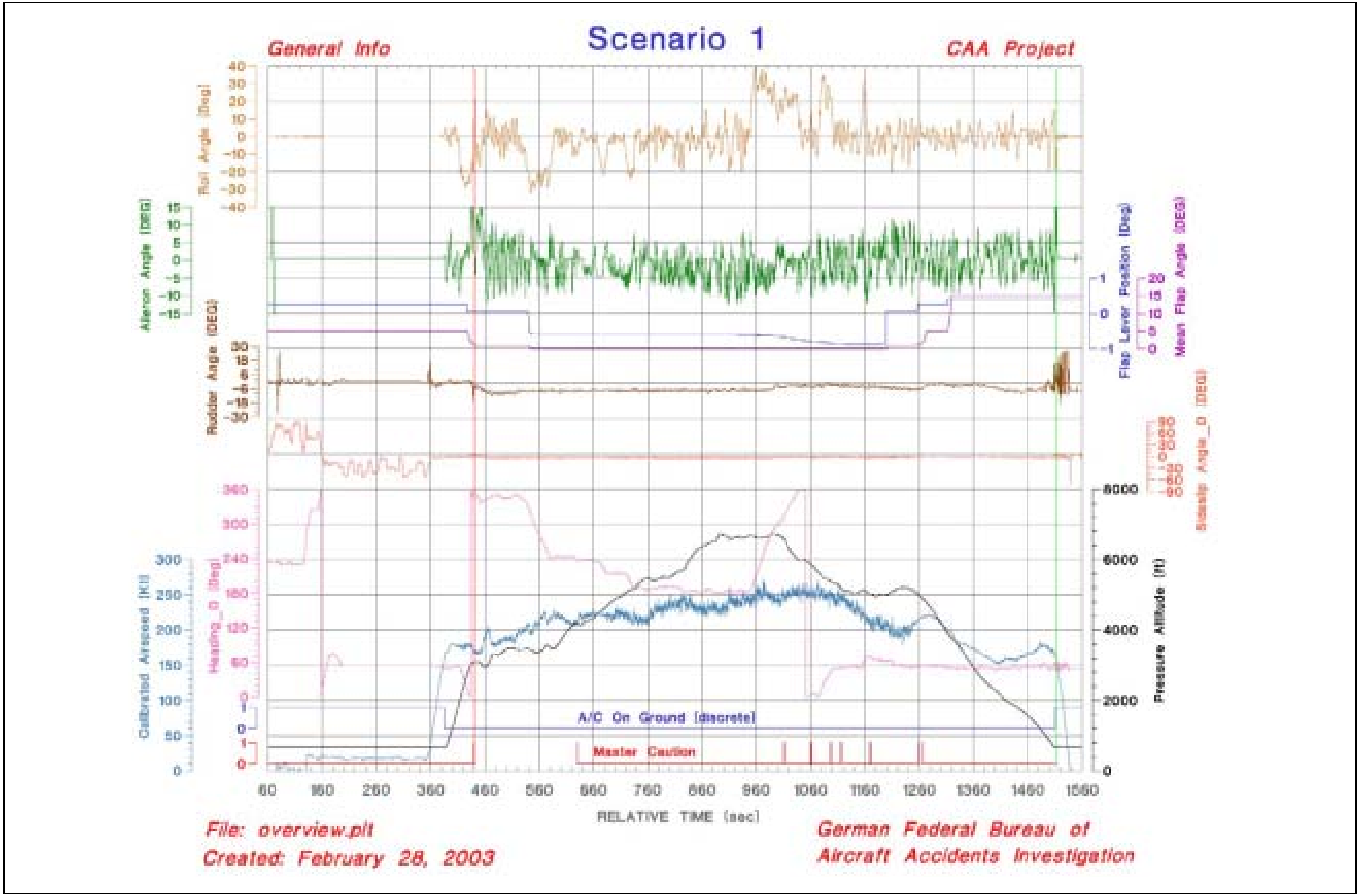

Figure 7 Data Analysis for Scenario 1 - BFU FDR Trace 3

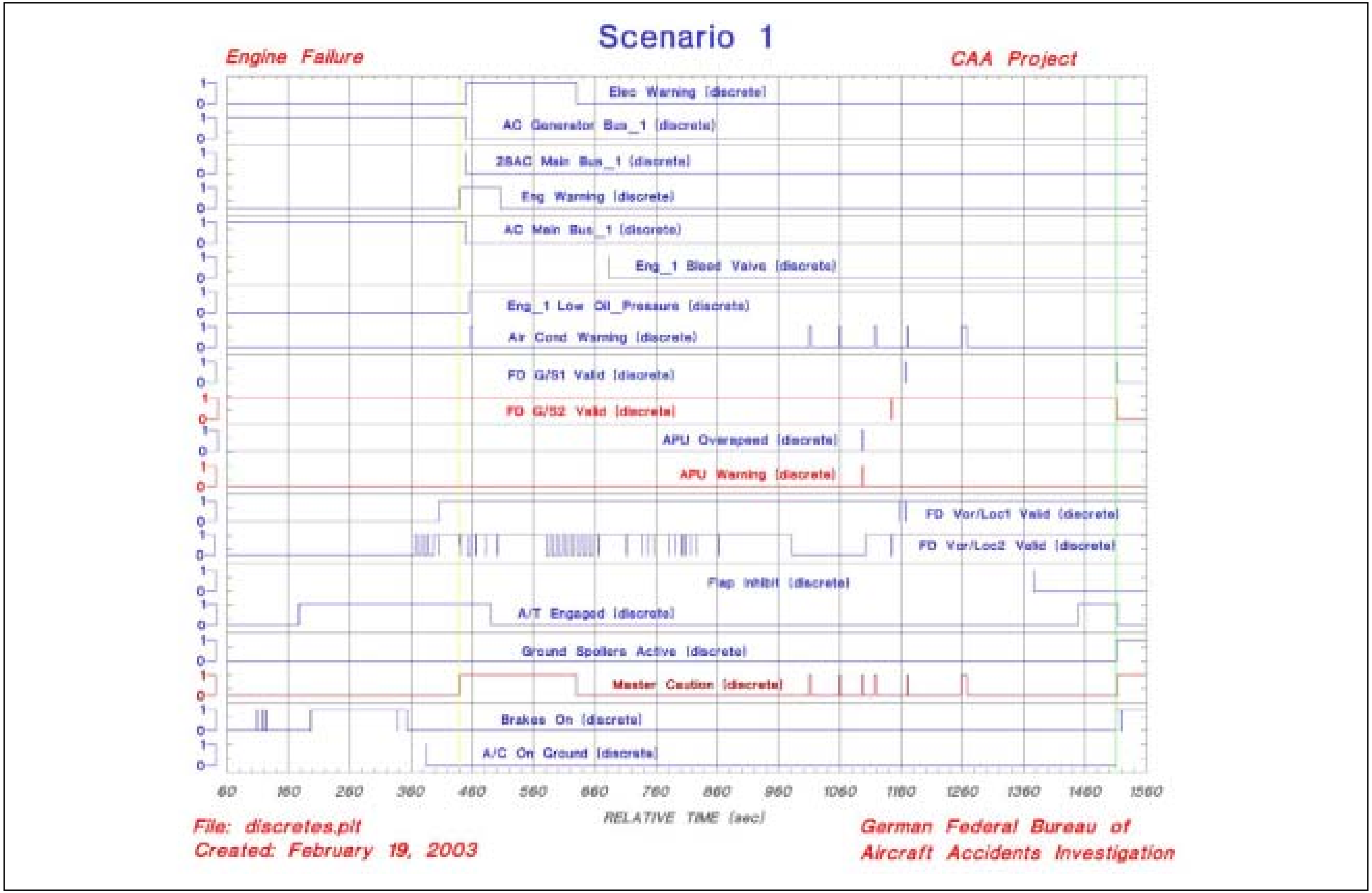

Figure 8 Data Analysis for Scenario 1 - BFU FDR Trace 4

4 Initial BEA Analysis Based On Image Data

Time	***Event***	***Remark***
13 h 38 min	*Take off*	
	The F/O is the Flying Pilot	
13 h 38 min 16	*The standard departure is not followed and turn left earlier*	
13 h 38 min 41	*Left engine failure*	
13 h 38 min 46	*Master caution*	
		Strong variation of the control column
13 h 38 min 50	*Master caution*	
	Secondary failures for hydraulic and electric	
13 h 38 min 56	*Electrical transfer with the lighting of electrical and hydraulic warning*	
13 h 39 min 37	*Power reduction on left engine then auto-throttle is stopped then the engine are shut-down.*	
13 h 40 min 02	*The left engine fire extinguish lever is pulled*	
13 h 41 min 43	*Auto Pilot A is engaged*	
13 h 42 min 13	*Captain read the check-list, F/O has the flight controls*	
13 h 42 min 54	*Shut down bleed valves, "isolation valve" on the off position*	
13 h 43 min 36	*Start the APU*	
13 h 44 min	*Landing gear lever to neutral position, auto brake to off position*	
	Difficult flight due to turbulences	
13 h 47 min	*They are going down to RNAV departure*	
13 h 47 min 16	*They are turning right*	
13 h 48 min 14	*Something relative to cross feed action ?*	
13 h 48 min 17	*Master caution Elec and Hyd light for 4 seconds*	
13 h 48 min 48	*Auto brake moved to max*	
13 h 49 min 11	*Master caution Elec and Hyd light for 4 seconds*	

	They are passing vertical Saint-Pré	*They are at 6000 feet over Saint-Pré but the minimal altitude is 7000 feet*
13 h 50 min	*Aligned on the runway 050*	
13 h 50 min 59	*Master caution Elec and Hyd light for 4 seconds*	
13 h 52 min 28	*Master caution Elec and Hyd light for 4 seconds when flaps are going out*	
13 h 54 min 32	*Stop the GPWS, flaps landing inhibit*	*Question : are English procedure is FE and not in QNH for landing?*
13 h 56 min 59	*Landing*	
	Stop of the plane on the runway	
		The take off was not from runway 23 but from runway 05 he was then passing over Chambéry

Probable cause of the incident : Failure on left engine with secondary failures on electrical and hydraulic systems. May be birds impact on left engine shortly after take off.

5 BFU Final Report Subsequent To Analysing Image Data

5.1 Preflight Checks

First Officer performs several checks

First Officer sets QNH on his altimeter

PIC sets speed markers on his speed indicator

First Officer sets speed markers on his speed indicator

First Officers sets, recalls or changes data on the right CMU

PIC checks selected parameters on the glareshield panel

PIC sets, recalls or changes data on he left CMU

First Officer performs lamp check

First Officer checks elevator and aileron movement by pushing and pulling control column and turning control wheel

PIC has control, now PF

Rudder check

First Officer performs some checks

5.2 Take Off

PIC sets take off power

Gear up

5.3 **Incident**

Engine failure

Pointers of N1, EGT, N2, FF and Oil Pressure of engine No. 1 moving to zero position

Master caution lamps on

First Officer sets altitude hold

PIC sets new heading

First Officer changes selected speed

PIC sets or changes selected vertical speed

PIC changes selected heading

First Officer resets Master caution

PIC changes selected vertical speed

Control handed over to First Officer, First Officer now PF

First Officer changes selected heading

Flight is quite rough, probably turbulences

First Officer changed selected vertical speed

PIC changes selected heading due to ground controller advise

First Officer changes selected speed

First Officer changes selected vertical speed

PIC changes selected heading due to controller advise

PIC changes selected altitude

Master caution lamps on, reset by PIC

5.4 **Approach**

First Officer changes selected speed

PIC changed selected heading

PIC changes selected course right and left

Master caution lamps on for short time

PIC changes selected heading due to controller advise

Master caution lamps on, reset by PIC

PIC changes selected altitude

PIC retrieves data from left CMU

PIC sets speed markers on his speed indicator

Master caution lamps on, reset by PIC

PIC changes selected speed

PIC sets QNH on his altimeter

PIC changes selected speed

Control handed over to PIC, now PF

5.5 Landing

Touchdown rather bumpy

Aircraft stop

End of movie

5.6 Conclusion

Shortly after take off engine No. 1 failed, the video showed that the pointers of N1, EGT, N2, FF and Oil Pressure of engine No. 1 moved back to the zero position. Engine No. 1 was cut off following the emergency procedure. The aircraft was prepared for a single engine landing.

The reason for the engine failure could not be retrieved from the video.

The sound track delivered an information about a health problem of a passenger and probably a cabin crew member.

The aircraft landed safely.

6 BEA Final Report Subsequent To Analysis Of FDR and CVR Data

Time	*Event*
13 h 37 min 51	F/O : rotate
13 h 38 min 02	Gear retraction
13 h 38 min 41	Left engine failure
	Lot of movement of the trim wheel
13 h 39 min 37	Landing gear configuration warning
13 h 40 min 02	The left engine fire extinguish lever is pulled
13 h 41 min 42	Pann announce to the VHF
13 h 41 min 43	Auto Pilot disconnect warning
13 h 42 min 13	Captain gives the flight controls to F/O and reads the check list
13 h 42 min 54	Talk about isolation of number 1
13 h 43 min 18	Auto Pilot disconnect warning
13 h 43 min 33	Sudden sound ? lightning strike or something
13 h 44 min 17	F/A is coming to the cockpit and gives information on the bumpy ride and inform the crew that a F/A has a broken leg. The captain inform they are going back to the airport
13 h 45 min 12	Altitude alert warning (3 times)
13 h 45 min 40	Altitude alert warning (3 times)
13 h 46 min 30	Talk about turbulences then check list about single engine approach
13 h 47 min 24	Altitude alert warning once
13 h 48 min 42	Altitude alert warning (5 times)

13 h 49 min 11	*The F/A on the passenger area has a multiple fracture on the leg*
13 h 49 min 37	*Altitude alert warning (2 times)*
13 h 51 min 18	*Altitude alert warning once*
13 h 52 min 49	*Alarm ?*
13 h 52 min 57	*Gear is going down*
13 h 54 min	*Landing check list is performed*
13 h 56 min 32	*GPWS warning "sink rate pull up" just before landing*
13 h 56 min 38	*Landing*

Probable cause of the incident: Failure on left engine then strong turbulences that create multiple fractures to a F/A leg and GPWS warning during the approach. Return to the airport.

7 Detailed CAA Analysis of Scenario 1

7.1 CAA Analysis Of Initial Reports

7.1.1 The Flight Crew Air Safety Report

The flight crew ASR was an accurate reflection of the basic flight details, although the initial autopilot B and autopilot CWS failures were not listed. This may be because they were detailed in the initial flight crew brief and so were considered to be 'known'.

7.1.2 Failure of the APU Starter

The APU Starter had a dormant failure. Both the BFU and BEA initial reports noted that the flight crew tried to start the APU but neither report indicated a failure to start.

It is notable that the flight crew ASR also made no reference to either a failed APU starter or to the absence of the APU function subsequent to their attempt to trigger it.

The 737-400 does have an APU BUS GEN light which would indicate the whether the APU Generator was supplying power. There are also EGT amp meters and a APU Low Pressure alert which would provide further indication of the presence or absence of electrical power. These are all located in the overhead panel.

Unfortunately, one of the limitations of this trial was that there was no view of the overhead panel. Therefore, in this instance, the image recorder system would have no view of the APU BUS GEN light, the EGT amp meters or the and APU Low Pressure alert and so could not have been used to determine whether the flight crew managed to restart the APU.

If the image recorder cameras did have a view of these indicators, it would have been possible to gain this information from an image recording system.

Although this is information that should be available on both the FDR and CVR, this is an example of where an image recording system can substantiate the information provided by the other recorders. There are two benefits associated with this.

Firstly, there are occasions when a combination of the FDR and CVR data provides sufficient information to strongly imply a probable cause but not enough to make any definitive statements. In this case, any corroborative information would be useful.

Secondly, increasing the number of data sources available to an accident investigator reduces the possibility that all sources of the data would be rendered useless as a result of poor maintenance or accident damage.

7.1.3 Autopilot Failures

Neither the initial failure of Autopilot B and CWS B, nor the subsequent failure of Autopilot A are apparent from any of the accident reports, including the flight crew ASR.

The absence of any reference to autopilot failures is surprising for a number of reasons:

a) The basic data sheet (i.e. who was flying, the take-off weight etc) specifically listed Autopilot B and CWS B as deferred engineering defects. Given that the initial BFU report quotes some of the information contained in this sheet, it is unlikely that they were unaware of the autopilot failures;

b) The FDR analysis should have found these failures and it is unlikely that any investigation would deem autopilot failure to be irrelevant. This implies that, had the autopilots failed, this fact would have been noted in the FDR report;

c) Although the flight crew might not have discussed the failure of Autopilot B and CWS B, as they constituted known failures, it is probable that they would discuss the failure of Autopilot A, particularly in light of the additional workload that would result from this. If the crew did discuss the failure of Autopilot A this would have been recorded on the CVR. Again, it is unlikely that this type of information would have been deemed irrelevant to any investigation; and

d) The Boeing 737 is equipped with "Autopilot Engage" lights for each of the autopilots, thus facilitating determination of the autopilot engagement status. These lights are located on the glare shield and would have been visible to the image recorder system cameras. It is, however, possible that the resolution of the recording made it impossible to determine whether these lights were lit.

The BEA image data analysis does make reference to Autopilot A being engaged, followed by a reference to flight crew reading checklists but it is not possible to tell what checklist was being used and whether the attempt to engage Autopilot A succeeded.

Given the absence of any reference to autopilot failures, let alone complete loss of the autopilot system, it is possible that these failures did not occur.

It is not possible to determine why the autopilot failures were not referenced in the reports for this scenario without talking to all parties involved in flying and analysing this scenario.

This issue was discussed during the initial wash up meeting, the results of which are detailed in Chapter 5 of this report.

7.1.4 Loss of Hydraulics and the Effect on Flight Crew Workload

The CAA believes that the intent of scenario set up was to force the flight crew to fly manually, resulting in a significant increase in flight crew workload. None of the supplied reports highlighted this or made any comment on the flight crew workload specific to this scenario.

The BEA statement of probable cause does refer to failures of the electrical and hydraulic systems. Although this combination of failures would result in an increased workload in terms of both physical and mental activities, the BEA report does not consider this.

The BFU FDR analysis also implies a failure of the hydraulic systems but, again, makes no reference to the implied crew workload.

7.1.5 Turbulence

The image data analysis made specific reference to flying difficulties that resulted from turbulence. This was not specifically identified in the FDR analysis and no information relating to turbulence was contained in the CVR analysis.

The FDR data showed a number of aileron movements and bank angle changes. These could have been a result of:

a) The effect of turbulence on the flight surfaces; and

b) Inputs from the flight crew to combat the turbulence.

The fact that the image data analysis made specific reference to turbulence corroborates the implication of the FDR data. This is a good example of image data providing evidence that confirms postulations based on other data. The benefits of this are discussed in paragraph 7.1.2 above.

It is also notable that the turbulence would have resulted in a significant increase in the effort required to perform physical tasks. This, in turn, would have added pressure to any necessary mental tasks. Again, none of the reports make any reference to this.

7.1.6 Cabin Crew Distractions

It is notable that the analysis of the image data makes no reference to any of the cabin crew interruptions that resulted from someone sustaining an injury. This is not surprising as the image recording system cameras are focussed forward towards the instruments and not backwards toward the flight deck door. The only thing the image recorder could show would be the flight crew turning to talk to someone behind them.

In the past, arguments have been put forward to justify a requirement for rear facing cameras; these arguments have been partly based on a need to highlight the effect of cabin crew distractions.

This has met with significant opposition as rear facing cameras would provide explicitly identifying images of the flight crew and thus pose a level of personal intrusion that the pilot associations believe to be unacceptable.

Some parts of this debate can now be addressed as a result of the analysis for this scenario.

The fact that the flight crew were talking to someone behind them does imply a level of distraction but, since image recorders provide images not sound, there is no means to determine how great a distraction this interruption constitutes. The cabin crew may have been asking the flight crew if they wanted coffee.

Excluding physical attacks on the flight crew, which are discussed earlier in this report, the actual information about the reason for any other interruption can only be gained from the CVR.

Since the CVR will provide the necessary information to determine the cause of an interruption, the only purpose that an image recorder could serve would be to confirm that an interruption took place.

Although corroborative information is usually helpful, it is unlikely that image data would be sufficiently useful in this case to justify rear facing cameras. This conclusion is based on two facts:

a) The image recorder would not provide information about the reason for, or scale of, an interruption; and

b) The image recorder could only infer an interruption had taken place if the flight crew actually turn to face the source of the interruption. Whether this physical reaction actually occurs would depend upon the flight crew and the circumstances they find themselves in.

As the details of the interruption should be recorded on the CVR, the image data would only have a greater significance if either the CVR data was missing or of inferior quality, or if the distraction caused the flight crew to look back at a crucial point in time.

Although the latter case is possible, the likelihood of it occurring may not be very high and whether the image recorder would detect that the crew should have been looking forward at this time would depend upon how good a view it had of both of the internal and external environment. It should also be noted that the quality of the internal and external views provided by an image recorder are dependent on the light quality of the environment and the camera's susceptibility to varying lighting conditions.

It is worth noting that it would have been very difficult to simulate the need to unlock the flight deck door and so this particular form of distraction could not be investigated during these trials.

It is also worth noting that, had the cabin crew/flight crew interactions taken place using the interphone, the only recorder that could provide any information relating to this would be the CVR.

7.1.7 **Minor Discrepancies**

The BFU CVR analysis highlighted an additional GPWS warning that was not listed in the simulator operator's debrief. The additional GPWS warning is related to the alert that was listed in the debrief and it is possible that this discrepancy occurred because the simulator operators mentally merged the two alerts.

The BEA image report makes a reference to Saint-Pre but the flight was out of Glasgow. There is no current explanation for this discrepancy.

These discrepancies were discussed during the initial wash up meeting, the results of which are detailed in Chapter 5 of this report.

7.1.8 **Summary of Information Gained from Initial Reports**

Based on the initial reports, there does not appear to be many significant differences between the data from the FDR and CVR and the data from the image recording. However, the initial analyses of the scenario shows the following:

a) The image recorder can provide information that is not explicitly present in other flight recorders, e.g. image recorders may be more effective in detecting turbulence;

b) It is probable that image recording would provide some information relating to distraction and other associated human factors. However, this scenario clearly demonstrates that there are limits to the information that can be gained; and

c) There is some information that can only be gained from the other types of flight recorder (e.g. the verbal content of cabin crew interruptions).

There were items of data that would have been available to the installed image recorder if a view of the overhead panel had been available. In this scenario, the missing information relates mainly to the loss of the autopilot and APU. Whether the image recorder would be the sole definitive source of this information would depend upon the number of parameters recorded by the FDR. If the number of recorded parameters were low, the image recorder would play a very useful role in any investigation in to similar incidents.

7.1.9 **CAA Questions Raised During Analysis Of The Accident Data:**

The CAA analysis raised a number of questions, however, a further study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers are only provided to those questions that relate to the issue being addressed by this research.

7.1.9.1 What impact does an APU Starter failure have on flight crew workload?

- This question is not relevant to the effectivity of image recorder systems.

7.1.9.2 Could the APU Starter failure be picked up by any of the recording technologies?

- Yes, this information could be recorded on an FDR.

7.1.9.3 Would the image recorder detect the absence of a functioning APU?

- The ability of an image recorder to detect the absence of a functioning APU depends upon whether it has a view of the APU control panel. If an image recorder system has such a view, it may be possible to detect this condition, depending upon the detail provided by the cameras and the overall flightdeck conditions (e.g. whether the view is obscured by smoke).

7.1.9.4 Did the simulator set-up actually allow the APU to start?

- Subsequent study determined that the simulator did not allow the APU to start, however, this question is not relevant to the effectivity of image recorder systems.

7.1.9.5 There was some mix up between scenarios - are BEA certain that scenario 3 took off from Geneva?

- This question is not relevant to the effectivity of image recorder systems.

7.1.9.6 Why were none of the Autopilot failures referenced in any of the reports?

- This question is not relevant to the effectivity of image recorder systems.

7.1.9.7 Did the fact that the scenario did not result in an accident mean that the investigators did not look into flight crew workload (possibly because the flight crew were seen to cope and thus the investigation focussed on system failures)?

- This question is not directly relevant to the effectivity of image recorder systems, however, it does raise two points:

  a) An image recorder system may well be able to provide information to support the analysis of workload and stress (see section 9.1 and Appendix 10 of this report); and

  b) This question highlights some of the human factors issues associated with accident investigation. These human factors issues have also been addressed in other scenario analyses and may merit further research.

7.2 CAA Analysis of Final Reports

7.2.1 Did an Analysis of the Complete Data Set Result in Opinion Changes?

The BFU made no technical changes to their opinion of probable cause as a result of reviewing the image data. However, their conclusions were amended slightly to include the corroborative evidence of the engine failure provided by the image data.

It is notable that neither of the BFU's statements of probable cause refers to turbulence as a contributing factor. This may be because they did not get the impression that the crew were having difficulty managing the effects of the turbulence and so did not deem it to be relevant.

It is notable that the BEA's conclusions have been slightly amended as a result of analysing the CVR. Specifically, their amended statement of probable cause includes references to the crew member injury and the GPWS warning. It is certain that the information regarding the crew member injury could only have been obtained from an analysis of the CVR. Equally, although the FDR would have recorded a signal determining that the GPWS system was active, only the CVR could define which warning/caution was actually given.

Since this constitutes information that would not have been available to the image recording system, the change in opinion is merely an accurate reflection of the sum of all the data.

A further difference in the BEA's conclusions is that the amended statement of probable cause contains no reference to the failure of hydraulic systems. This discrepancy was discussed in the initial wash up meeting, the results of which are detailed in Chapter 6 of this report.

The BEA also removed the reference to bird strikes from their statement of probable cause, presumably because there was no data to substantiate this.

7.2.2 Limitations Imposed by the Supplied Data

The BEA did not supply any specific FDR analyses and so it was not possible to comment on what information was derived from the FDR.

7.2.3 Comparison of BFU and BEA Analyses of Image Data

7.2.3.1 After comparison of the BFU image data analysis against the BEA image data analysis the following differences were noted:

a) The BEA made no generic statements about the overall use of the image data and so it is not possible to determine whether they reached similar, general conclusions; and

b) The BFU analysis makes no reference to any attempt to engage either Autopilot A or the APU.

In general, both analyses were detailed and informative but each reveals a different approach to the data. The BFU's analysis focuses mainly on the flight crew actions while the BEA analysis focuses more on the aircraft systems and the environment the flight crew were working in. Both approaches provide significant information relating to the scenario but it is probable that a combination of these approaches would supply more useful information.

7.2.3.2 In addition to the difference in approach to the data, the following additional differences were noted:

a) The BFU analysis provides more details of the pre-flight checks than the BEA analysis. Despite this, the BFU analysis of the image data provides no information about the 'deferred system defects' that were present when the flight crew took control of the flight deck;

b) Had a view of the overhead panel been available, it is possible that the additional details relating to the pre-flight checks would have found the APU failure and helped to highlight potential difficulties for the crew. This suggests that a detailed analysis of pre-flight checks is helpful when analysing image data; and

c) The image recorder system cameras would have had a view of the Autopilot engage lights, however, it is unlikely that an investigator would expect these to be illuminated prior to take off and so it is unlikely that the analysis of the pre-flight checks would have found the autopilot failures. This leads to the conclusion that it may be advisable to provide guidance on assessing pre-flight images provided by image recorder systems.

The BFU analysis of the image data provides more details of the pre-flight checks than were available from the CVR/FDR analysis since the CVR report contains only extracts of the CVR information. It is not possible to determine whether this information is provided solely by the image recorder.

The BFU image data analysis also makes specific reference to the flight being rough and notes that this is 'probably' due to turbulence. Although this is a slightly less positive statement than the one from BEA, it does confirm the image recorder's ability to show turbulence. It also highlights the fact that the image data was the only source of any direct comments relating to turbulence.

Both the BFU and BEA analyses of the image data contain a lot more information about the specific pilot actions and the warning and caution lamps than is contained in the FDR/CVR analysis. This implies that the image data may be more effective in terms of determining some flight deck display information and the specific actions of the flight crew; however, this is only an implication and not a definitive fact.

7.2.4 The BFU's General Comment on the Usefulness of Image Data

7.2.4.1 The BFU made a generic statement that applies to each of the individual scenarios. This is as follows:

"*The videos show all the details of pre flight preparation and how the crew handled incident situations as well as the additional workload.*

Important is that the crew does not only read the checklists but really check the items on the checklists.

The videos show information about actions like setting courses, headings, altitudes, speeds or input of new data or changing data on the CMU. The crew may not talk about those actions and that information may also not be available on the FDR.

The description of actions or information retrieved from the videos are presented in chronological order. Information about those actions are partially also available on the CVR.

Master caution is also listed because in some cases it was not clear whether the FDR master caution bit was valid or an erroneous info. Furthermore Master caution can be used to synchronize FDR and video due to the fact that the videos contains Universal Time Constan".

Based on this supplemental text, it is possible to see that that the BFU believe there are specific areas in which the image data definitively provided additional information, namely:

a) Actual adherence to checklists (which infers that it would be possible to determine if an inappropriate checklist was used);

b) Crew actions that would not be recorded by the CVR or FDR (including some forms of silent communication - e.g. pointing etc); and

c) The way in which the flight crew handles their workload.

The data relating to crew workload is significant and BFU's statements regarding the ability to determine how the crew handle their workload need to be carefully considered.

Although it is possible to determine that the crew are under stress from the CVR, it is not possible to determine the cause of the stress (i.e. the crew could be stressed due to workload, communication difficulties, simple concern about the situation they are in, system malfunctions etc). From the generic BFU statement, it would seem that the image data at least shows how the crew handle their workload. While this does not actively dismiss the other possible sources of stress (some or all of which could still be present) it will at least provide some information. However, the issue of whether or not an accident investigator would be able to postulate that workload was a factor in an incident/accident based on image data is still not completely resolved.

7.2.4.2 In general terms, flight crews have two types of work, physical tasks and mental tasks. A considerable amount of research has been dedicated to the interaction of these types of work, most of which is outside the scope of this paper. However, in simplistic terms, the following is true:

a) An excessive number of physical tasks, or a set of physical tasks which require great strength or dexterity, may make even a small number of the simplest mental tasks very difficult for a flight crew;

b) An excessive number of mental tasks, or a set of particularly complex mental tasks may make simple physical tasks very difficult; and

c) Either one of these combinations could result in an accident or incident.

Although image data could provide evidence of the physical workload a flight crew are faced with, it would be difficult to make any positive statements about their mental workload.

It should also be noted that there are 'gradients' of workload and there may be situations where, due to fatigue or distraction, the crew are less able to combine mental and physical tasks than usual. This is something that would be almost impossible to determine from any flight recorder data.

The BEA made no generic statements about the overall use of the image data and so it is not possible to determine whether they reached similar, general conclusions.

7.2.5 BEA's CVR Analysis

The BEA CVR analysis appears to be somewhat less detailed than the BFU CVR analysis but this may be due to BEA choosing to submit a smaller subset of their CVR analysis than was chosen by BFU. A comparison of the two analyses shows that the BEA's subset of CVR information did not omit anything that was directly relevant to the incident.

The BEA analysis of the CVR also highlights that the crew were discussing turbulence. This would support the data provided by the image system, and provides a further example of one recorder providing information to substantiate the information provided by another.

7.2.6 **CAA Questions Raised During Analysis of the Accident Data:**

The additional analysis of the extra data does not provide answers to any of the CAA's previous questions relating to Scenario 1 but it has resulted in the additional questions listed below.

Once again, study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers will only be provided to those questions that relate to the issue being addressed by this research.

7.2.6.1 Why was the reference to failures of the hydraulic system omitted from the BEA's final report?

- This question is not relevant to the effectivity of image recorder systems.

7.2.6.2 Would the presence of a BEA FDR analysis have changed their conclusions?

- This question is not relevant to the effectivity of image recorder systems.

7.2.6.3 Why do none of the BFU analyses make reference to turbulence?

- This question is not relevant to the effectivity of image recorder systems.

7.2.6.4 Is it possible to see how physically hard flight crew have to work based on image data?

a) An image recorder system may well be able to provide information to support the analysis of workload and stress (see section 9.1 and Appendix 10 of this report).The analysis of physical workload could also assisted by the use of Type Ia FDRs which require the recording of force measurements; and

b) An investigator will only note that the crew were subject to an abnormally physical workload if they perceive that this is the case during their analysis. Perception of abnormal physical workload is likely to depend upon the investigator's preconceptions about how hard a flight crew would have to work during a normal flight. This indicates a further set of human factors related to accident investigation.

7.2.6.5 Are all the pre-flight checks available on the CVR as well as the image recorder?

- This question is not relevant to the effectivity of image recorder systems.

7.2.6.6 Is the image recorder more effective in determining cautions/warnings than a combination of CVR and FDR?

a) The ability of an image recorder to detect and record cautions/warnings will depend upon the views available to it; and

b) In general the FDR should have recordings of all warnings that cannot be determined by other means (ie. CVR) and the CVR should have recordings of all aural alerts, however, the previous statement does not necessarily apply to all cautions and status indications. Where these are not recorded on either FDR or CVR, an image recorder could provide the only source of this information. This means that, at the very least, image recorders should provide a source of confirmation to support FDR and CVR data and, in some cases, may provide information that is not provided elsewhere.

7.3 Summary For Scenario 1

There were some surprising omissions from both sets of analyses, notably the apparent APU Starter and Autopilot A failures. Equally, although both sets of analyses contained sufficient data to infer an excessive physical workload, neither made specific reference to this (The issue of mental workload is not discussed here, as it would be difficult to make useful conclusions relating to an investigator's ability to detect this based on flight recorder data).

The analyses of this scenario show that image data can provide the following information that is additional to data provided by FDR and CVR:

a) Actual adherence of the crew to checklist procedures; and

b) Crew actions not recorded by CVR or FDR (e.g. some checklist actions and most forms of silent communication).

It can also be seen that image data can provide substantiation for information provided by the other recorders (e.g. the image recorder provided evidence of severe turbulence which confirmed the CVR's recording of crew discussions relating to turbulence). In some cases this will provide the accident investigator with a means of balancing the image recorder's view of a situation with a crew's view of a situation (i.e. was the turbulence actually severe?).

There may be other means to cross validate FDR and CVR data but, in cases where this data only implies a set of events, any form of cross validation must be considered a possible means of achieving resolution.

The analyses of this scenario data also shows that the image data cannot provide certain types of information (e.g. status of systems which have no display and the level of verbal communication between the crew). These types of data still need to be obtained from the FDR and CVR.

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Appendix 2 Investigation Data for Scenario 2

NOTE: All quoted material (e.g. Flight Crew ASRs and Investigation Reports) are shown in italics.

1 De-brief from Simulator Operator

LXGVA - to GVA	
23. KONIL Departure	
Initial FL90	
Taxi	*14:10*
Take Off	*14:12*
Right Tyre Burst Outer 143kts	*14:13*
Right Tyre Burst Inner 146kts	*14:13*
Fast Leak In Hydraulic System A	*14:14*
Fast Leak In Hydraulic System B	*14:14*
RADAR Fail - Unable to vector - Continue SID	*14:15*
Oven Smoke In Rear Galley	*14:17*
Oven Fire - Not In Oven But Behind Oven - Extinguishers Not Effective	*14:21*
Cabin Address Delegated To Cabin Crew - "10 Minutes To Landing	*"14:21*
Uncontrolled Fire In Rear Galley	*14:26*
Called 17 Miles Final	*14:29*
Right Brakes Fail - No Indication	*14:31*
Landing	*14:36*

2 Flight Crew ASR

Shortly before rotate light rumbling felt - engine parameters normal.
TAKE OFF CONTINUED.

About 500 AGL master caution "HYD" F/O reported Low P "A" system engine, shortly followed by electric pump "A" system quantity seen reducing.

"B" system failed - quantity zero around 3000 AGL.

SID continued with intention to hold at SPR to assess.

Manual reversion QRH actioned.

Rear galley fire reported. At this stage 1 out 3 portable extinguishers had been used and smoke reported not too bad. Galley power switched off. Advised using second bottle and report.

Whilst entering hold at SPR cabin crew advised second bottle used and heat evident behind galley surfaces.

NITS briefing gives intention to land in 10 minutes.

2 minutes later cabin crew reported fire uncontained - hold converted to straight in approach RWY 23.

Descent/Approach and LDG checks completed descending on GP to successful FLAP 15 Landing

PAX evacuated.

3 Initial BFU Analysis Based on FDR and CVR Data

3.1 Flight Plan Data

Date:	*30 August 2002*
Time:	*14:12 take off*
Departure Airport:	*Geneva*
Departure Runway:	*23*
Captain's Name:	*Malcolm Terry*
Fist Officer's Name:	*James Taylor*
Deferred Engineering Defects:	*none*
Cloud Base at Take Off:	*500 ft*
Visibility:	*5 km*
Landing Airport:	*Geneva*
Landing Runway:	*23*
Cloud Base at Landing:	*500 ft*
Visibility:	*5 km*

3.2 Scenario Description From FDR Parameters

The time reference was derived from the recorded parameter "Relative Time", starting at 0s and ending at 2658s.

Taxi and take off run were found to be under normal conditions.

Rel. Time: 1200s: *Parameter "A/C ON Ground" indicates "Air", Aircraft in rotation phase.*

Rel. Time: 1208: *Parameter "Hydraulic A Pressure" began to decrease to 0 within 14s.*

"Hydraulic A Low Pressure Warning".
Indication of "Master Caution" and "Hyd Warning" for a few seconds.
Pressure Altitude: 1900ft (1013).
Calibrated Airspeed: 165kt.

Rel. Time: 1270s: *Parameter "Hydraulic B Pressure" began to decrease to 0 within 8s.*
"Hydraulic B Low Pressure" Warning.
Indication of "Master Caution" and "Hyd Warning" for a few seconds.
Pressure Altitude 4500ft (1013).
Calibrated Airspeed: 190kt.

After Hydraulic loss the parameter "Capt Wheel Force" showed a 3 to 4 times higher value to achieve the same aileron deflection than before, when hydraulic pressure was available.

Rel. Time: 1329: *Aircraft began right turn to an average heading of 43°.*

Rel. Time: 1395: *"Master Caution" and "Flt Control Warning" active for about 48s.*

Rel. Time: 2035: *"Master Caution" and "Air Condition Warning" activated for 80s.*

During the approach to runway 23 in Geneva it was difficult to stabilise the aircraft on localizer and glide slope. About 8s before touchdown the localizer deviation showed -0.45 units and glide slope deviation showed -2.8 units. There was no reference to recalculate these units to dots. So the effective deviation is unknown. The bank angle on touchdown was 8°. Immediately after touchdown the aircraft turned right by about 8° and was brought back to the centreline by action of the right pedal (rudder).

3.3 Scenario Description From CVR

The CVR Transcript is more descriptive. Only important parts are reported in detail.

In addition to the double hydraulic failure a cabin attendant reported a fire and smoke in the rear galley as well as the unsuccessful attempt to extinguish the fire.

Also here the CVR delivered a good impression of the scenario and important information, not available on the FDR.

The flight deck crew handled the situation in a professional manner following the fundamentals of the crew coordination concept.

3.4 Conclusion

The aircraft lost both hydraulic systems shortly after take off. There was no FDR parameter available indicating the reason of the hydraulic failures. Also the conversation on the CVR did not deliver a information what caused the hydraulic loss.

The CVR delivered additional information about a fire probably caused by an oven and smoke in the rear galley. The cabin crew tried to extinguish the fire but was not successful. The crew handled the situation in a professional manner using the relevant emergency procedures.

The aircraft landed safely but on fire. Passengers were evacuated.

3.5 BFU CVR Analysis

Partial CVR transcript Session 2

Rel. Time		
CVR(min:s)	*FDR(s)*	
->13:03	*->1004*	*Preflight checks and briefings*
13:03	*1004*	*Request Taxi*
15:12	*1133*	*Clear take off two three, tk(?) zero one*
16:01	*1182*	*(?) power set*
16:06	*1187*	*80 knots*
16:20	*1201*	*Rotate*
16:25	*1206*	*Positive climb*
16:26	*1207*	*Gear up please*
16:27	*1208*	*Gear up*
17:01	*1242*	*Flaps one*
17:02	*1243*	*Flaps one*
17:41	*1282*	*Hydraulic system failed*
18:08	*1309*	*tk(?) departure zero one, mayday, mayday, mayday, we have a (?) double hydraulics failure, we like to hold in (KEMIT?)*
18:33	*1334*	*[Several checks, starting emergency procedures]*
20:32	*1453*	*[Cabin attendant reports smoke in the galley, problems with oven(s), use of fire extinguisher]*
20:44	*1465*	*[Advise to switch off power for the ovens]*
21:08	*1489*	*[Briefing about landing procedure - flaps 15 landing and other items like landing and approach checklist]*
23:28	*1629*	*[Cabin attendant reports that fire behind the oven in the rear galley can not be exstinguished, 2 bottles already shot]*
24:44	*1705*	*[Crew instructs air traffic controller about fire]*
28:07	*1908*	*Approach checklist is complete*
28:33	*1934*	*[Cabin attendant reports smoke and heat in the rear galley]*
29:21	*1982*	*[Cabin attendant reports that cabin is secured for landing]*
29:28	*1989*	*Request for straight approach to RWY 23*

29:52	*2013*	*[Morse code of ILS DME ISW received]*
30:44	*2065*	*(?) captured, then we can make it*
31:46	*2127*	*[Starting landing checklist]*
32:18	*2129*	*[Reporting tk(?) zero one on final]*
32:36	*2177*	*Mayday Mayday tk(?) zero one is on 17 miles final RWY 23, the aeroplane on fire*
32:59	*2200*	*We got three greens on ...*
33:06	*2207*	*Cabin is secured for landing, flaps ... 15 - checked*
34:54	*2315*	*Flaps 15 - ... flaps 15 checked ...*
35:03	*2324*	*We have three greens, flaps 15*
35:10	*2331*	*Yea, we have checked the landing list available(?)*
35:15	*2336*	*[Briefing before landing]*
36:59	*2440*	*Cabin crew take your seats for landing*
37:01	*2442*	*Mayday tk(?) zero one is 4 miles ...*
37:19	*2460*	*tk(?) zero one, we land*
37:53	*2494*	*tk(?) zero one, fire is in the rear ...*
38:10	*2511*	*[PIC takes over control]*
38:32	*2533*	*Reduce power*
38:39	*2540*	*Power off ...*
38:58	*2559*	*[Reverser on]*
39:15	*2576*	*Sixty knots*
39:21	*2582*	*Forty knots*
39:33	*2594*	*... evacuation ...*
39:46	*2607*	*[PA to cabin about evacuation]*
40:27	*2648*	*{End of CVR recording}*

3.6 BFU FDR Traces

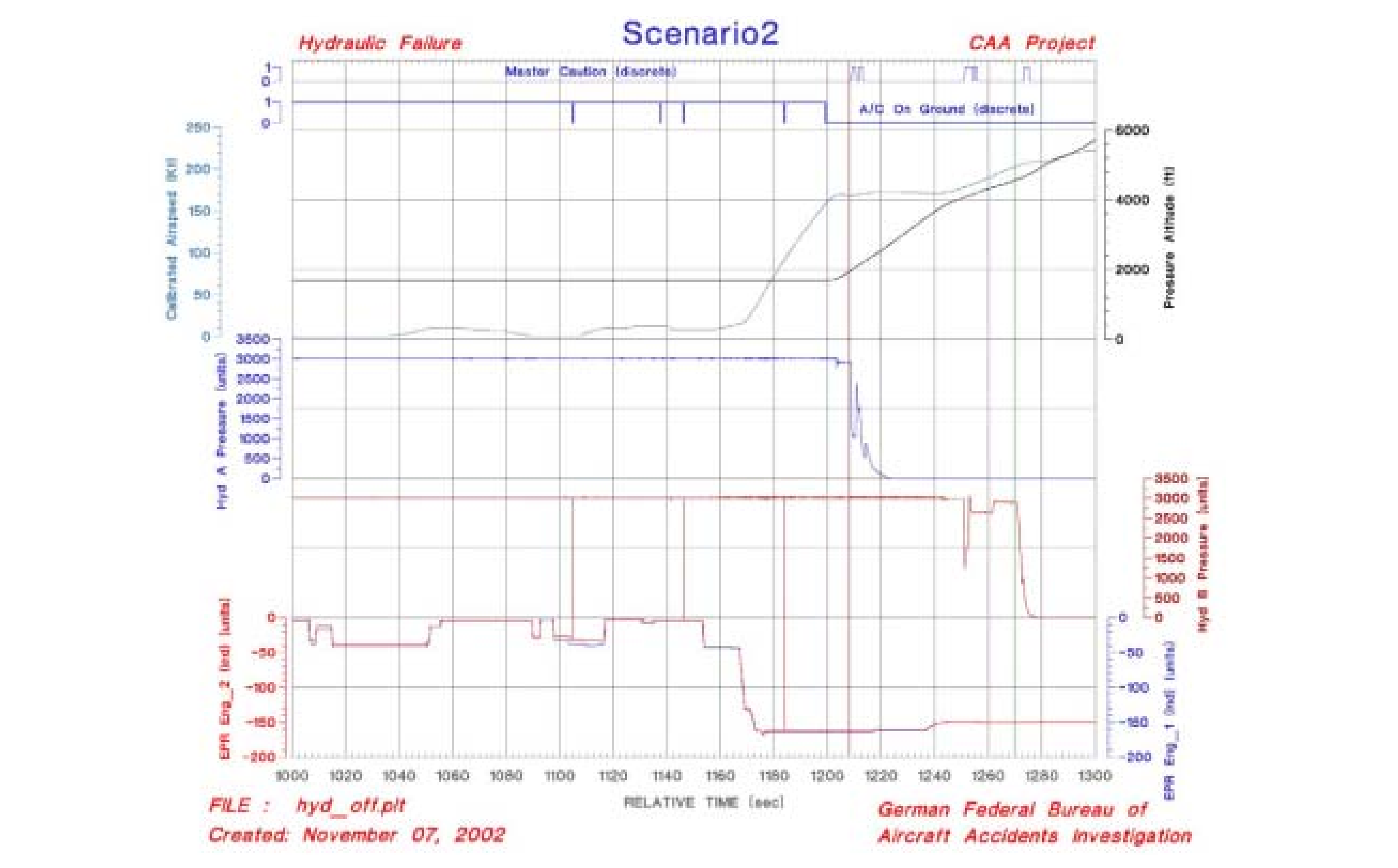

Figure 9 Data Analysis for Scenario 2 - BFU FDR Trace 1

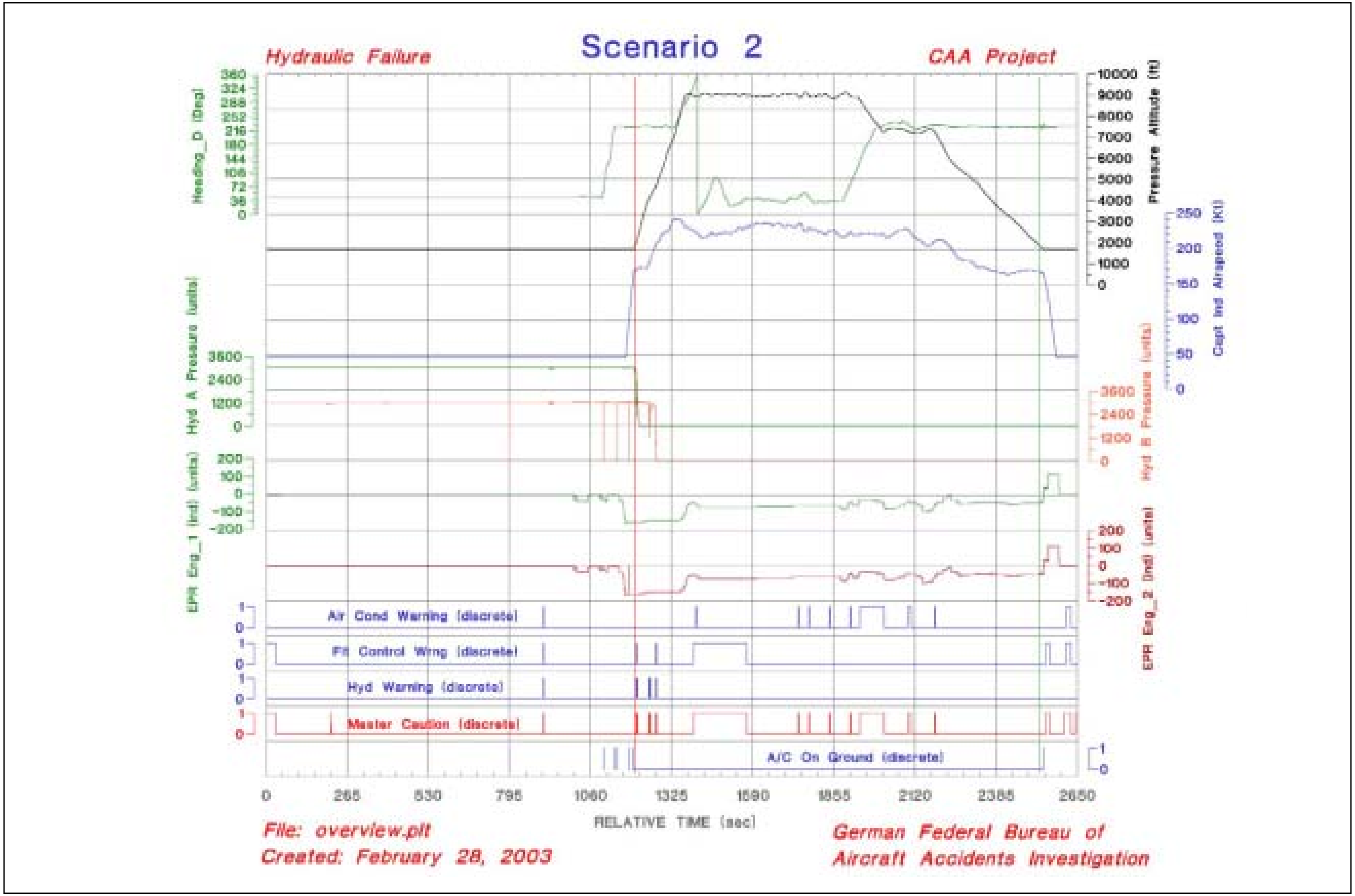

Figure 10 Data Analysis for Scenario 2 - BFU FDR Trace 2

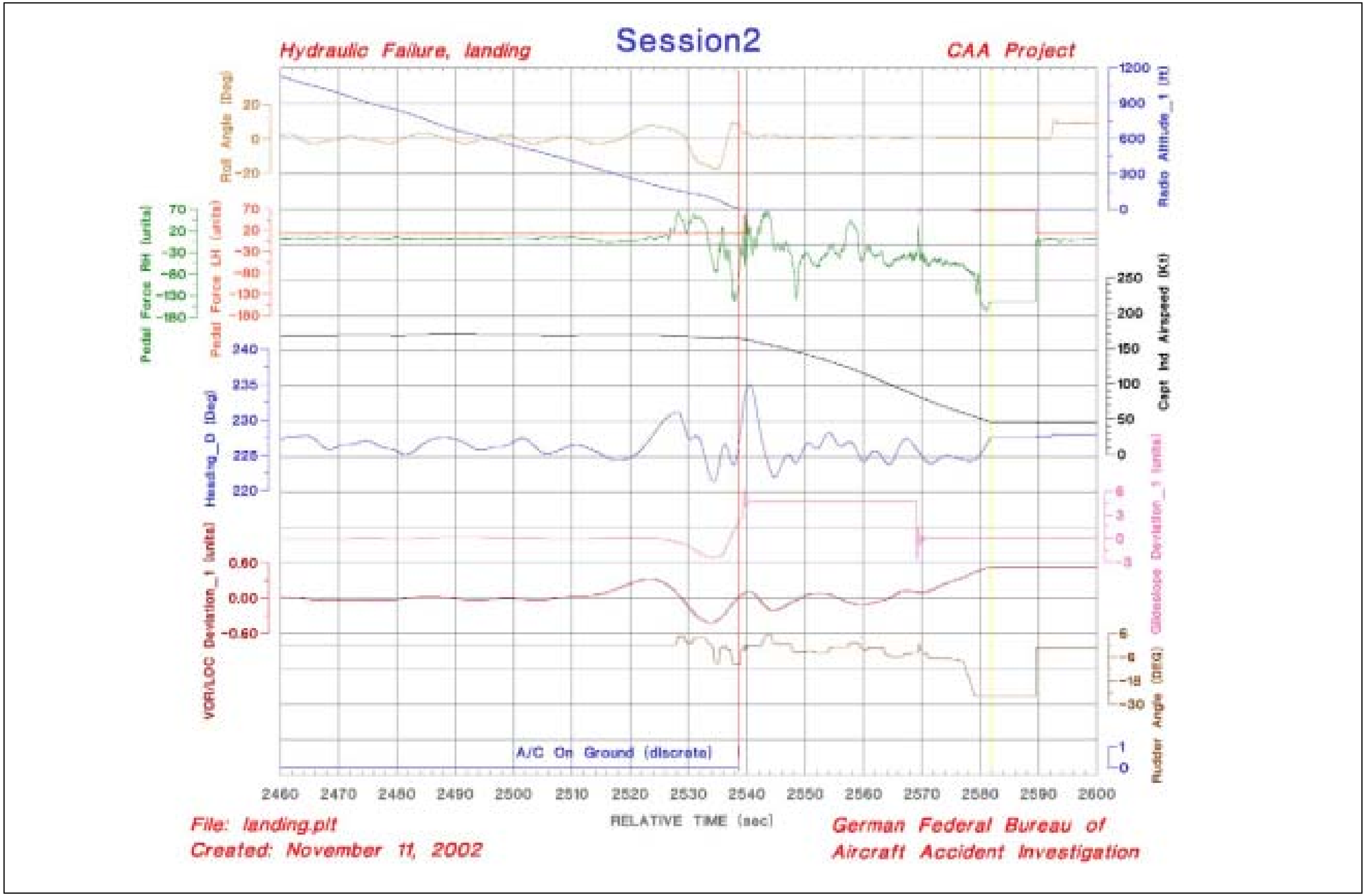

Figure 11 Data Analysis for Scenario 2 - BFU FDR Trace 3

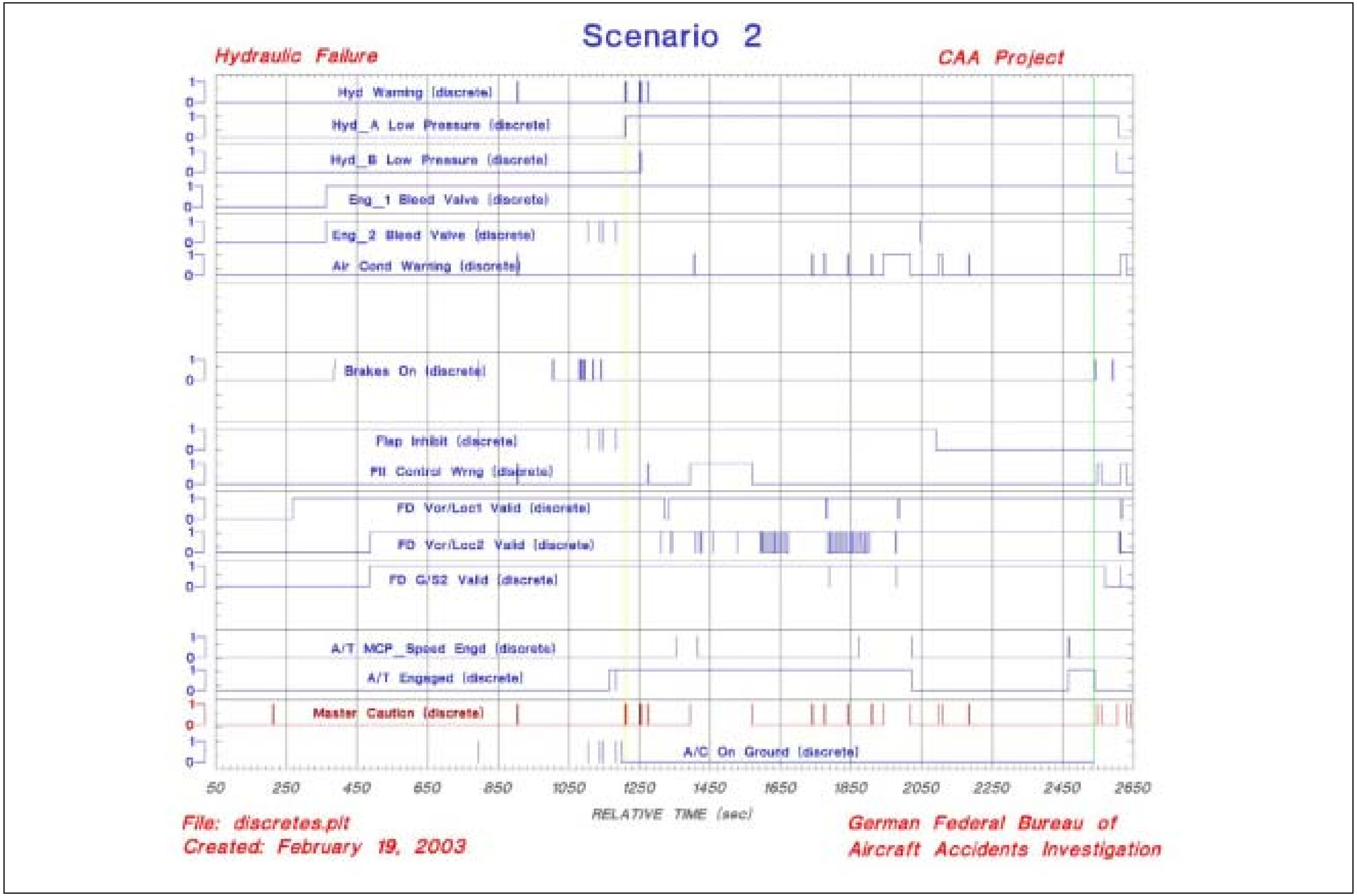
Scenario 2
Hydraulic Failure
CAA Project
Hyd Warning (discrete)
Hyd_A Low Pressure (discrete)
Hyd_B Low Pressure (discrete)
Eng_1 Bleed Valve (discrete)
Eng_2 Bleed Valve (discrete)
Air Cond Warning (discrete)
Brakes On (discrete)
Flap Inhibit (discrete)
Fll Control Wrng (discrete)
FD Vor/Loc1 Valid (discrete)
FD Vor/Loc2 Valid (discrete)
FD G/S2 Valid (discrete)
A/T MCP_Speed Engd (discrete)
A/T Engaged (discrete)
Master Caution (discrete)
A/C On Ground (discrete)
1
0
50
250
450
650
850
1050
1250
1450
1650
1850
2050
2250
2450
2650
RELATIVE TIME (sec)
File: discretes.plt
Created: February 19, 2003
German Federal Bureau of
Aircraft Accidents Investigation

Figure 12

4 BEA Initial Report Based On Image Data

Time	***Event***	***Remark***
	Start of recording	
14 h 12 min	*Take off starting*	
14 h 13 min	*rotation*	
14 h 13 min 26	*Complete loss of hydraulic pressure circuit A (left) when landing gear is retracted*	*Master caution lights 300 feet after take offFrom this point the master caution will light many times and will be cancelled*
14 h 14 min 12	*Complete loss of hydraulic pressure circuit B (right)*	
14 h 16 min	*Emergency Checklist is read*	
14 h 16 min 40	*Master caution lights + 2 other light*	
14 h 22 min	*End of standard departure and put in hold circuit*	
14 h 22 min 50	*Master caution lights + other light*	
14 h 24 min	*The F/O take the control*	
14 h 25 min	*Master caution lights+ other light*	*Maybe schedule off descent*
14 h 29 min	*Master caution lights*	
14 h 30 min	*End of read of the Checklist*	
14 h 35 min	*The captain takes the control for the landing*	
	The F/O has some trouble to use the reverses Speed brakes are moved manually	
14 h 36 min 30	*Park brake on*	
14 h 37 min	*Evacuation preparation*	
		The view on the throttle is missing
		The view of the upper panel is missing
14 h 16 min 58	*The four pumps are stopped*	*The pilot shows the second pump consistent with the left side*
		The auto pilot was not engaged which is consistent with the loss or hydraulic pressure

Probable cause of the incident: loss of the hydraulic pressure on the two circuits when the gear is retracted. Interruption of the flight and evacuation after landing.

5 BFU Final Report Subsequent To Analysing Image Data

5.1 Preflight Checks

PIC set QNH on his altimeter

First Officer sets, checks or changes course on left course selector

First Officer sets, checks or changes course on right course selector

PIC sets, recalls or changes data on left CMU

First Officer sets, recalls or changes data on right CMU

PIC sets, recalls or changes data on left CMU

PIC sets, checks or changes preset altitude

Could identify simulator's call sign "GCAT" on note put onto center pedestal by First Officer

(I did not understand the call sign on the voice recorder)

First Officer set, checked or changes preset altitude

PIC checks preset parameters on glare shield panel

Rudder check

PIC checks elevator and aileron movement by pushing and pulling control column and turning control wheel

PIC is PF at this time and starts taxiing

5.2 Take Off

PIC sets take off power

Gear up

Master Caution Lights coming up, reset,

coming up again, reset

5.3 Incident (Double Hydraulic Loss)

Left hydraulic pressure indicator pointer moving to zero

Right hydraulic pressure indicator moving to zero

Selected speed changed

Emergency Procedure processed by crew

Master caution light coming up, reset

First Officer sets, recalls or changes data on right CMU

First Officer changes selected course on right side

Control handed over to First Officer, First Officer now PF

PIC changes selected altitude

PIC changes selected heading

PIC sets or changes vertical speed

PIC changes selected heading

Master caution lights on, reset later

5.4 Approach

PIC sets approach mode (presumable, not clearly identified)

PIC sets, recalls or changes data on left CMU

PIC and First Officer set speed markers on airspeed indicators

First Officer sets QNH on his altimeter

PIC changes selected speed

PIC sets QNH on his altimeter

PIC takes over control, now PF

First Officer has right hand close to control wheel and left hand on thrust levers

5.5 Landing

Touch down

Aircraft stop

End of movie

5.6 Conclusion

The aircraft lost both hydraulic systems shortly after take off. The video showed that the pointers of the Hydraulic Pressure indicators moved back to the zero position. The indication of the Low Oil Pressure warning lights could not clearly be identified due to the low video resolution, but the Master Caution lights could be identified.

The crew handled the incident following the emergency procedures. The PF had difficulties to control the aircraft. This is indicated by high control column and control wheel activity.

A cabin attendant reported a fire caused by an oven in the rear galley and that it was not possible to extinguish the fire.

The aircraft landed safely.

The reason for the hydraulic loss and the fire could not be retrieved from the video/ sound information.

6 BEA Final Report Subsequent to Analysing FDR and CVR Data

Time	***Event***
14 h 12 min	*Take off starting*
14 h 13 min 11	*rotation*
14 h 13 min 19	*Gear is up*
14 h 13 min 26	*Master caution hydraulic loosing the A system*
14 h 14 min 09	*Complete loss of hydraulic pressure engine 2*
14 h 14 min 52	*Mayday announce to the VHF double hydraulic failure*
14 h 15 min 50	*Altitude alert warning*
14 h 16 min	*Emergency Check list is read*
14 h 17 min 25	*F/A inform the captain about smoke detection close to door 4. No success to stop the smoke. One extinguisher was used by a "girl"*
14 h 20 min 23	*F/A inform the captain about the fire. No success to stop with the second extinguisher. Fire on the rear galley. They will be on the ground in 10 minutes*
14 h 22 min	*They put in hold circuit to make a point on the situation*
14 h 21 min 50	*F/O inform the ATC about the complication with fire and request landing in Geneva*
14 h 24 min 26	*Altitude alert warning and descent holding pattern at 7000*
14 h 25 min 28	*F/A inform they can see flames and smoke passengers in the back are upset*
14 h 26 min 02	*Altitude alert warning*
14 h 27 min 56	*Altitude alert warning not very loud*
14 h 28 min	*Check list is read*
14 h 29 min	*Announce to the VHF on approach with an aircraft on fire*
14 h 35 min 04	*The captain takes the control for the landing*
14 h 35 min 33	*Landing with trouble with reverses*
14 h 36 min 16	*Very load broadband noise for 4 seconds ?*
14 h 36 min 32	*Evacuation preparation with evacuation on the rear and on the front*

Probable cause of the incident: loss of the hydraulic pressure on the two circuits when the gear is retracted. Fire detected on the rear galley. Interruption of the flight and evacuation after landing.

7 Detailed CAA Analysis for Scenario 2

7.1 CAA Analysis of Initial Reports

7.1.1 The Tyre Burst

The flight crew ASR provides an accurate summary of the basic flight details. The ASR indicates that the crew did identify a 'rumbling' sensation that would have been associated with the tyre bursts. Although they did not audibly identify the correct source of the rumbling, they performed a set of engine checks to ensure that it was still appropriate to take off.

Neither the BFU FDR/CVR report nor the BEA image data report makes any reference to the tyre burst, the rumbling sensation or any crew discussions relating to the rumbling sensation.

Although the absence of a reference to sound is predictable for the image data report, it is, perhaps, surprising that no reference to this is made in the CVR analysis. There are two possible explanations for this:

a) There was no sound associated with the rumbling and the crew did not discuss it; or

b) There was no sound associated with the rumbling and any crew discussion relating to the noise was deemed to be irrelevant to the investigation.

The first of these explanations is possible, since there are predefined responses to such events rendering flight crew discussion unnecessary.

The second explanation is unlikely as, if the crew are heard discussing a 'rumbling' immediately prior to further system failures, the crew discussion may well provide clues as to the cause of the subsequent failures and so would hardly be deemed irrelevant.

This issue could not be resolved from an analysis of the provided data, however, further discussions with the flight crew revealed that the flight crew acknowledged the event and took suitable action without need for any discussion.

7.1.2 The Effect of the Tyre Burst on the Landing Sequence

The scenario started with both the inboard and outboard tyres bursting on the right hand main landing gear. Apart from the immediate effect on other systems as a result of flying debris, this has certain predictable effects on the landing sequence. These are:

a) There would be no braking ability on the right hand side; and

b) The aircraft would slew to the right on touch down and then slew to the left as a result of maximum braking on the left hand side.

The BFU report notes that the aircraft "turned right by about 8° and was brought back to the centreline by action of the right pedal (rudder)" immediately after touchdown. This would account for the effect of the burst tyres.

The flight crew ASR makes no reference to this but, as the crew were able to correct the centreline deviation and had a number of more pressing problems (e.g. an uncontrolled fire in the galley), it is not surprising that this detail was omitted.

The BEA image data analysis makes no reference to aircraft slewing or to the crew controlling it with a rudder pedal input. The latter is to be expected since the image data is intended to show displays and general flight deck environment and so the cameras would not be focussed on the rudder pedals.

Since rudder pedal input information is gained from FDR data, this omission from image data is not significant.

As the preferred image recorder camera layout did not provide external views, it would not have been possible to detect a deviation from the centre line from image data alone.

The image recorder may have recorded the flight crew's response to the deviation (as long as that response was visible to the cameras) but the crew response would need to be interpreted before it could be linked to a centreline deviation.

Had external images been provided, it is possible that the image recorder system would have been able to provide more information on the centreline deviation. However, it should be noted that the location of an image recorder system camera will affect its ability to determine/measure centreline deviations.

7.1.3 Loss of Hydraulics and the Effect on Flight Crew Workload

Once again, this intent of this scenario was to force the flight crew to fly manually, resulting in a significant increase in their physical workload.

Again, despite the references to a double hydraulic failure in both the BEA and BFU reports and a direct reference to manual reversion in the flight crew ASR, neither set of investigation reports highlighted this or made any comment on the flight crew workload specific to this scenario.

This was discussed with the accident investigators and they noted that they would not report that the flight crew appeared to be stressed or subjected to a detrimentally high workload, unless they had evidence that showed this.

As the investigators did not see/hear symptoms of stress or work overload, no reference was made to the flight crew workload.

7.1.4 The Fire

It is notable that the analysis of the image data makes no reference to one of the major sources of distraction during this scenario (i.e. the uncontained fire in the galley). Since this became the flight crew's main priority, and forced them to expedite their approach and landing, this is a significant issue.

The uncontained fire meant that the flight crew did not have time to work through the usual procedures of establishing a holding pattern whilst using checklists and other flight deck information to determine what was happening and how best to deal with it. In fact, in this situation, they had no need to diagnose the problem. They knew what it was and they only had one option - land as soon as possible.

However, as the fire was in the rear galley, a flight deck image recorder would not provide any evidence as to why they decided to land immediately.

The only information an image recorder could provide would be that, for reasons unknown, the flight crew had apparently rushed their approach and landing, rather than taking time to establish what was happening. This would, clearly, be inaccurate, and could have resulted in an inappropriate finding of pilot error.

This leads to the conclusion that image recorder data must be corroborated with the information provided by the other two recorders and other available evidence. Failure to do so may result in an erroneous conclusion of pilot error.

7.1.5 The Thrust Reversers

The image recording report notes that the First Officer was having difficulty operating the thrust reversers. No explanation is provided for this, possibly because the data on the image recorder was insufficient to do so.

Neither the FDR, the CVR nor the flight crew's report makes any reference to the First Officer's difficulty with the thrust reversers.

The absence of information relating to this in the FDR and CVR reports is presumably because the recorders contained no data that pointed to this.

The absence of information on this in the flight crew ASR is likely to be a result of one of two things. Either it was not a significant problem or the flight crew had so many other more serious problems that this was not something that they remembered.

Although this is an example of the image recorder highlighting physical difficulties that the flight crew are faced with, it is difficult to precisely determine how great an impact this had on the outcome of the scenario.

Based on the fact that CVR analysis does not highlight any discussion relating to this problem, it may be assumed that either it was not a significant enough problem to merit discussion or any discussion related to it was not deemed to be significant in terms of the investigation.

This issue was discussed during the initial wash up meeting, the results of which are detailed in Chapter 6 of this report.

7.1.6 Summary of Information gained from Initial Reports

This scenario clearly shows some of the major strengths of each of the recorder types. It can be seen that, while there are things that only an image recording system can show, there are equally things that only an FDR can show and things that only a CVR can show.

This scenario does appear to highlight some of the basic advantages of an image recording system but it also makes the limitations of those advantages very clear.

7.1.7 CAA Questions Raised During Analysis of the Accident Data

The initial analysis of this scenario did not raise any questions that could not be answered without reference to other members of the research team.

7.2 Analysis of Final Reports

7.2.1 Did an Analysis of the Complete Data Set Result in Opinion Changes?

The BFU made no technical changes to their opinion of probable cause as a result of reviewing the image data. However, their conclusions were amended slightly to include the corroborative evidence of the hydraulics failures and turbulence provided by the image data.

The BEA's opinion of probable cause did change as a result of analysing all the available data, however, the extent of the change was limited to including a reference to the galley fire. Since this has already been highlighted as information that would not have been available to the image recording system, the change in opinion is merely an accurate reflection of the sum of all the data.

7.2.2 Limitations Imposed by the Supplied Data

The BEA did not supply any specific FDR analyses and so it was not possible to comment on what information was derived from the FDR.

7.2.3 **Comparison of BFU and BEA Analyses of Image Data**

7.2.3.1 As for scenario 1, both analyses were detailed and informative but each reveals a different approach to the data. Again, the BFU's analysis focuses mainly on the flight crew actions while the BEA analysis focuses more on the aircraft systems and the environment the flight crew were working in. This is a difference that is common to the analyses of all scenarios and which results in slightly different issues for each scenario.

In addition to the difference in approach to the data, the following additional differences were noted:

a) The BFU analysis provides more details of the pre-flight checks than the BEA analysis. As no system failures were present prior to the take-off roll, it is unlikely that this would provide information that directly applies to this scenario. It does, however, provide information about whether the flight crew followed all the correct procedures prior to starting their take-off run;

b) A notable omission from the BFU report was any reference to the loss of hydraulic pressure. The reason for this omission is not certain but it may stem from the fact that BFU had already referenced this in the FDR and CVR analysis. It may also be due to the particular slant of the BFU analysis, which focussed on the flight crew activity rather than the systems and flight deck environment. It is possible that this approach led them to omit some information;

c) The BEA report also notes three other items of information that do not appear in the BFU's analysis of the image data:

   i) The First Officer's difficulty with the reversers;

   ii) The evacuation preparation; and

   iii) The '*four [fuel?]'* pumps being stopped.

The lack of reference to the First Officer's difficulty with the reversers may be because the BFU did not consider this to be relevant to the outcome of the incident. This would appear to be consistent with the flight crew's lack of reference to this problem. The fact that BEA mentioned it may due to one of two reasons:

   i) They believed it may have some relevance to the outcome of the scenario; or

   ii) They had no other information to work with and so noted everything they saw;

d) One final point to note on the subject of the First Officer's difficulties with the thrust reversers is that BEA also makes reference to this in their FDR/CVR analysis.

   The FDR would not record the fact that the First Officer was having difficulties selecting reverse thrust and it is not immediately apparent what information they could have obtained from the CVR to lead to this conclusion.

   If the flight crew had discussed this issue it seems reasonable that a reference to this would have appeared in both reports.

7.2.3.2 There are two possible reasons for this difference between the BFU and BEA CVR analyses:

a) Firstly, BFU may have heard a reference to the First Officer having difficulties selecting reverse thrust; and

b) Secondly, BEA may have been actively listening for evidence on the CVR that confirmed what they'd already seen on the image recorder.

The first option is unlikely as difficulty in selecting, or inability to select, thrust reverse can have a significant effect on the outcome of an incident/accident.

The second option is more likely as it is indicative of the usual manner in which accident investigations are performed.

If the second option is the actual explanation for this disparity, then it indicates that the selection of the first type of data to be analysed can affect the way in which subsequent data is analysed.

7.2.3.3 The absence of any reference to the evacuation in the BFU report may be because it was not considered relevant to the investigation. It is equally likely that, since the analysis of the CVR had already highlighted that an evacuation had taken place, the BFU did not feel it necessary to reference it again in a further analysis of different data.

The reason for the omission of information on the fuel pumps in the BFU report is likely to be very similar, even though the FDR report does not specifically highlight the fuel pumps. It is also possible that BEA only made reference to this to confirm that the flight crew followed the relevant procedures. This is a valid point to make but it is difficult to know whether it would have been made if the BEA had more than one source of data to look at.

7.2.3.4 The fact that BEA saw the image data first (without being able to look at other data to assist their investigation) may be relevant to any analysis of the difference between the two reports. By the time BFU saw the image data they had already seen the FDR data and listened to the CVR data. Based on this, they had formed an opinion of the cause of the incident. This may have led them to perform a simpler analysis of the image data that was solely intended to confirm or deny their original supposition.

If the BFU's analysis of the image data was more simplistic than their analysis of the FDR and CVR, one further question that should be asked is whether this was a conscious decision or the result of a set of human factors relating to accident investigation.

7.2.3.5 This set of differences highlights two limitations of this research:

a) The investigations were not realistic in that each of the investigators was forced to work with incomplete sets of data at the start of their investigation.

   Although this was necessary to determine whether the image data provided any information that was not provided by the other recorders and to highlight any changes in opinion between the initial and final reports, the way in which this data was supplied to the investigators may well have triggered a set of human factors that were specific to this set of investigations.

   Normal accident investigations may not be affected in this way as all the available data can be worked on before a conclusion is drawn about the cause of an accident/incident; and

b) There was insufficient time to ask a fourth, independent, investigation agency to replay all the available data in the usual manner (i.e. before determining probable cause) and draw a third set of conclusions.

7.2.4 General Image Recorder Issues

7.2.4.1 The BFU's General Comment on the Usefulness of Image Data

The BFU made a generic statement (applicable to all scenarios) effectively saying that the image data definitively provided additional information, namely:

a) Actual adherence to checklists (which infers that it would be possible to determine if an inappropriate checklist was used);

b) Crew actions that would not be recorded by the CVR or FDR (including some forms of silent communication - e.g. pointing etc); and

c) The way in which the flight crew handles their workload.

This is a significant benefit, as it will enable investigators to determine whether the flight crew used checklists.

Whether or not they are able to determine that the correct checklist has been used will depend upon the resolution of the image data and the availability of corroborating information (i.e. CVR).

7.2.4.2 **Failed Mitigation Attempts**

The BFU analysis provides information about the flight crew actions, many of which may not be recorded on either the FDR or CVR.

The ability to record details of flight crew actions that may not be available on other recorders means that it would be possible to see things that the flight crew tried but failed to achieve.

If the flight crew try to perform a particular action but fail to achieve the desired result (e.g. because of a system failure), the only thing that an FDR could record would be the absence of the relevant system input.

If the flight crew discussed the problem, the CVR would contain some evidence pointing to their difficulties. However, although it is probable that the flight crew would discuss problems like this, it is not guaranteed. It is also possible that any "discussion" would be silent (i.e. one member of the flight crew sees the other's difficulty, tries to help and fails and ultimately uses some form of sign language to indicate that the attempt should be ceased).

In the absence of any other evidence of flight crew difficulties, it is possible that image recorder data could provide an explanation for why a flight crew apparently failed to perform an obvious action to mitigate a situation that led to an incident or accident.

This may result in a smaller number of probable cause statements containing references to pilot error.

7.2.4.3 **Comparison of Analysis Approaches**

As the BEA analysis focuses mainly on the aircraft systems, it does not provide so much information about the flight crew activity. This may well have led to some information being omitted that could have been picked up by the image recorder.

Although the BEA analysis provided a great deal of information about why the crew performed certain tasks (i.e. what the aircraft systems were doing) its particular slant has possibly resulted in the omission of information about what the crew were doing. This is further evidence that:

a) The usefulness of image data depends upon how it is analysed; and

b) A combination of the BFU and BEA approaches would have resulted in a more useful set of data.

Although it is certain that the flight crew had a very high physical workload, neither of the analyses of image data make reference to this. In fact the BFU analysis of the image data makes it very difficult to discern that the flight crew workload was unusual in any way.

The BEA analysis does make reference to loss of all hydraulics, from which one can infer a high workload, but it makes no reference at all to the physical effort being expended by the crew.

Based on this, the only conclusion that an analysis of the two reports can result in is that, although there was evidence that would suggest an excessive **physical** workload, neither report chose to highlight this.

This was discussed with the investigators and, as stated previously, they did not see/hear symptoms of stress or work overload in the data available and so did not highlight stress or work overload as potential causal factors.

Although the sheer number of failures and distractions does imply a very high **mental** workload, it is extremely unlikely that any flight recorder could provide sufficient evidence to enable an investigator to make any definitive statement relating to this.

7.2.5 Issues Raised During the Analysis of Initial Reports

7.2.5.1 The analysis of the initial reports discussed the following issues:

a) The tyre bursts;

b) The effect of the tyre burst on the landing sequence;

c) The loss of hydraulics and the effect on flight crew workload;

d) The fire; and

e) The thrust reversers.

The analysis of the final reports has already discussed the cabin crew interruptions as a result of the fire, the First Officer's difficulty with the thrust reversers and the high physical workload that resulted from the double hydraulics failure.

7.2.5.2 Neither the BEA nor the BFU analysis of the image data made reference to the tyre bursts. As discussed in the analysis of the initial reports, this is not really surprising as there would be very little information that an image recorder could detect relating to such an incident.

With reference to a tyre burst, an image recording system could only have provided information on the following:

a) Whether there was any silent communication between the flight crew as a result of the tyre burst; and

b) Whether the crew were distracted while assessing the problem or (e.g. by other system failures) or affected by other human factors.

It is notable that neither image data analysis refers to the crew checking the engine parameters. This is an example of something occurring that no flight recorder would be able to detect because it would involve determining exactly what instrument(s) the flight crew's eyes were focussed on, and exactly what mental processes were taking place.

7.2.5.3 The effect of the tyre burst on the landing sequence was discussed during the analysis of the initial reports. The BFU analysis of image data adds nothing to the previous conclusions on this subject.

Since the BEA did not provide any specific FDR data it is impossible to determine whether they noted anything significant relating to the aircraft landing.

7.2.6 **CAA Questions Raised During Analysis of the Accident Data**

The additional analysis of the extra data does not provide answers to any of the CAA's previous questions but it has resulted in the additional questions listed below.

Once again, study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers will only be provided to those questions that relate to the issue being addressed by this research.

7.2.6.1 Does the order in which the different types of flight recorder data are analysed have any effect, i.e. does the selection of the initial type of flight recorder data affect the analysis of the subsequent flight recorder data and does that affect the final result?

a) The different analysis results provided by BFU and BEA suggest that this may well be the case. This is another indicator of human factors issues that are related to accident investigation;

b) The investigator reports for scenario 4 demonstrate this point clearly and support the facts indicated by the analysis of this scenario. Scenario 4 highlighted the following points which are also applicable to this scenario:

i) BFU analysed the CVR/FDR data first and the flight crew are heard to remark on smoke in the flight deck. During BFU's subsequent analysis of image data, they noted the presence of smoke;

ii) BEA analysed the image data first and so did not have the benefit hearing the flight crew discussions first. The absence of this information may have contributed the fact that BEA did not remark on smoke in the fight deck during their image data analysis. It is possible the BFU specifically looked for the smoke because they had heard the flight crew remark upon it.

c) Studying the accident investigator conclusions for this scenario and scenario 4, it becomes evident that analysing image data first may assist in the analysis of the CVR and, potentially the FDR;

d) This is because image data could, potentially, provide explanations for events investigators couldn't otherwise explain (i.e. the "why" behind the what). However, it should be noted that this research forced investigators to analyse data in isolation, which is something they would not normally do. If all the data is analysed simultaneously (and, possibly iteratively) the order of data analysis may not be so significant.

7.2.6.2 Did the way in which the investigators were forced to draw two part conclusions introduce a set of human factors issues that were specific to these investigations?

The answer to this is probably yes. The nature of this research meant that investigators were forced to analyse data sources separately when they would normally assess the complete picture. See Chapter 7, paragraph 2 and Appendix 6 of this report and Chapter 10, reference document 3.

7.2.6.3 How big an impact did the two differing focuses on the image data analysis have on the determination of probable cause?

a) It is difficult to provide a definitive answer to this question. However, this research has shown that there are different ways in which image data can be analysed and it indicates a need for further research in to the best way to analyse image recorder data. This research is probably best co-ordinated by accident investigation agencies and the pilot associations;

b) Although the CAA analysis did identify both differing approaches to the analysis of image data and a series of human factors, it is difficult to determine their relative contributions to the overall result.

7.2.6.4 Did the flight crew look back towards the cabin crew during the discussions about fire?

This question is not relevant to the effectivity of image recorder systems.

7.3 **Summary For Scenario 2**

Neither of the accident reports correctly determined the initial cause of the problems (i.e. the tyre burst). As previously discussed, this was a largely predictable outcome, the only element of surprise being that neither of the CVR analyses mentioned any flight crew discussion concerning a 'rumbling noise'.

There were some differences between the reports. The BEA reports highlighted system issues that the BFU reports did not - this was particularly true with respect to the two image data analyses. The BFU reports provided information about what the crew were doing that was absent from the BEA analyses - an example of this is the pre-flight checks.

The differing analyses of the image data clearly show that the investigator's focus or 'slant' has a definite effect on the amount useful information that can be obtained from an image recorder.

While this is almost certainly true for any other kind of flight recorder data too, it may be especially true for image recorders. This is because an image recorder contains a roughly equal combination of information about 'what happened' and 'why it happened', whereas an FDR usually contains more information about 'what happened' and a CVR usually contains more information about 'why it happened'.

It is true to say that both FDRs and CVRs will contain both types of information but possibly not in as greatly a combined manner as an image recorder.

Although this scenario demonstrates some of the advantages of an image recording system (e.g. the ability to see what alerts were displayed to the flight crew) it also clearly shows that the scope of these benefits does have limits. Some of those limits are due to system constraints, such as the absence of audio information, and some of those limits are due to the way in which the data is analysed.

This scenario does show that it would be possible to determine that a flight crew tried and failed to achieve one or more physical tasks. This means that it may be possible to determine that a flight crew were unable to perform necessary mitigating actions rather than simply failing to take them.

It is surprising that the image data was not used to demonstrate that the flight crew were subjected to an excessive workload. Although this information could have been inferred from the FDR and CVR data, one of the previous assumptions about image data was that it would be able to show excessive physical workload. Both the analysis of this scenario, and the analysis of scenario 1, appear to refute that theory.

This scenario shows that there are several occasions when the image data provides substantiation for the FDR and/or CVR data. One example of this is that the FDR and CVR analyses report that the hydraulics had failed and the BEA image data analysis also references complete loss of hydraulic pressure. As previously discussed, data that corroborates the FDR and CVR information can be very useful in cases when determining probable cause is difficult.

Once again, it is possible to see that there are some forms of information that can only be obtained from the FDR (e.g. the centre-line deviation and associated rudder input) and some which can only be obtained from the CVR (e.g. the Captain's discussions with the cabin crew).

It is also interesting to note that this scenario shows that there are some forms of information that cannot be obtained using any type of flight recorder (e.g. what the flight crew are looking at). Although this infers that there is 'missing information' it is probable that there would be some form of crew response to what they are looking at, either in the form of physical actions or crew discussion. This being so, the 'missing information' may well have little effect on the determination of probable cause.

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Appendix 3 Investigation Data for Scenario 3

NOTE: All quoted material (e.g. Flight Crew ASRs and Investigation Reports) are shown in italics.

1 De-Brief from Simulator Operator

Failure

Time

Take Off

15:30

Engine 1 non extinguishable fire 146kts (Vr 142kts). Flame out

Ladies and gentlemen please remain seated

1531

Captain report fires left wing

1532

Cabin secure for landing. Some (6) pax still standing

2 mins before LDG

2 Flight Crew ASR

KONIL 2A Departure 23 GVA

Shortly after rotate call (142kts) engine fire bell sounded followed by the failure of the No 1 engine.

A/c was climbed away; the engine positively identified and the appropriate QRH actioned.

Lateral profile flown in accordance with the emergency procedure.

A/P B engaged and a/c accelerated at 2,900' QNH on high speed schedule.

Both extinguishers had been fired ~ fire warning remained.

During left turn at Kemit, cabin crew reported panic in cabin due to the fire being visual from No 1 engine

Left turn in the hold was converted into a visual approach for a downwind landing 05.

Pax evacuation followed after successful landing

3 Initial BFU Analysis based on FDR and CVR Data

3.1 Flight Plan Data

Date:	*30 August 2002*
Time:	*15:30*
Departure Airport:	*Geneva*
Departure Runway:	*23*

Captain's Name:	*Malcolm Terry*
Fist Officer's Name:	*James Taylor*
Deferred Engineering Defects:	*none*
Cloud Base at Take Off:	*CAVOK*
Visibility:	*CAVOK*
Landing Airport:	*Geneva*
Landing Runway:	*05*
Cloud Base at Landing:	*CAVOK*
Visibility:	*CAVOK*

3.2 Scenario Description From FDR Parameters

The time reference was derived from the recorded parameter "Relative Time", starting at 0 and ending at 1132.30s.

Taxi and take off were found to be under normal conditions.

Rel. Time: 582s:	*During climb at a pressure altitude (1013) of 1680ft and a calibrated airspeed of 148kt "Fire Warning" along with "Master Caution" were activated.*
Rel. Time: 593s:	*"Eng. Warning" activated.*
Rel. Time: 606s:	*"Hyd Warning" and Elec Warning" activated.*
Rel. Time: 610s:	*"Eng 1 Low Oil Pressure" activated.*
Rel. Time: 616s:	*"AT Engaged" disengaged, "Eng. 1 Throttle Pos" set to 0, "EPR Engine 1" decreased to 0 within 1 sec.*
Rel. Time: 620s:	*"Eng Warning" deactivated.*
Rel. Time: 886s:	*"Hyd Warning" and "Master Caution" deactivated.*

The engine failure was covered following the emergency procedure. The crew reported engine fire to the ground controller. The fire light remained on (known from CVR) but "Fire Warning" was deactivated after 5s.

The activation of "Hyd Warning" cannot be explained. "Hydraulic Pressure A" and "Hydraulic Pressure B" remained on high level of 3002 units.

The aircraft turned left for an approach to runway 05 in Geneva.

At Rel. Time 978s localizer- and glide slope deviation jumped to zero and remained on zero during heading changes of the aircraft in the approach phase. So it was not clear whether the aircraft was on the glide path.

After touch down there were some small periodic heading changes until the aircraft came to a stop.

3.3 Scenario Description from CVR

The CVR transcript is more descriptive. Only important parts of conversation and handling activities are reported in detail.

The most important information was that the engine fire on engine No. 1 could not be extinguished. During approach the warnings "Too low terrain" and "sink rate" could be heard.

3.4 Conclusion

During climb a fire warning of engine No.1 was generated. The CVR delivered the information that the fire could not be extinguished and that passengers were recognizing the fire. During the approach the parameters "localizer deviation" and *"glide slope deviation" jumped to zero about 58s before touch down. This may be the reason for a too high sink rate. The crew handled the situation in a professional manner using emergency procedures and - as far as could be heard - doing all necessary checks. The aircraft landed safely. The passengers were evacuated.*

3.5 **BFU CVR Analysis**

Partial CVR transcript Session 3

Rel. Time		
CVR(min:s)	*FDR(s)*	
->08:42	*->523*	*Preflight checks, checklists, briefing*
08:45	*526*	*tk(?) zero one is ready for take off*
09:16	*557*	*Power set*
09:23	*564*	*80 knots*
09:39	*580*	*Rotate*
09:40	*581*	*[Engine fire warning sound]*
09:41	*582*	*Engine fire*
09:46	*587*	*[Sound of engine rundown]*
09:50	*591*	*Gear up*
09:51	*592*	*Positive climb*
10:07	*608*	*Engine fire number one*
10:13	*614*	*Number one thrust lever*
10:14	*615*	*Checked*
10:15	*616*	*[several checks and handling noise]*
11:23	*684*	*30 seconds ... second bottle being fired, fire light still on*
11:34	*695*	*... tk(?) one, engine fire on departure ... KEMIT ...*
12:00	*721*	*Engine is shut down, fire is still ...*
12:00	*721*	*[Cabin attendant reporting about problems in the cabin because passengers see fire on the left wing]*
12:31	*752*	*[Beginning of several checks and discussions, briefing, preparation for landing]*
15:07	*908*	*The ILS is selected*
15:31	*932*	*[PA to cabin to prepare for landing]*
16:02	*963*	*On the ILS*
16:43	*1004*	*[PIC takes over control]*
16:54	*1015*	*"Too low terrain, too low terrain, sink rate"*
17:11	*1032*	*"Sink rate, sink rate"*
17:20	*1041*	*160 knots*

17:23	*1044*	*140 knots*
17:26	*1047*	*120 knots*
17:29	*1050*	*100 knots*
17:33	*1054*	*80 knots*
17:36	*1057*	*60 knots*
17:40	*1061*	*Cut reverse, reverse idle, 40 knots*
18:00	*1081*	*[PA to evacuate passengers]*
18:50	*1131*	*{End of CVR recording}*

3.6 BFU FDR Traces For Scenario 3

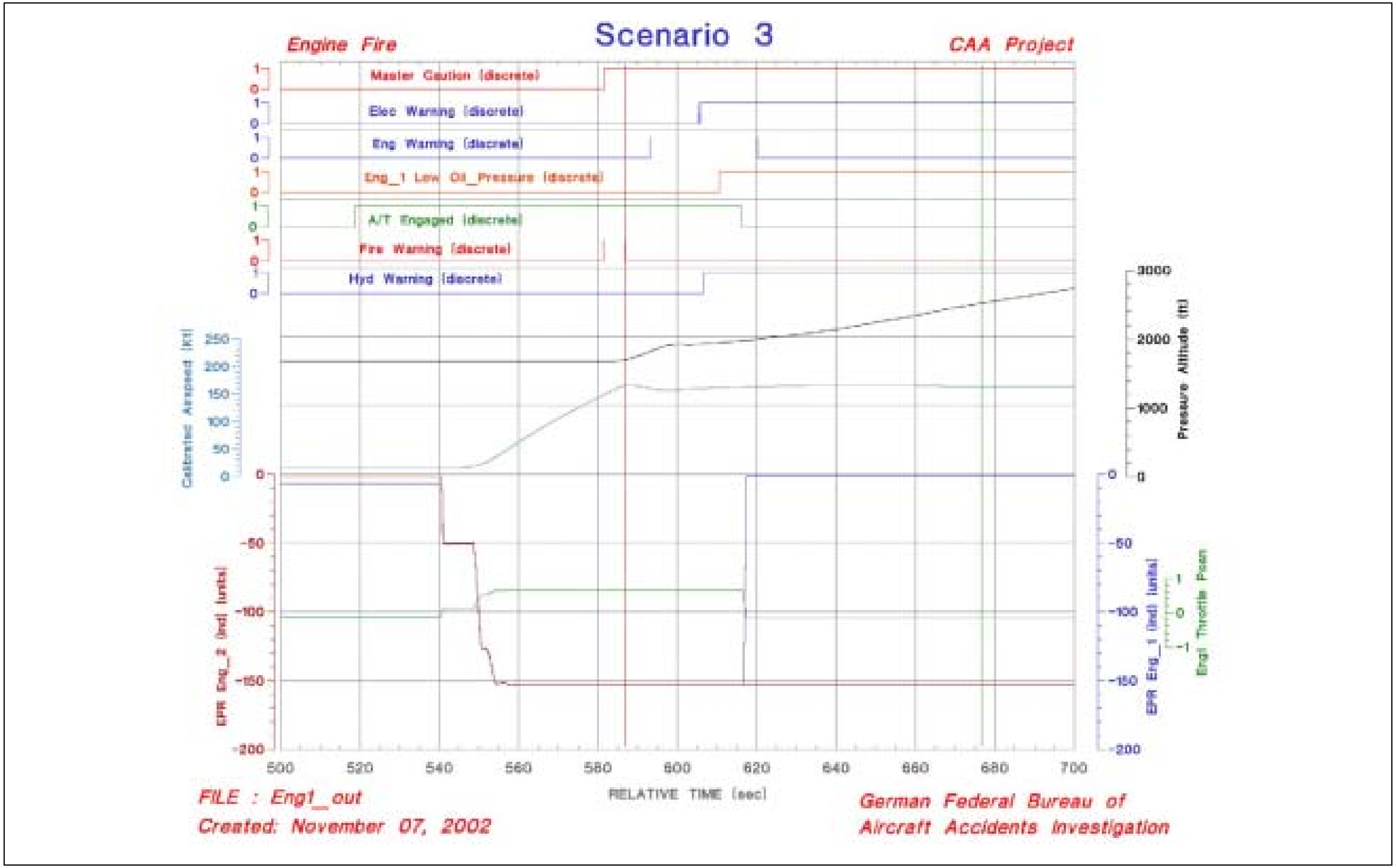

Figure 13 Data Analysis for Scenario 3 - BFU FDR Trace 1

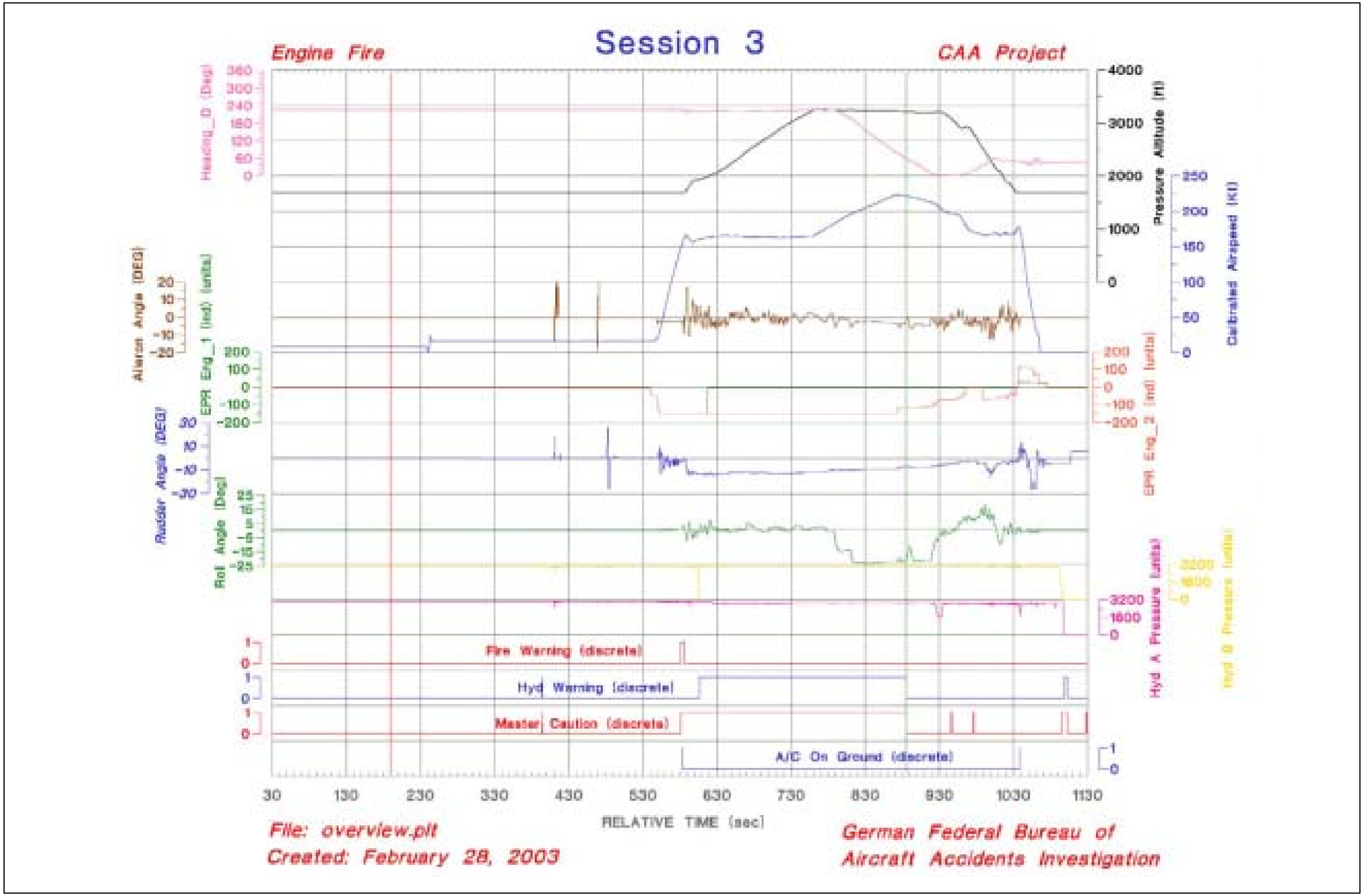

Figure 14 Data Analysis for Scenario 3 - BFU FDR Trace 2

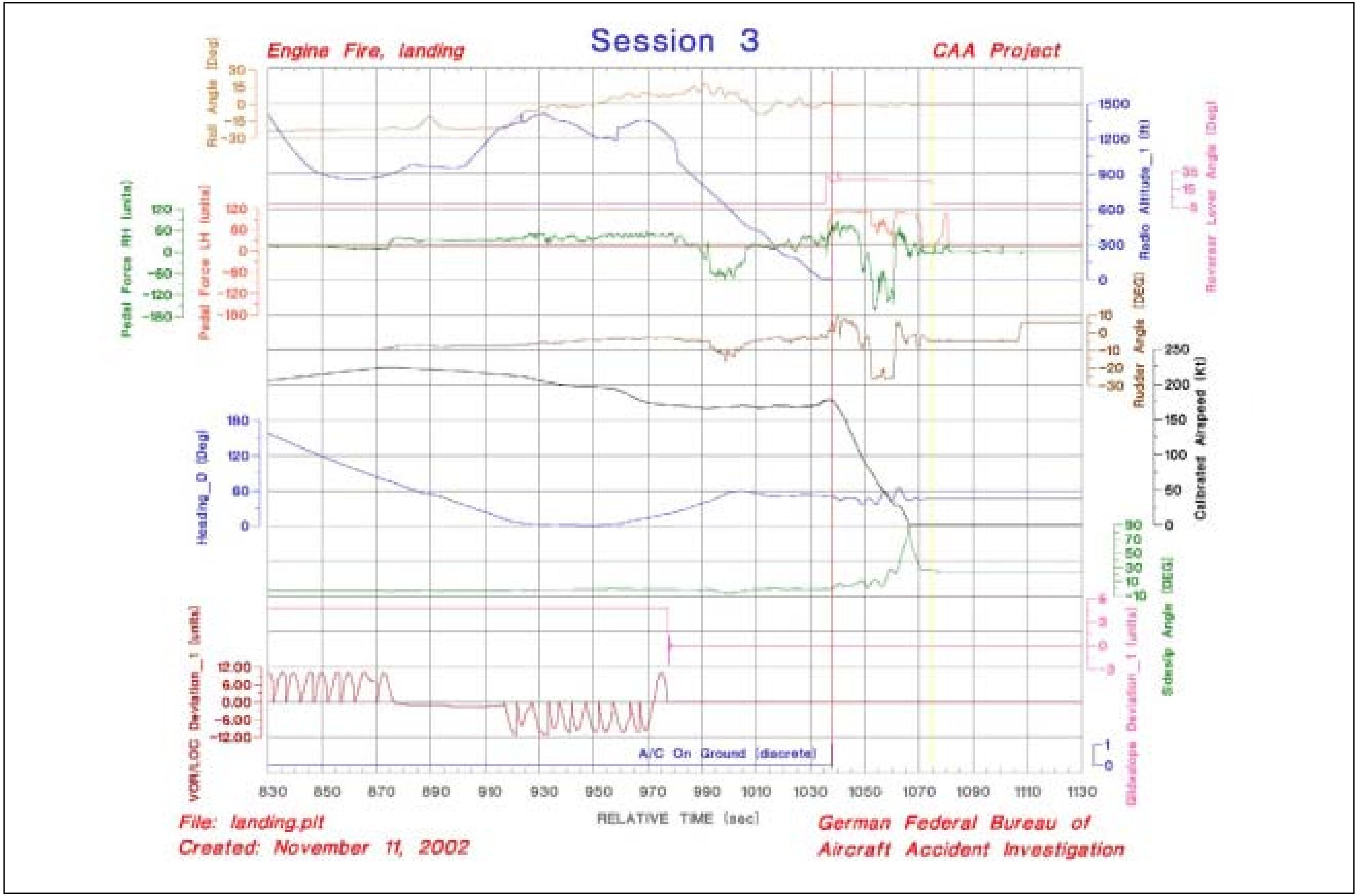

Figure 15 Data Analysis for Scenario 3 - BFU FDR Trace 3

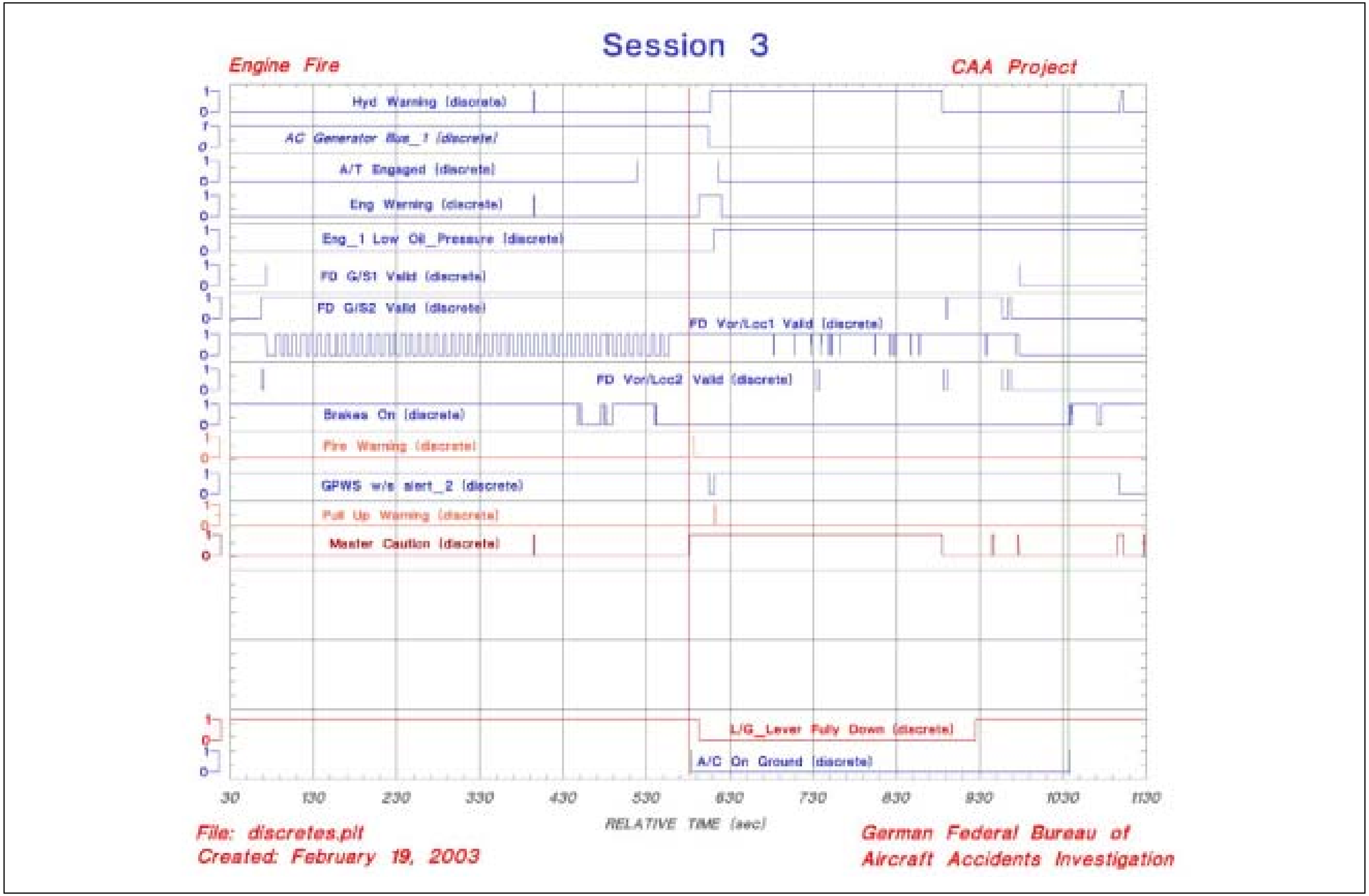

Figure 16 Data Analysis for Scenario 3 - BFU FDR Trace 4

4 BEA Initial Report Based On Image Data

Time	***Event***	***Remark***
	The F/O is the flying pilot	
15 h 31 min 20	*Master caution followed by master warning fire engine number 1 after V1*	*We don't see clearly V1 and V2*
	Flight is continued and the gear retracted	
15 h 31 min 46	*Electrical stop*	
15 h 32 min 05	*Fire extinguish lever on left hand side*	
15 h 32 min 25	*Light still on*	
15 h 32 min 35	*Second percussion follows*	*Fire not extinguished after the first percussion 30 seconds after first attempt the second is done*
	Fire still not extinguished on left engine	
		Sometimes before the Auto-pilot B was engaged
	Loss of part of the instruments on the left hand side	
15 h 36 min 08	*Emergency check list is read*	
15 h 36 min 54	*APU is prepared*	
15h 37 min 04	*Landing gear down selection*	
15 h 37 min 58	*Landing*	
15 h 39 min 58	*Preparation evacuation*	

Probable cause of the incident: Non contain fire on left engine.

5 BFU Final Report Subsequent to Analysing Image Data

5.1 Preflight Checks

PIC sets, recalls or changes data on left CMU

First Officer sets, recalls or changes data on right CMU

PIC sets, recalls or changes data on right CMU

First Officer sets or changes selected speed

PIC sets QNH on his altimeter

First Officer sets or changes selected speed

First Officer checks preset parameters on glareshield panel

PIC performs lamp check

PIC checks elevator and aileron movement by pushing and pulling control column and turning control wheel

Rudder movement check

First Officer checks trim setting

5.2 **Take Off**

First Officer has control, now PF, sets take off power

Gear up

5.3 **Incident**

Engine fire indication

Master caution and fire warning lamps on

N1, EGT, N2, FF and Oil Pressure pointers of engine No. 1 moving to zero position

Fire warning lamps remain on

First Officer changes selected speed and altitude

First Officer changes selected heading

First Officer sets, recalls or changes data on right CMU

First Officer changes selected speed

First Officer changes selected heading

PIC sets new course

Master caution lamps on and reset by First Officer

PIC retrieves speed from CMU and sets speed markers on his speed indicator

Master caution lamps on and reset by First Officer

PIC takes over control, now PF

5.4 **Landing**

Touch down

Aircraft stop

End of movie

5.5 **Conclusion**

During climb after take off a fire warning was indicated by the fire warning lamp and the acoustical warning. Engine No. 1 was identified to be on fire and was cut off following the emergency procedure. The aircraft was prepared for a single engine landing.

The sound track delivered the information that the engine fire could not be extinguished and that passengers recognised the fire.

The aircraft landed safely.

6 BEA Final Report Subsequent To Analysing FDR and CVR Data

Time	*Event*	*Remark*
	The F/O is the flying pilot	
15 h 30 min 40		
15 h 31 min 19		*Capt : Rotate*
15 h 31 min 20	*Master caution followed by master warning fire engine number 1 after V1*	*Engine fire warning sound*
15 h 31 min 32	*Flight is continued and the gear is retracted*	
15 h 31 min 48	*Electrical stop*	*Captain identifies fire engine number one agreed by F/O*
15 h 31 min 52	*Fire check list is read*	
15 h 31 min 48		
15 h 32 min 04	*Fire extinguish lever on left hand side*	*Fire extinguisher lever is used*
15 h 32 min 25	*Light still on*	*Capt : 30 seconds fire still on*
15 h 32 min 34	*Second percussion follows*	*Second bottle is fired*
15 h 33 min 06	*Fire still not extinguished on left engine*	*Capt : Second bottle fired and the fire is still on*
15 h 33 min 14	*Captain reads the procedure for one engine operation*	
	Loss of part of the instruments on the left hand side	*Cabin informed by F/A that a lot of passengers saw fire on the left engine and feel smoke in the cabin Captain ask if there is still a fire on the left engine*
15 h 35 min 19		*Flaps up with speed check*
	Discussion on the procedure for landing	
15 h 37 min 13	*Emergency check list is read*	*Captain send a message to the passengers for a landing in 3 minutes*
15 h 37 min 59	*APU is prepared*	*Passenger cabin secured*
15h 38 min 36	*Landing gear down selection*	*GPWS "too low terrain, too low terrain sink rate"*
15 h 38 min 52		*GPWS "sink rate sink rate"*
15 h 38 min 56		*Landing with reverses*
15 h 39 min 38	*Preparation evacuation*	*Preparation evacuation*

Probable cause of the incident : Non contained fire on left engine.

7 Detailed CAA Analysis For Scenario 3

7.1 CAA Analysis of Initial Reports

7.1.1 The Flight Crew ASR

Once again, the flight crew ASR provides an accurate reflection of the scenario. The flight was aborted very quickly as a result of the inability of to extinguish the engine fire and so this scenario is shorter than the others.

7.1.2 The Engine Fire

In this scenario, the engine fire resulted in a basically predictable system failure; the indicated loss of electrical and hydraulic power.

None of the initial reports specifies whether some or all of the electrical and hydraulic systems were lost. However, given that only one engine was lost and the flight crew ASR makes no reference to manual reversion, it is likely that only the systems powered by engine number one were lost.

Although this would result in an increased workload, it should not have been outside the normal events flight crews are trained for.

The inability to extinguish the fire, together with reports of 'panicking passengers' would have resulted in an increased mental workload, particularly since the crew had to land with some passengers still standing.

While this may have affected the flight crew's ability to respond to subsequent events, it would not be possible for any flight recorder to indicate how big an effect the increased mental workload would have had on the outcome of the scenario.

There is one apparent anomaly associated with this scenario. The BEA analysis of the image data makes reference to two percussions. This implies that the image data for scenario 3 was accompanied by sound.

Although this is possible given the way in which the cameras were set up for this trial, it is not representative of the current proposals for image recorder systems.

The apparent presence of audio data with the image data is also surprising, as the previous image data analyses have made no obvious references to audio data.

Further discussion on this matter revealed that the "percussion" referred to in the BEA report was generated by the fire extinguishers.

As the reference to an audio input only occurs in this scenario and the data from that did not change the conclusions drawn as a result of image analysis, this anomaly is not considered be significant.

7.1.3 The Hydraulics Systems

The BFU FDR/CVR report notes that this scenario resulted in the generation of a "Hydraulics" warning. The report notes that this "cannot be explained" as both hydraulic pressure A and hydraulic pressure B remained on a high level. Although the BFU report does not explicitly state that this fact remained true for the complete flight, the inference is that it did.

The absence of any reference to loss of hydraulics in either the BEA image report, the BFU CVR analysis or the flight crew ASR provides further confirmation that, despite the presence of a hydraulics warning, there were no failures of either hydraulic system.

This raises two questions. Firstly, why was a hydraulics warning generated when neither of the hydraulic systems had any faults? Secondly, as an uncontrollable engine fire could reasonably be expected to result in the loss of the hydraulic system powered by that engine, so why were both hydraulics systems unaffected?

Although it is possible that this was either the result of a simulator glitch or that it was an error in the running of the scenario, the real reason for this event cannot be determined from the data provided.

7.1.4 Lack of ILS

The BFU FDR report highlighted the fact that the ILS signals went to zero. This is a good example of data that can be found from an analysis of the FDR and supported by the image recording system. Unfortunately, this fact was not identified in the BEA image data analysis. There are several possible reasons for this including:

a) The image recorder system cameras did not have a view of the relevant instrument;

b) The image recorder system cameras did have a view of the relevant instrument, but the resolution of the image was insufficient to detect the ILS moving to zero;

c) The BEA did not register that the ILS went to zero; or

d) The image recorder systems did record the fact that the ILS went to zero but the BEA did not believe that it was relevant.

The first possibility does not apply as the image recorder system did have a camera that was focussed on the relevant part of the display panel.

The second possibility is plausible, but since the ILS went to zero and stayed there, this should have been possible to detect.

The third option is possible, however, the BEA image recording report does reference the loss of instruments and it is more probable that they included loss of ILS in the generic reference to loss of instruments.

The fourth possibility is the most likely as the ILS went to zero because the flight crew were not landing on the usual runway. Given this fact, the flight crew would have expected the ILS to go to zero and would not have been concerned by this fact. Equally, as they could see the runway in front of them, they would not have been too concerned about the loss of an ILS.

The BEA could well have looked at the situation facing the flight crew, realised what their reaction was likely to be, and decided that, although they could see that the ILS was set to zero, it was not relevant to the outcome of the incident.

7.1.5 Summary of Information gained from Initial Reports

This scenario highlights a number of areas where image recorder data could have been used to support the indications of probable cause suggested by the other recorders. Unfortunately, the analysis of the image data does not seem to have achieved this. There are a number of potential explanations for this and it is possible that the differing analysis approaches adopted by BEA and BFU also contributed to this effect. It is recommended that issues such as this be addressed when developing training material for image data analysis.

Despite this, the analyses do show some evidence of image recorder data being used to support the findings from other types of flight recorder. The benefits of this have been discussed in review of other scenarios and the fact that this result is echoed in the analysis of this scenario serves to strengthen the point.

The analyses also highlight some of the points made in the analyses of previous scenarios, including the strengths and limitations that apply to image recorder data.

7.1.6 CAA Questions Raised During Analysis of the Accident Data:

The CAA analysis raised a number of questions, however, a further study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers will only be provided to those questions that relate to the issue being addressed by this research.

a) Why was a hydraulics warning generated when there were no hydraulic system failures?

- This question is not relevant to the effectivity of image recorder systems.

b) Why didn't the hydraulic system associated with engine 1 experience a drop in pressure subsequent to the engine being shut down?

- This question is not relevant to the effectivity of image recorder systems.

c) Did the BEA miss the fact that the ILS signal went to zero?

- This question is not relevant to the effectivity of image recorder systems.

d) Did the BEA determine that the zero ILS signal was irrelevant to the outcome of the incident?

- This question is not relevant to the effectivity of image recorder systems.

7.2 CAA Analysis of Final Reports

7.2.1 Did an Analysis of the Complete Data Set Result in Opinion Changes?

The BFU opinion of probable cause is slightly different following the review of the image data. In this case it would appear that the statement of probable cause is limited to what an analysis of the image data can provide and not an overall conclusion based on all the data. Despite this most of the major contributing factors to the incident have been listed.

The BEA made no changes to their statement of probable cause.

7.2.2 Limitations Imposed by the Supplied Data

The BEA did not supply any specific FDR analyses and so it is not possible to comment on what information was derived from the FDR.

7.2.3 Comparison of BFU and BEA Analyses of Image Data

As for each of the previous scenarios, both analyses were detailed and informative but the same difference in approach highlighted in the analyses of scenarios 1 and 2 can be seen for scenario 3.

In addition to the difference in approach to the data, the following additional issues were noted:

a) **Checklists**

The BFU provided a general statement about the usefulness of checklists that seems to apply to all of their analyses.

The BEA's only reference to the use of checklists appears in their CVR analysis. This is almost certainly a result of the focus of their image data analysis which was directed at system state rather than crew actions.

The effect of the differing analysis approaches is discussed elsewhere in this report.

b) **Hydraulics Warning**

Although the BFU FDR analysis indicates that a hydraulics warning was generated, there is no evidence of this in any of the CVR or image data reports.

This is surprising as, if a hydraulics warning was generated, there should be evidence of this on the CVR (e.g. via a aural alert) and it is possible that the image recorder system cameras would have picked up the relevant visual alert.

The absence of any other corroborative evidence of the hydraulics warning implies that, although the FDR data indicated the presence of this warning, the warning itself was not actually generated. This supports the suggestion raised during the analysis of the initial reports, i.e. either:

i) The presence of the hydraulics warning was the result of a simulator glitch; or

ii) The engine failure should have resulted in some degradation of the relevant hydraulic system, which, for reasons unknown, did not occur.

c) **Loss Of Instruments**

The BEA CVR analysis notes a 'Loss of part of the instruments on the left hand side'. This corroborates the information provided in the BEA Image Recorder Analysis, however, it does raise an interesting question.

Since the BEA CVR analysis makes no reference to any crew discussion on this subject, how was the loss of instruments determined during the CVR analysis?

7.2.4 The BFU's General Comment on the Usefulness Of Image Data

The BFU made a generic statement (applicable to all scenarios) effectively saying that the image data definitively provided additional information, namely:

a) Actual adherence to checklists (which infers that it would be possible to determine if an inappropriate checklist was used);

b) Crew actions that would not be recorded by the CVR or FDR (including some forms of silent communication - e.g. pointing etc); and

c) The way in which the flight crew handles their workload.

The relevance of this statement to the analyses for this scenario is analysed below.

The BFU analysis provides information about the flight crew actions, many of which may not be recorded on either the FDR or CVR. The issues associated with the provision of addition information about flight crew actions are discussed in the CAA analysis for scenario 2. The conclusions drawn there are equally applicable to this scenario.

As for the previous scenarios, the BEA's analysis focuses mainly on the aircraft systems. Again, the issues associated with this are discussed in the CAA analysis for scenario 2.

Compared to the previous two scenarios, the flight crew had a slightly lower physical workload, mainly because they did not lose the hydraulic systems.

Again, although this scenario would have resulted in a mental workload that was higher than usual, it is difficult to compare the relative mental workloads imposed by the different scenarios and impossible to make any sensible determination of mental workload using flight recorders. This being so, this issue will not be discussed any further for this scenario.

7.2.5 **Passenger Unrest**

The simulator operator's debrief states that the cabin was secured for landing with six passengers still standing. Since this statement was included in the debrief, it must be assumed that the flight crew were informed of this fact.

None of the analyses makes reference to this, despite the fact that it must have constituted a distraction to the flight crew.

The FDR could not have provided any information to suggest this, however, since the image data was supported by audio information, it is surprising that neither the analyses of the CVR data or the image data made reference to this fact.

There are two possible explanations for this:

a) Either the simulator operator did not pass this information on to the flight crew; or

b) The investigators did not believe this information was relevant.

The first explanation appears to be unlikely. If the debrief specifically noted that passengers were standing, it is likely that the flight crew were informed.

The flight crew ASR does not definitively support this supposition, however, the generic statement 'cabin crew reported panic in cabin' could cover it.

If the investigators were aware that of the fact that passengers were standing at the point when the cabin was secured for landing, it is surprising that they did not comment on it. Although the aircraft landed safely and there were no cabin crew reports of injuries, this would have constituted a distraction to the flight crew.

7.2.6 **Loss of ILS**

The BFU analysis of the image data has one surprising anomaly. Despite the fact that the ILS going to zero was specifically noted in the FDR analysis, the BFU has not used the image recorder data to support this finding.

The reason for this omission is difficult to determine and relies and answers to the same set of questions that were raised against the BEA analysis, namely:

a) Did the image recorder system cameras have a good view of the ILS data?

b) Did the BFU miss the fact that the ILS signal went to zero?

c) Did the BFU determine that the zero ILS signal was irrelevant to the outcome of the incident?

Equivalent questions were asked during the CAA's analysis of the BEA data and the answers to these questions are provided in that analysis.

7.2.7 **CAA Questions Raised During Analysis Of The Accident Data:**

The additional analysis of the extra data does not provide answers to any of the CAA's previous questions but it has resulted in the additional questions listed below.

Once again, study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers will only be provided to those questions that relate to the issue being addressed by this research.

a) Since the BEA CVR analysis highlights the loss of instruments but makes no reference to any crew discussion on this subject, how was the loss of instruments determined during the CVR Analysis?

- This question is not relevant to the effectivity of image recorder systems, however, it may be indicative of the fact that BEA's analysis of the CVR data was influenced by what they had already seen in their analysis of the image data.

b) Why was no reference made to standing passengers in any of the incident reports?

- This question is not relevant to the effectivity of image recorder systems.

7.3 **Summary For Scenario 3**

Once again there were differences in emphasis between the BEA and BFU analysis of the image data. The conclusions that may be drawn from this are noted in the analysis of scenario 2.

This scenario shows that there are several occasions when the image data provides substantiation for the FDR and/or CVR data. One example of this is that the FDR and CVR analyses report that an electrical system had failed and the BEA image data analysis corroborates this.

As previously discussed, data that corroborates the FDR and CVR information can be very useful in cases when determining probable cause is difficult.

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Appendix 4 Investigation Data for Scenario 4

NOTE: All quoted material (e.g. Flight Crew ASRs and Investigation Reports) are shown in italics.

1 De-brief from Simulator Operator

Failure	***Time***
Eng 2 fan blade loss *Flameout No 2*	*120 kts* *140 kts*
Auto electric transfer fail *APU starter fail*	*- undisclosed* *undisclosed*
F/O loss of all screens	*15:07*
Smoke from instrument panel	*15:12*
ADI P1 Fail	*15:12*
Both on Oxygen(introduces intercom communication)	*15:13*
Vectors and descent for return (Mayday)	*15:14*
CCI Request to Captain for seat belts off Surprise at oxygen masks ESTC	*15:16*
Moderate Cobblestones Turbulence back to light for comfort	*15:18*
Oxygen off (smoke gone) *Micro burst & Downdraughts 50%*	*15:18* *15:21*
CC called to view flaps after gear down	
CC called to report	*15:23*
Cleared land 500	*15:24*
ATC Report Fire engine u/s on RWY Continue approach	*15:25*
"Windshear" "Windshear"Go-Around V SP increased - F/O	*15:26*
"Go-Around - were losing it" Capt	*15:26*
Excessive bank noted	*15:27*
P2 handling on standby	*15:29*
InstStby compass open	*15:32*
Discussion of reasons for failures…	*15:35*
…and how to fly approachVectors to 15 mile final at Capt request	*15:39*
Flap one selected	*15:40*
Microburst 75% (ft/min?) armed for approach	
CC requested to view flaps	*15:43*
Gear and 15 degree flap	*15:44*
CC report "OK"	*15:45*

Capt advised "expect heavy ldg"	*15:45*
Cloud base Reduced to 300' for final approach.	*15:47*
Flood light selected off by Capt	
Ldg > within limits	*15:49*
"Sink Rate" "Windshear" "Glide slope"	*15:49*

2 Flight Crew ASRs

2.1 Captain's ASR

EFATO # 2, smoke on flt deck

windshear go around

Flap 15 degree landing

G/S warning short finals

Please remove mud from wheels

2.2 First Officer's Comments

P2 T/O RWH 05 SLA

EFATO # 2 Eng, subsequent failure of all P2 instruments leading to handover of control to captain.

Smoke on flight deck with Air Cond drill actioned. RWY 05 emergency turn flown, a/c accelerated and cleaned up.

SE approach made to RWH 05 GLA but G/A due windshear. A/C re-restored for another a/p into GLA due PIK unavailable.

Windshear on short on finals gave Glide slope warning, a/c landed but left paved surface to left briefly. A/C stopped on runway.

3 Initial BFU Analysis based on FDR and CVR Data

3.1 Flight Plan Data

Date:	*31 August 2002*
Time:	*15:00*
Departure Airport:	*Glasgow*
Departure Runway:	*05*
Captain's Name:	*Malcolm Terry*
Fist Officer's Name:	*James Taylor*
Deferred Engineering Defects:	*none*
Cloud Base at Take Off:	*500ft*
Visibility:	*5km*
Landing Airport:	*Glasgow*
Landing Runway:	*05*
Cloud Base at Landing:	*300ft*

Visibility: 5km

3.2 Scenario Description from FDR Parameters

The time reference was derived from the recorded parameter "Relative Time", starting at 0 and ending at 2664.233s.

Taxi was not recorded. Begin of take off run was found to be under normal conditions.

Rel. Time:	*15s:*	*During take off run "Eng 2 Vib" jumped from 0.85 to 5.04, "Calibrated Airspeed": 125kt.*
Rel. Time:	*19s:*	*"A/C on Ground" deactivated -> rotation phase.*
Rel. Time:	*20s:*	*"Engine 2 Thrust" decreased to 0 within 6s, "N1 RPM", "N2 RPM", "EPR Eng 2" and "EGT Eng 2" also decreasing to 0.*
Rel. Time:	*25s:*	*"Eng Warning" activated for 1.2s.*
Rel. Time:	*35s:*	*"AC generator Bus 2", "AC Main Bus 2", "28 AC Main Bus 2" Warnings activated. "Calibrated Airspeed": 156kt, "Pressure Altitude" (1013): 996ft.*
Rel. Time:	*40s:*	*"Eng 2 Low Oil Pressure" activated.*
Rel. Time:	*66s:*	*Several "Master Caution" Warnings during the whole flight.*
Rel. Time:	*112s:*	*"AT Engaged" deactivated.*
Rel. Time:	*120s:*	*"Air Cond Warning" activated for 2.2s*
Rel. Time:	*144s:*	*"Air Cond Warning" activated for 5.5s.*
Rel. Time:	*146s:*	*"Eng 2 Throttle Posn" removed to 0.*
Rel. Time:	*159s:*	*"Hyd Warning" activated for 136s.*
Rel. Time:	*377s:*	*Several "Air Cond Warning" during the whole flight.*
Rel. Time:	*589s:*	*"APU Warning", "APU Overspeed" activated for 174s.*
Rel. Time:	*862s:*	*"Hyd Warning" activated.*
Rel. Time:	*999s:*	*"DC Bus 2" Warning activated.*
Rel. Time:	*1161s:*	*"Hyd Warning" deactivated.*
Rel. Time:	*1173s:*	*"AT Engaged" activated.*

Parameters "FD GS/1 Valid", "FD VOR/LOC 1 Valid" toggled several times.

During the first approach at Rel. Time 1202s the reverser lever was moved from -26 to -196 units. "Radio Altitude": 453ft, "Calibrated Airspeed": 144kt.

5s later the aircraft was descending to a radio altitude of 135ft, 7s later the aircraft climbed to 280ft and descended again to 112ft before climbing to the second approach and landing.

The second approach was more or less stabilized. Localizer deviation was close to 0, glide slope deviation was -2.5 units (conversion to dots is unknown). On indication of "AC on Ground" the "Pitch Angle" was 2.6 deg., the "Roll Angle" was 9.2 deg., the aircraft was nearly exactly on glide path.

The "LH Pedal Force" was 0 during the flight, but jumped to about 100 units immediately after touch down. The "RH Pedal Force" showed activity during the whole flight. The rudder movement was equivalent to the "RH Pedal Force". This is *quite unusual and might be an error of the simulator data. After touch down the aircraft changed heading first up to 71 deg. than back to 32 deg. and stopped with a heading of 48 deg.*

The centreline heading is 53 deg.

3.3 Scenario Description From CVR

The CVR transcript is more descriptive. Only important parts of conversation and handling activities are reported in detail.

Also here the CVR presented a good impression of the scenario. A lot more problems than could be retrieved from the FDR arised like smoke in the cockpit, an electric failure, the misapproach and go around and also warnings during the approaches like "wind shear", "pull up", "sink rate" and "glide slope".

3.4 Conclusion

About 50s after take off the No. 2 engine failed due to high vibration. This is a typical situation of a bird strike damaging the fans. About 5 min. later the cockpit crew noticed smoke in the cockpit and used the oxygen masks.

Due to a misapproach the crew decided to do a go around. During the climb phase there was a remark that the aircraft may loose petrol.

The crew prepared for landing and advised the cabin that it could be a hard landing.

The crew handled all problems in a professional manner performing - as far as it could be heard - all necessary checks.

The aircraft landed safely.

3.5 BFU CVR Analysis

Partial CVR transcript Session 4

Rel. Time		
CVR(min:s)	***FDR(s)***	
00:53	*8*	*Power is set*
01:01	*16*	*Rotate*
01:07	*22*	*Positive climb*
01:08	*23*	*One engine running down*
01:10	*25*	*... gear up*
01:32	*47*	*You have control [control handed over to PIC]*
01:51	*66*	*Engine failure, engine running down*
01:54	*69*	*Number two ...*
03:00	*135*	*Number two ... flaps one*
03:03	*138*	*Okay, flaps one checked*
03:18	*153*	*Flaps one, please ...*
03:21	*156*	*Flaps one*

03:30	*165*	*Pan, pan, pan, pan, pan, pan, tk(?) one, we have(?) an engine failure, commit the emergency turn procedure ... heading zero nine five ... the golf lima golf*
03:42	*177*	*[Discussions about procedures, handling of several items]*
04:37	*232*	*[Morse code of GOW, first time reception]*
04:55	*250*	*... tk(?) one, we are on the right turn back for the golf oscar whisky*
05:04	*259*	*[Several checks and handling]*
06:15	*330*	*We got smoke*
06:39	*354*	*Oxygen ... set*
06:42	*357*	*[Sound of breathing through oxygen mask starts]*
08:42	*477*	*Mayday, mayday, mayday, tk(?) one, we now have smoke on the flight deck, ...*
08:53	*488*	*... 15 miles in(?)...*
09:05	*500*	*... one nina five, tk(?) one*
09:14	*509*	*... 500, nina nina zero, tk(?) one*
09:32	*527*	*[Conversation about engine failure and what to do]*
10:31	*586*	*... low oil pressure ...*
10:43	*598*	*... flaps are up but(?) we lost the ACA(?)...*
10:58	*613*	*[Advise to cabin attendant to inform passengers about the return to Glasgow]*
11:00	*615*	*[Conversation, partially unreadable and beginning of several handlings]*
13:02	*737*	*[Release of oxygen masks]*
13:29	*764*	*[Discussion about an electric failure and a restart of ??]*
13:45	*780*	*Right heading zero one zero, GOW localizer established...*
14:54	*849*	*Select flaps five ...*
14:57	*852*	*Okay, flaps one(?) coming up*
16:08	*923*	*tk(?) one, can you give me the DME right for descent to 3000 ft please on the ILS*
17:00	*975*	*[Cabin attendant advised to check whether the flaps are moving down]*
17:18	*993*	*Gear down, gear down (acknowledged)*
17:54	*1029*	*[Cabin attendant confirms movement of the flaps on both wings]*
18:09	*1044*	*[Cabin attendant advised to secure cabin for landing]*
18:19	*1054*	*Speed brakes ...*
18:26	*1061*	*Landing gear is down, three greens, cabin is secured for landing ...*

18:31	*1066*	*And flaps 15 ...*
19:02	*1097*	*[Request for landing clearance]*
19:50	*1145*	*On glide, coming down*
20:39	*1194*	*We do have to go around*
20:41	*1196*	*Flaps one*
20:45	*1200*	*"Wind shear, wind shear, wind shear"*
20:50	*1205*	*"Pull up, pull up, pull up"*
20:56	*1211*	*"Glide slope"*
20:57	*1212*	*Speed's increasing, we are climbing, we are climbing*
21:00	*1215*	*We are losing petrol(?)*
21:04	*1219*	*Give full power*
21:06	*1221*	*"Glide slope"*
21:14	*1229*	*We are coming (??) safety now*
21:16	*1231*	*All right, flaps one*
21:25	*1240*	*Gear up*
21:26	*1241*	*Maintain positive climb, gear coming up*
22:22	*1297*	*Hey, the bank angle*
24:00	*1395*	*[Control handed over to F/O]*
24:44	*1439*	*[tk(?) one requesting wether report]*
26:02	*1517*	*Ah, roger, we'd like another approach RWY zero five please*
29:41	*1736*	*[There seem to be a problem with the IRS] Could be (??) failure*
29:54	*1749*	*Right 245 tk(?) one*
29:57	*1752*	*[Several checks]*
30:50	*1805*	*tk(?) one, fifteen miles please*
31:26	*1841*	*[There seem to be problems with fuel flow] hopefully(?) the cross feed is open*
32:13	*1888*	*... set, (?) flaps fifteen ...*
32:40	*1915*	*Check fuel balance ...*
32:43	*1918*	*[several checks]*
35:29	*2084*	*Right 290, tk(?) one*
35:34	*2089*	*Flaps five please*
35:36	*2091*	*Because this is where the troubles begin ...*
36:14	*2129*	*Right 330, tk(?) one*
37:02	*2177*	*355 is the heading, tk(?) one*

37:03	*2178*	*We are going back for another attempt to landing, and ahh it could be very heavy ...*
39:14	*2129*	*Gear down please*
39:19	*2314*	*Weight is 20500*
39:22	*2317*	*Flaps 15*
39:26	*2321*	*Landing checklist, and I tell you, double check*
39:28	*2323*	*[Landing checklist procedures]*
39:36	*2331*	*Gear down, three green*
39:53	*2348*	*[Cabin attendant advised that landing will probably be a very hard landing]*
40:07	*2362*	*tk(?) one 9 miles zero five*
41:06	*2421*	*On the glide path*
41:42	*2457*	*Clear land zero five, tk(?) one*
43:08	*2543*	*"Sink rate, pull up, pull up, wind shear, wind shear, wind shear"*
43:17	*2552*	*"Glide slope '15times'"*
43:41	*2576*	*"Wind shear, wind shear, wind shear"*
43:50	*2585*	*[Probably touch down]*
43:59	*2594*	*All right, we got you on the runway*
44:04	*2599*	*60 knots*
44:09	*2604*	*[Engine cut off]*
45:02	*2657*	*{End of CVR recording}*

3.6 BFU FDR Traces For Scenario 4

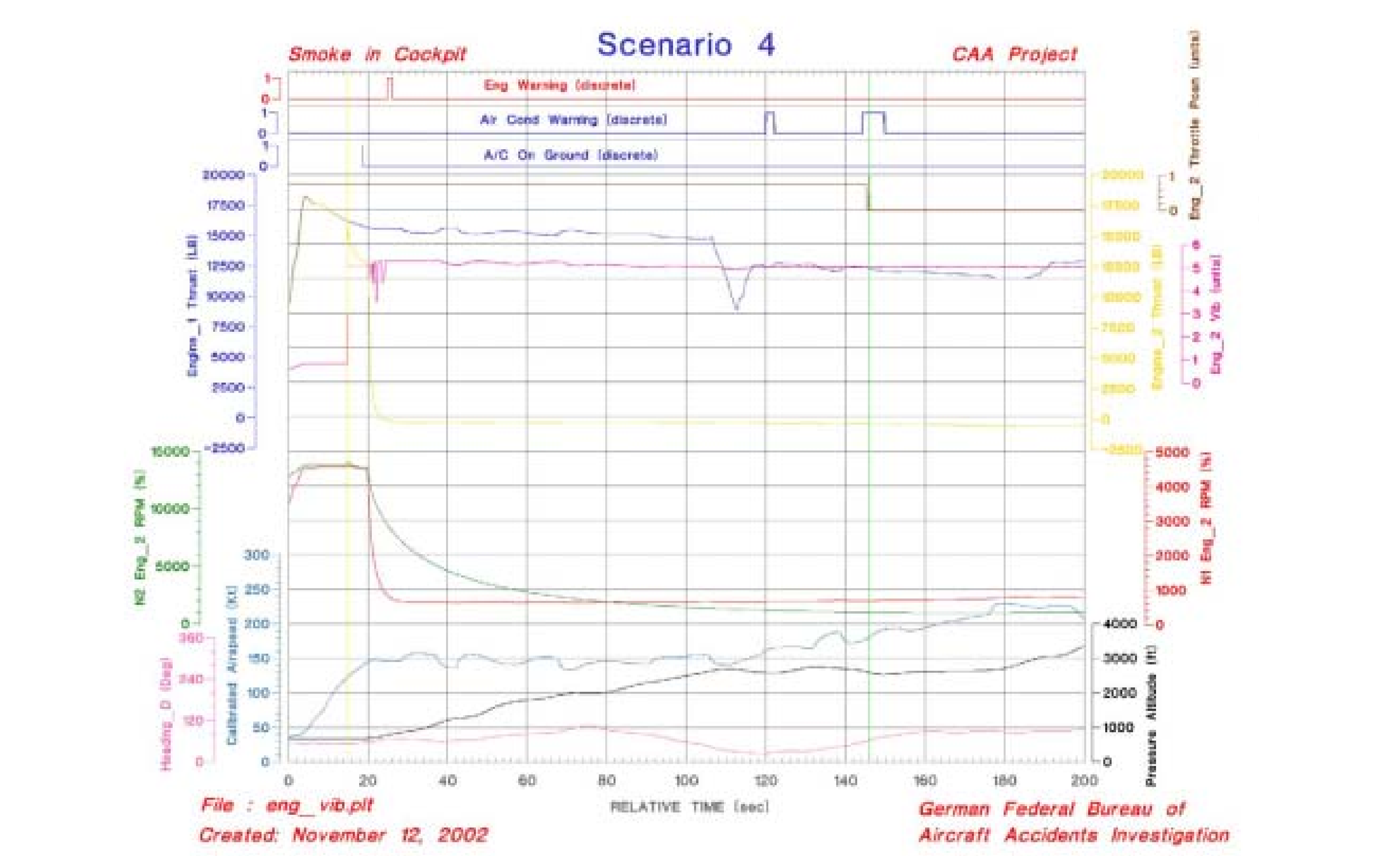


Figure 17 Data Analysis for Scenario 4 - BFU FDR Trace 1

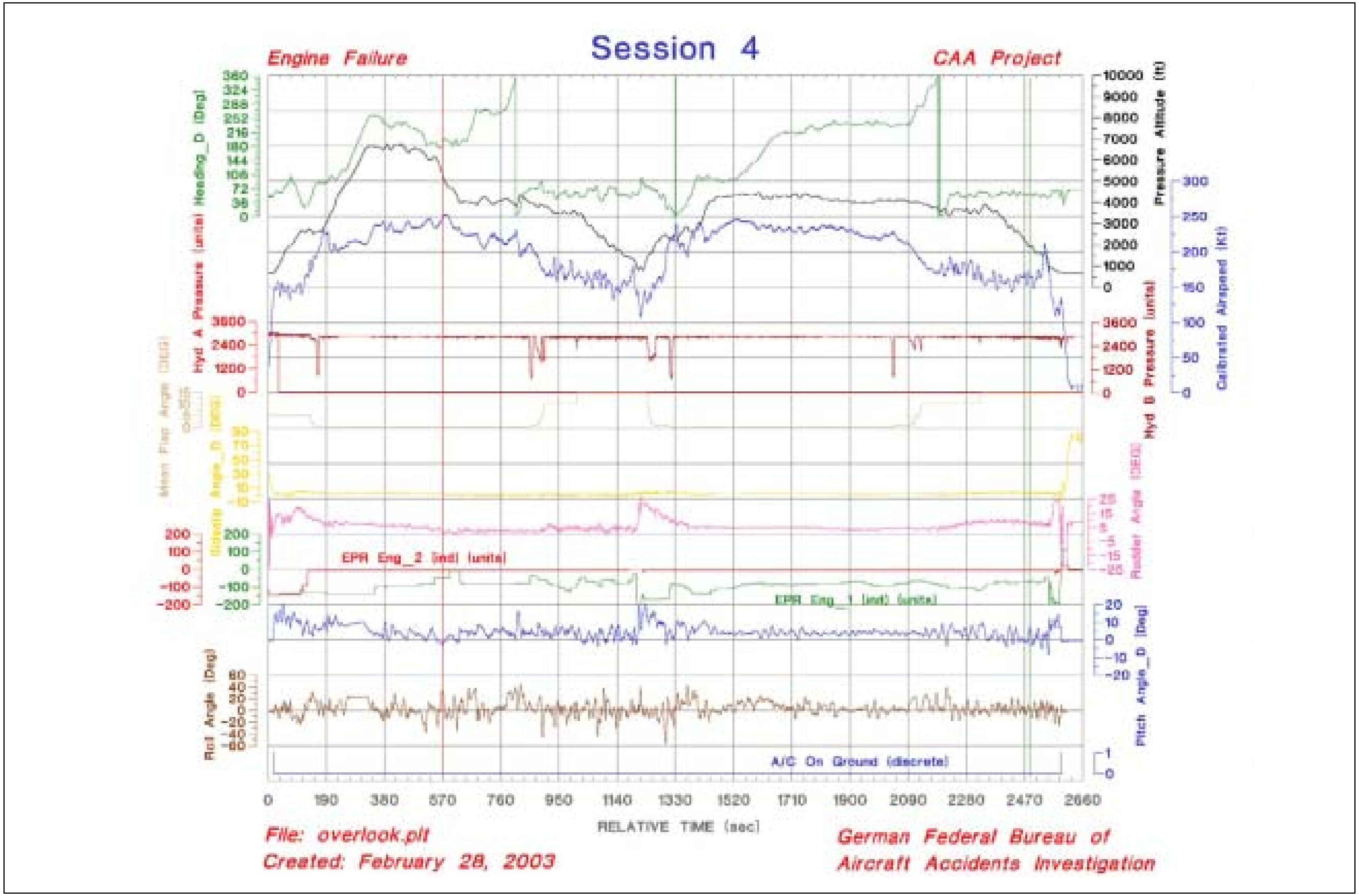


Figure 18 Data Analysis for Scenario 4 - BFU FDR Trace 2

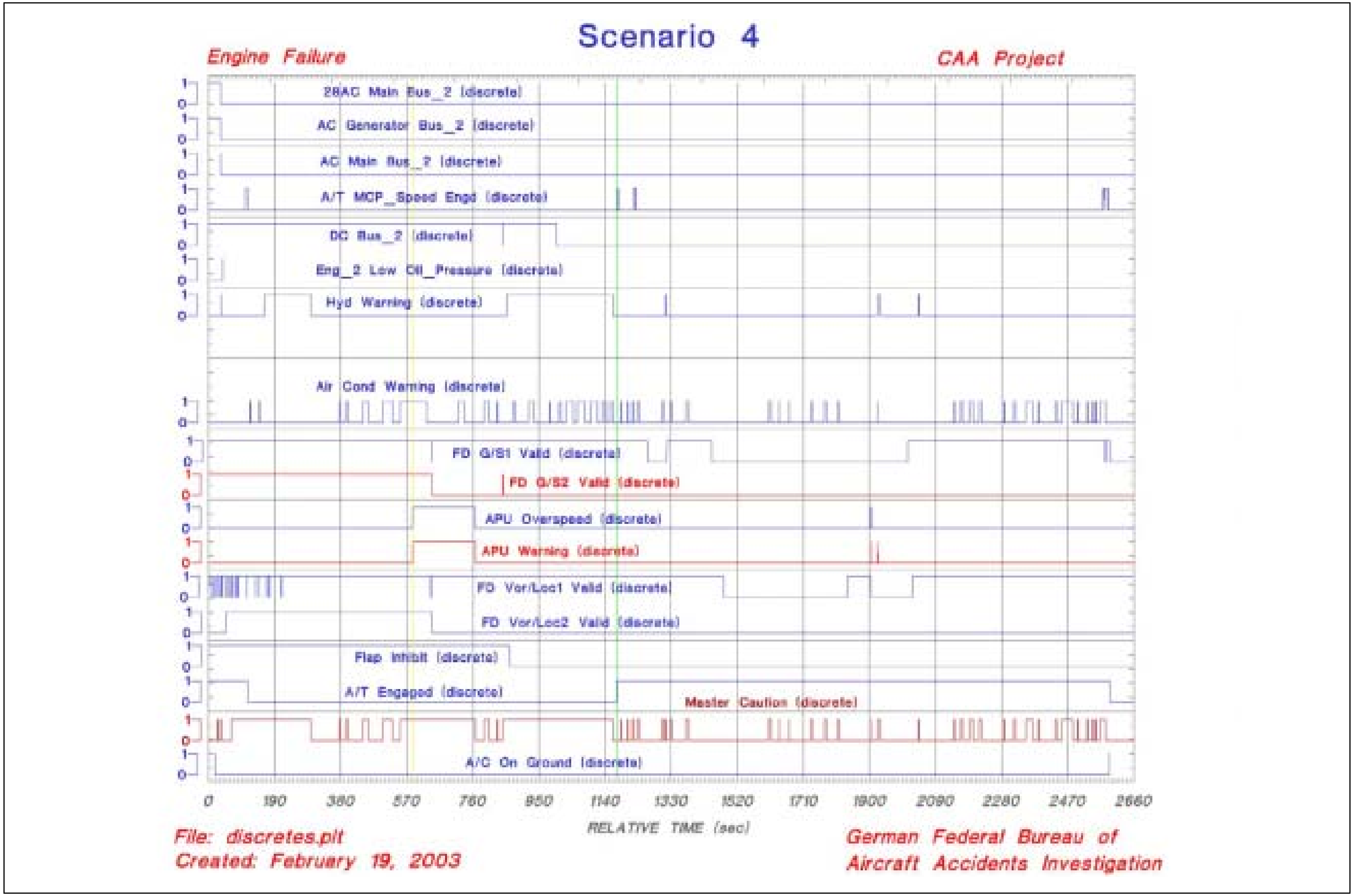


Figure 19 Data Analysis for Scenario 4 - BFU FDR Trace 3

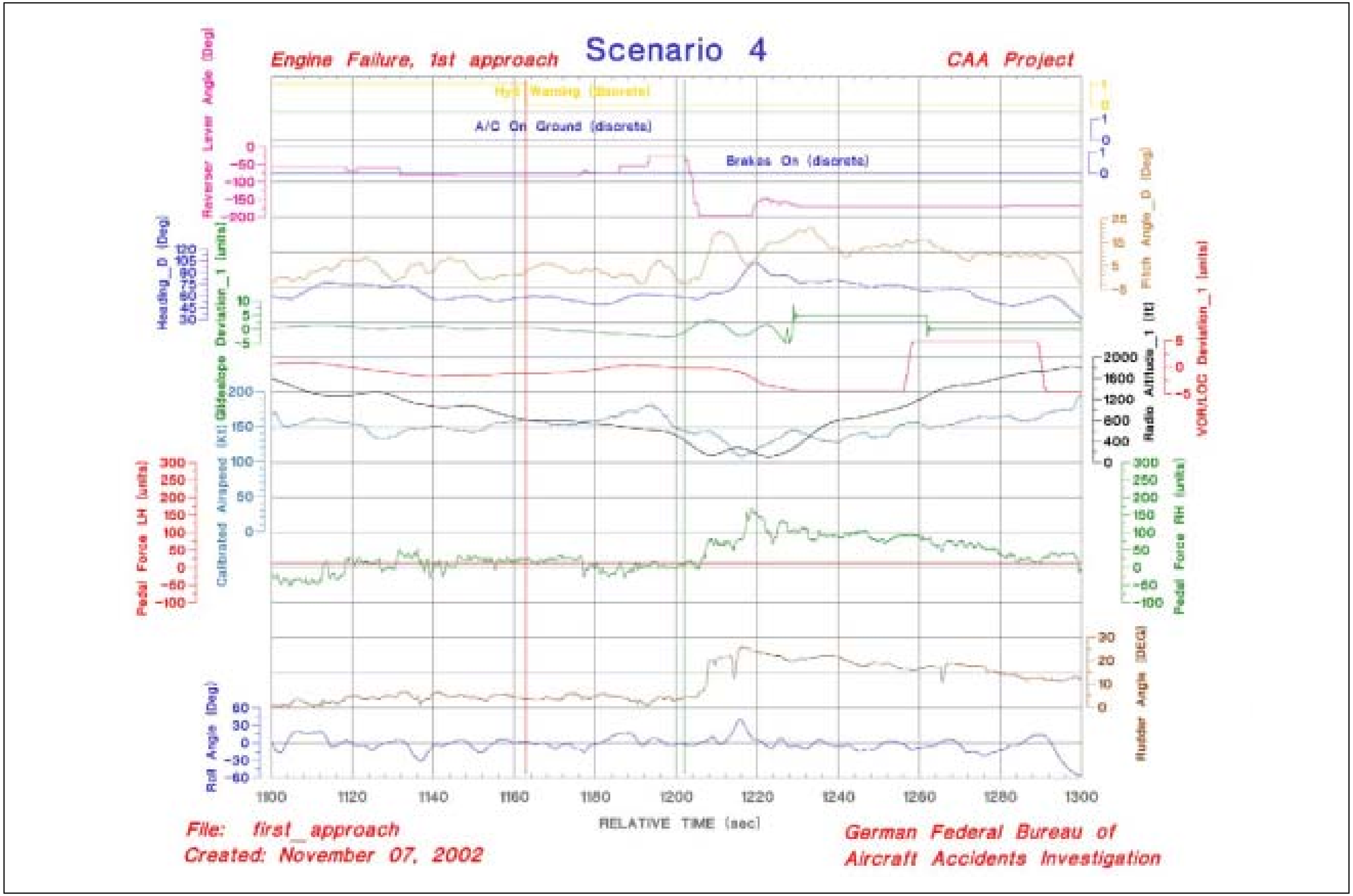


Figure 20 Data Analysis for Scenario 4 - BFU FDR Trace 4

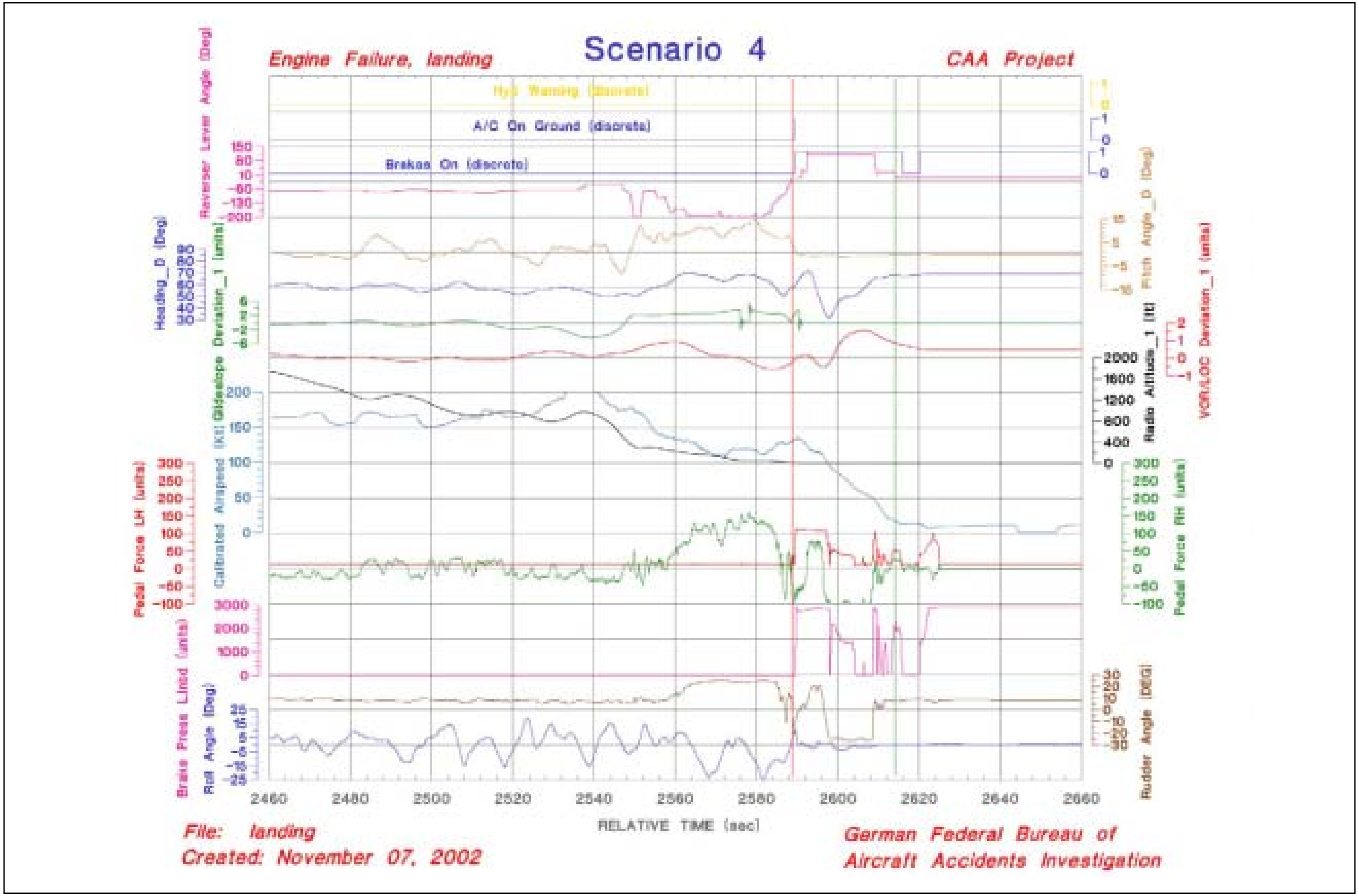


Figure 21 Data Analysis for Scenario 4 - BFU FDR Trace 5

4 BEA Initial Report Based on Image Data

Time	***Event***	***Remark***
15 h 06 min 22	*Engine failure at take off, difficult to keep the axe*	
15 h 06 min 26	*Complete failure of right engine*	
15 h 06 min 44	*F/O loose his screens indicate an electrical failure*	
15 h 06 min 54	*Captain takes the control*	
15 h 08 min	*Pull the right extinguisher followed by overheat information*	
15 h 11 min 20	*APU is started*	
15 h 11 min 30	*The cross feed is open*	*Auto Pilot A was engaged sometime before*
15 h 11 min 46	*The auto pilot disconnects then something is pushed on the overhead panel*	
15 h 12 min 09	*The F/O uses the Oxygen mask*	
15 h 12 min 06	*Captain loses the horizon*	
15 h 12 min 16	*Shows the standby horizon*	
15 h 12 min 25	*The Captain uses the Oxygen mask and loose the glasses*	
15 h 12 min 58	*Captain recover the glasses*	
15 h 13 min 23	*Checklist are given to the F/O The captain takes the control*	
15 h 13 min 41	*Checklist actions*	
15 h 17 min 08	*Preparation before landing*	
15 h 17 min 19	*Master caution " elec "*	*electrical problem*
15 h 17 min 29	*Oxygen mask are removed*	
15 h 18 min 56	*APU is started*	
15 h 20 min 12	*Auto-brake disarm*	
15 h 20 min 31	*Flaps are get out*	
15 h 21 min 05	*Overshoot the axe*	
15 h 21 min 06	*Variation of hydraulic pressure on B circuit*	
15 h 22 min 46	*Landing gear - Loss of hydraulic indication*	
15 h 24 min 03	*Lighting of the cockpit*	
15 h 24 min 57	*Trim is used manually by the Captain*	
15 h 26 min 30	*Go Around at 100 feet + master caution*	

15 h 26 min 08	*high on the plan*	
15 h 26 min 12	*Negative vario > 2000 ft/min*	
15 h 26 min 21	*Go Around at 300 feet then turn right to heading 50°*	
15 h 26 min 39	*Positive vario > 2000 ft/min*	
15 h 26 min 52	*Flaps are retracted then landing gear is retracted*	
15 h 27 min 20	*Light are on in the cockpit*	
15 h 29 min 32	*F/O takes the control*	
15 h 32 min 36	*EFIS transfer without results*	
15 h 35 min 18	*Landing gear on neutral position*	
15 h 41 min 55	*Last turn*	
15 h 43 min 14	*ILS information on stand-by horizon*	
15 h 48 min 00	*F/O is flying*	
15 h 48 min 37	*Negative vario 3000 ft/min*	
15 h 48 min 38	*Captain takes the control*	
15 h 49 min 20	*LandingDifficult to keep the axe*	
15 h 49 min 50	*Park brake on*	
		Information is missing because the view of the overhead panel is missing

Probable cause of the incident: failure on the right engine at take off followed by electrical and hydraulic problems.

5 BFU Final Report Subsequent To Analysing Image Data

5.1 Preflight Checks

PIC sets, recalls or changes data on left CMU

PIC sets or changes selected speed

First Officer sets speed markers on his speed indicator

PIC sets speed markers on his speed indicator

First Officer sets, recalls or changes data on right CMU

First Officer sets or changes course on left course selector

First Officer sets or changes selected altitude

First Officer sets or changes course on right course selector

First Officer sets, recalls or changes data on right CMU

PIC sets, recalls or changes data on left CMU

PIC checks elevator and aileron movement by pushing and pulling control column and turning control wheel

5.2 **Take Off**

First Officer is PF

Tape off power set

Gear up

Electric failure,

Master caution lamps on,

Instrument lights, PFD and Navigation Display on F/O side off

Airspeed frozen to actual value

Control handed over to PIC, now PF

5.3 **Incident**

Engine failure, No. 2 engine

Pointer of N1, EGT, N2, FF and Oil Pressure moving to zero position

Master caution lamps on

First Officer changes selected heading

First Officer changes selected speed

PIC changes selected heading

First Officer resets Master caution

PIC changes selected heading

Smoke coming through left air outlet of air condition

First Officer takes oxygen mask

PFD on PIC's side off

First Officer takes control, now PF

PIC takes oxygen mask

PIC takes control, now PF

First Officer changes selected heading and altitude

Master caution lamps on

Master caution lamps off

Master caution lamps on when First Officer pulls gear lever into middle position

First Officer changes selected course on left course selector

First Officer changes selected heading

First Officer sets, recalls or changes data on right CMU

5.4 **First Approach**

PIC selects ILS mode on emergency horizon

First Officer checks or sets QNH on left altimeter

PIC sets speed markers on his speed indicator

PIC and First Officer remove oxygen masks

Master caution lamps off after restart of electric trim

First Officer changes selected heading due to advise of atc controller

High bank angle during right turn

Short electric power interrupt, master caution lamps on

First Officer changes selected speed

Gear lever pulled into gear down position

First Officer checks selected speed

ILS indicator on emergency horizon shows a/c on localizer and glide path

A/c right of centerline

Master caution lamps on for a short time

A/c over glide path

Decision for go around

Master caution lamps on for a short time

Gear up

Master caution lamps on

Master caution lamps reset by First Officer

Master caution lamps on

First Officer changes selected heading

First Officer changes selected altitude

Master caution lamps on for short time

Control handed over to First Officer, now PF

First Officer has to look to emergency horizon to control a/c

PIC changes selected heading due to atc controller advise

Master caution lamps on for short time

PIC sets, recalls or changes data on left CMU

PIC pulls gear lever into middle position

PIC changes selected speed

Master caution lamps on for short time

5.5 **Second Approach**

PIC selects ILS mode on emergency horizon

PIC changes selected heading due to atc controller advise

Master caution lamps on for short time

PIC changes selected heading due to atc controller advise

Master caution lamps on for short time

A/C on centerline

Master caution lamps on, reset by PIC

Gear down

Master caution lamps on, reset by both

A/c on glide path

Master caution lamps on

Glideslope indicator shows a/c too low

Master caution lamps on for short time

Master caution lamps on due to glideslope warning

Touch down

Aircraft stop

End of movie

5.6 Conclusion

The video showed that in the take off phase due to an electric failure the instrument lights, PFD and Navigation Display on F/O side were switched off. The Airspeed on the F/O's Airspeed Indicator was frozen to the value in this moment.

Shortly after take off engine No. 2 failed. The video showed that the pointers of N1, EGT, N2 and Oil Pressure of engine No. 2 moved back to the zero position. The engine was cut off following the emergency procedure and the aircraft was prepared for a single engine landing.

After the engine failure smoke was detected in the cockpit. The cockpit crew took their oxygen masks.

Furthermore the PFD on the PIC side was switched off probably due to an additional electric failure.

Only the emergency horizon was available now. Due to a too high localizer and glide path deviation the crew took the decision for a go around and second approach.

The second approach was successful. The aircraft landed safely.

6 BEA Final Report Subsequent to Analysing FDR and CVR Data.

Time	***Event***
15 h 06 min 23	*Rotation*
15 h 06 min 22	*Engine failure at take off*
15 h 06 min 51	*F/O indicates he has lost his screen*
15 h 06 min 54	*Captain takes the control*
15 h 07 min 13	*F/O indicates an engine 2 failure*
15 h 08 min 18	*Red warning*
15 h 08 min 52	*F/O announce pan on the VHF due to an engine failure with emergency procedure requested*
	Discussion on the procedure followed by check list
15 h 10 min 59	*Altitude Alert*
15 h 11 min 38	*Captain indicates they got smoke*
15 h 11 min 44	*Auto pilot disconnect warning*
15 h 12 min 05	*The F/O uses the Oxygen mask*
15 h 12 min 51	*Both pilots are using the intercom through the oxygen mask*
15 h 14 min 05	*Mayday announce to the VHF with information on smoke on the flight deck*
15 h 15 min 45	*Altitude alert warning*
15 h 16 min 05	*F/A in the flight deck Captain ask him to inform the passengers that they are going back to Glasgow*
15 h 17 min 11	*Captain talk about the standby horizon*
15 h 17 min 19	*electrical problem*
15 h 18 min 26	*Oxygen mask are removed*
15 h 18 min 52	*Talk about electric problems at the beginning*
15 h 19 min 37	*Altitude alert warning*
15 h 20 min 21	*Flaps 1 are selected followed by a horn*
15 h 20 min 43	*Flaps 5 are selected*
15 h 20 min 46	*Altitude alert warning*
15 h 20 min 52	*Approach check list*
15 h 21 min 06	*Flaps 10 are selected*
15 h 21 min 08	*Altitude alert*
15 h 21 min 18	*Altitude alert*
15 h 22 min 18	*Call the F/A and ask him to check if the flaps will going down soon*
15 h 22 min 44	*Gear down*

15 h 22 min 55	*Flaps 15 are selected*
15 h 23 min 08	*F/A informs that all seems ok and F/O informs that it will be a normal landing*
15 h 23 min 45	*Landing check list*
15 h 24 min 38	*They are cleared for the landing by the ATC*
15 h 26 min 08	*GPWS "wind shear, wind shear, wind shear"*
15 h 26 min 13	*Go around and GPWS "pull up, pull up, pull up, glide slope" di*
15 h 26 min 30	*GPWS "glide slope" Captain feel they are loosing control*
15 h 26 min 41	*Flaps one selection*
15 h 26 min 50	*gear is retracted*
15 h 29 min 24	*F/O takes the control*
15 h 30 min 13	*F/A enter the flight deck*
15 h 31 min 26	*Request to the ATC for a new approach*
15 h 35 min 20	*approach check list*
15 h 38 min	*briefing*
15 h 42 min 07	*Call to the F/A to ask him to check the flaps again the crew inform the landing can be "heavy"*
15 h 44 min 41	*Gear down*
15 h 44 min 52	*Flaps 15*
15 h 45 min 00	*Landing check list*
15 h 45 min 15	*F/A inform the crew that the flaps are going out he is informed that it will be an hard landing*
15 h 47 min 15	*Cleared to land by the ATC*
15 h 48 min 34	*GPWS "sink rate pull up pull up wind shear wind shear" during this time the Captain takes the control*
15 h 48 min 43	*GPWS "glide slope" (20 sec)*
15 h 49 min 08	*GPWS "wind shear wind shear wind shear"*
15 h 49 min 16	*Landing with reverses used*

Probable cause of the incident: failure on the right engine at take off followed by electrical and hydraulic problems. Wind shear during landing obliged the crew to go around once.

7 Detailed CAA Analysis for Scenario 4

7.1 CAA Analysis Of Initial Reports

7.1.1 The Flight Crew ASRs

This is the only scenario for which the flight crew submitted two complementary ASRs. There may be several reasons for this, but given the very high workload in terms of both physical and mental tasks, the probable reason for this pattern shift is fatigue.

While this is indicative of a number of human factors issues, it does not have any direct bearing on the issues being addressed in this paper.

On first review, the ASRs appear to be very brief given the number of problems the flight crew were faced with. However, a closer analysis of the ASRs shows that, although the crew did not detail all the weather conditions they were faced with, they have mentioned most of the crucial factors relating to this incident.

One interesting omission from the flight crew ASRs was the lack of any reference to electrical and hydraulic failures (note that this kind of information was provided in the flight crew ASRs for other scenarios). There are several possible explanations for this, including:

a) The flight crew were so tired by the end of the 'flight' that they forgot to include a reference to these failures; or

b) Since the electrical and hydraulic failures were a predictable outcome of the engine loss, the flight crew may not have felt the need to comment on these failures in their ASRs.

It is very difficult to comment on the first possibility since this would require making some determination of how tired the flight crew were and how this affected each of them while drafting their ASR.

It is also difficult to comment on the second option, however, this may be a more likely explanation of the problem. The flight crew would have known the probable effects of an engine loss and may well have expected any ground based personnel dealing with their ASR to have the same knowledge.

7.1.2 Smoke in the Flight Deck

7.1.2.1 The instrument panel started to emit smoke during this scenario. This is the source of a very obvious, and somewhat surprising difference between the two sets of initial analyses.

The presence of smoke is made very clear in the CVR analysis. The crew are heard discussing the smoke and this is directly referenced in the BFU conclusions.

The FDR analysis makes reference to 'Air Cond' warnings. Although these may have been taken by the investigators to be indicative of smoke, they were actually generated as a result of an off-schedule descent. This would have been instantly recognisable by the crew and, in the circumstances, would probably have resulted in a silent communication that could be not be detected by the FDR or CVR.

Neither of these facts is surprising. It is predictable that the flight crew would discuss the smoke and, given that they donned oxygen masks, thus resorting to intercom communication, conventional flight recorders could easily pick up the presence of smoke. What is surprising is that the image data analysis makes no reference to smoke in the flight deck at all.

The BEA analysis of the image data does explicitly state that the Captain and First Officer used their oxygen masks but it provides no explanation for this action. It is very difficult to determine the reason for this. It could stem from several factors, including:

a) The BEA did see the smoke but did not believe that it was relevant to the incident;

b) The BEA did see the smoke but felt that a reference to the Captain and First Officer donning oxygen masks was sufficient to indicate the presence of smoke; or

c) The BEA did not see any smoke in the image data.

The first explanation is extremely unlikely. It is not credible that an accident investigator would deem smoke in the flight deck to be irrelevant to an incident or accident.

The second explanation is also unlikely as a flight crew may well don oxygen masks because they can smell smoke without actually being able to see smoke. The use of oxygen masks could equally imply a drop in cabin air pressure (if at high altitude).

This means that a statement of crew action cannot be taken to provide definitive evidence of the cause of the action.

The third explanation is the most likely. As the smoke was being emitted from the instrument panel, the flight crew would have been able to see it, even if the smoke was not particularly dense. However, this does not mean that the smoke was dense enough to be picked up by a camera.

Neither the scenario description provided by the simulator operator, the flight crew ASRs or the CVR analysis specifies which instrument the smoke was coming from and so it is not possible to make any judgement as to whether a different camera placement would have changed this situation.

Equally, it is not impossible that the BEA did see the smoke and, due to a range of human factors issues, simply did not register it.

7.1.2.2 A further unknown is exactly how much smoke the simulator operator pumped in to the flight deck. Without knowing this, it is impossible to make any determination of whether the image recorder system cameras should have detected the smoke.

This issue cannot be resolved without gaining answers to the following questions:

a) How much smoke was pumped in to the flight deck?

b) Which instrument was emitting the smoke and did the cameras have a clear view of it?

c) Did the BEA see the smoke?

This discrepancy between the recorder analyses brings one of the supposed benefits of image recorder systems in to doubt.

It has been postulated that image recorder systems would provide evidence of flight deck smoke. In fact this has been mentioned in the analyses of several high profile accidents, including the Swiss Air accident where fire/smoke in the flight deck is believed to have been a significant factor.

The initial analyses of this scenario would not seem to support this.

7.1.2.3 It is clear from these analyses that the presence of smoke in the flight deck is apparent from the CVR.

Since donning oxygen masks results in change of communication systems, which can readily be detected by conventional recorders, it would seem that the most likely use of image recorder data is confirmation of the reason for donning the masks, in this case, the smoke.

There are, however, two situations where an image recorder could be the only source of information about smoke in the flight deck:

a) The flight crew may not discuss the smoke; or

b) The CVR is unserviceable or its data is unreadable.

The first option is possible, however, it is only really likely if fumes overcome the flight crew before they realise the situation they are in. There has been at least one accident where this occurred and so this must be assumed to be a viable possibility.

The second option is a possibility that accident investigators are faced with during every accident/incident investigation.

In either of these situations, image recorders could provide the only definitive evidence of smoke in the flight deck. Although this would be a huge step forward for some investigations, it should not be forgotten that image recorder systems are not, apparently, guaranteed to provide this information.

This statement also applies to the ability of image recorder systems to provide corroborative evidence of smoke in the flight deck.

7.1.2.4 One further point that should be addressed is the ability of an image recorder system to provide a representative idea of the visibility the flight crew has of their environment when there is smoke in the flight deck.

If there is smoke in the flight deck, the flight crew will don oxygen masks. Although the oxygen masks will protect them from the worst physiological effects of the smoke, they will partly obscure their vision. Image recorder system cameras will not have this additional impedance to "vision".

Inversely, it is also true to state that flight crew will be closer to the instrument panel than the image recorder system cameras and, as such, have a better chance of seeing what is happening than the image recording system cameras.

These inverse facts lead to the inevitable conclusion that, in the event of smoke, an image recorder's view of the flight deck is not completely representative of the flight crew's view.

7.1.3 **Loss of the First Officer's Displays**

The simulator operator's debrief indicated that all the First Officer's displays failed. While this is supported by the BEA analysis of the image data, it is not supported by the analysis either of the FDR data or the CVR data. Although it is not surprising that the FDR analysis did not pick this fact up, it is surprising that it was not referenced in the analysis of the CVR.

There are various possible reasons for this, including:

a) The flight crew did not discuss the loss of displays; and

b) The flight crew did discuss the loss of displays but the BFU did not believe that it was relevant to the incident.

The first possibility is unlikely but, due to the high physical and mental workloads that the flight crews were subjected to, it is possible the conversations were silent (i.e. gestures rather than words).

The second possibility is extremely unlikely. It is not credible that an accident investigator would deem the loss of the First Officer's instruments to be irrelevant to an accident/incident.

The absence of any information relating to the loss of the First Officer's displays from either the FDR or CVR analyses would seem to indicate that this is one example where an image recording system could be the sole source of information relating to this particular type of failure.

In reality, this is unlikely to be the case; it is probable that there would be some verbal reference to the loss of displays. However, in the absence of audible discussion or a serviceable CVR, an image recorder would have a vital role to play in informing accident investigators about the loss of flight crew displays.

Even if the loss of displays was discussed audibly and the CVR was serviceable, the analyses of this scenario would seem to suggest that, at the very least, an image recording system would provide useful corroborative evidence to support any theories relating to loss of flight crew displays.

Although the analyses of these scenarios do not support such a theory, it is possible that an image recording system would also be able to provide information relating to which displays had failed.

The analyses of this scenario support a theory that has been proposed by both the pilot's unions and the accident investigators. Both bodies have suggested that it is possible that the FDR may record information that was not shown to the flight crew. In this case, an image recording system would provide vital evidence to explain flight crew actions that may otherwise be deemed 'pilot error'.

7.1.4 Failure of the APU Starter

The APU Starter had a dormant failure. This fact is not directly apparent from either the BFU or the BEA initial report. It is also notable that neither of the flight crew ASRs made any reference to either a failed APU starter or to the absence of the APU function.

The BFU CVR analysis does refer to an electrical failure accompanied by a restart of an unidentified system. This may refer to an attempt by the flight crew to restart the engine using the APU, however, if the APU starter really had failed this attempt should have been unsuccessful.

The BEA image data analysis makes two direct references to the APU being started. Again, if the APU Starter had really failed, the attempts to start the APU would have failed.

It is possible that the double reference to the APU being started actually refers to two separate attempts to start the APU, both of which failed, but it is not possible to definitively determine this from the information available.

As discussed in scenario 1, the 737-300 does have an APU BUS GEN light which would indicate the whether the APU Generator was supplying power. However, this is located in the overhead panel and so would not have been seen by the cameras installed for this trial. If the image recorder cameras did have a view of these indicators, it could have been possible to gain this information from an image recording system.

Although this is information that should be available on both the FDR and CVR, this is a further example of where an image recording system can substantiate the information provided by the other recorders. The benefits associated with this are discussed in the previous scenarios.

7.1.5 **Failure of Auto Electric Transfer**

7.1.5.1 The simulator operator's debrief indicates that a dormant failure of the auto electric transfer system was present before the flight started, however, none of the accident reports, including the flight crew ASRs, make any reference to this.

The flight crew response to failure of the auto electric transfer system cannot be completely explained. It seems likely that they would have expected the auto transfer system to restore their instrumentation, but the absence of any response to the continued lack of instrumentation cannot be determined from the information provided.

It is reasonable to expect that the flight crew would have used checklists in this case, which infers that there should have been some reference to this failure on the CVR.

It is also reasonable to expect some reference to the resulting flight crew action on the image recorder (e.g. checklists being used). Despite this, none of this information appears in either analysis.

This implies that, either:

a) The flight crew did not attempt to re-route the power;

b) The flight crew did attempt to re-route the power but did not discuss this; or

c) The flight crew did attempt to re-route the power, did discuss the issue and the discussion was included in the BFU's generic reference to 'Discussion about electrical failure'.

As previously discussed, the first possibility cannot be further evaluated without consulting the flight crew.

The second option is possible. Given the high workload the 'discussion' about this could have been silent.

The third option is also possible, however, whether the BFU really did include the attempts to re-route power in a generic reference to discussions about electrical problems cannot be ascertained without further information from the BFU.

7.1.5.2 If the BFU did realise that the flight crew could not (or did not) transfer to another source of electrical power, it is surprising that they did not reference this in their determination of probable cause.

Since the auto electric transfer system switches are located in the overhead panel, it is possible that, had the simulator been equipped with a camera pointing towards the overhead panel, the BEA would have been able to determine whether the flight crew did attempt to re-route the power.

The issues listed above cannot be resolved without answers to the following questions:

a) Did the auto electric transfer system actually have a dormant failure?

b) Did the flight crew attempt to re-route the source of electrical power?

c) Did the BFU include any flight crew discussions about the auto electric transfer system in their generic reference to 'discussions about electrical failures?

7.1.6 **Loss of Captain's Glasses**

The analysis of the image data for this scenario highlights the ability of an image recording system to identify one particular type of information that neither the FDR nor CVR could definitively identify.

The image data analysis notes that the Captain lost his glasses and had to retrieve them. This would constitute a distraction that occurred at a particularly stressful time, i.e. when the flight crew were donning their oxygen masks.

Although this would have constituted a distraction that could only be identified using an image recorder, the impact of this event on the overall outcome of the scenario is likely to be small. This is because at the point when the Captain was donning his oxygen mask, the First Officer would have been in control. That said, it is reasonable to assume that other, similar distractions could occur which may have a greater impact on the overall result.

The FDR would be definitively unable to detect an event such as this and it is unlikely that the flight crew would discuss it in sufficient detail for the CVR to be able to identify the specific occurrence.

7.1.7 **Summary of Information gained from Initial Reports**

This scenario provides further demonstrations of the points discussed in previous scenarios.

In addition to this it also raises three other, very significant points.

Firstly, the initial analyses of this scenario show that, when analysed in isolation from other recorder data, image data could be actively misleading. This is a significant point as various organisations have postulated that image recorders could be used to replace the need for FDRs or CVRs.

Although the analyses of this scenario do not completely refute that idea, they do highlight the need for a very careful investigation of the information that would be provided.

Secondly, the analyses of this scenario would seem to support the theory that image recorder data could show that information that was recorded on the FDR was not displayed to the flight crew. This, again, is significant as it may lead to a reduction in the number of accidents that are deemed to result from pilot error.

Finally, the initial analyses of this scenario would appear to indicate that an image recorder is not guaranteed to detect smoke in the flight deck, even if it is visible to the crew. This is significant as it implies that one of the main proposed uses of image recorders cannot necessarily be achieved.

7.1.8 **CAA Questions Raised During Analysis of the Accident Data:**

The CAA analysis raised a number of questions, however, a further study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers will only be provided to those questions that relate to the issue being addressed by this research.

a) How much smoke was pumped in to the flight deck?

- This question is not directly relevant to the effectivity of image recorder systems and the likely ability of image recorders to detect smoke in the flight deck is discussed in this scenario analysis and Chapter 8 paragraph 3.2 of this report.

b) Which instrument was emitting the smoke and did the cameras have a clear view of it?

- This question is not directly relevant to the effectivity of image recorder systems and the likely ability of image recorders to detect smoke in the flight deck is discussed in this scenario analysis and Chapter 8, paragraph 3.2 of this report.

c) Did BEA see the smoke?

- It is not possible to provide a definitive answer to this question but, as BEA did not refer to smoke in their image data analysis, the most probable assumption is that they did not.

d) Is it possible for the flight crew to be overcome by fumes before realising there was smoke on the flight deck?

- It is possible for flight crews to be overcome by fumes without ever knowing that the fumes were present. This is because some fumes are very faintly coloured and odourless (e.g. carbon monoxide).

e) Did the APU Starter Fail?

- This question is not relevant to the effectivity of image recorder systems.

f) Did the auto electric transfer system actually have a dormant failure?

- This question is not relevant to the effectivity of image recorder systems.

g) Did the flight crew attempt to re-route the source of electrical power?

- This question is not relevant to the effectivity of image recorder systems.

h) Did the BFU include any flight crew discussions about the auto electric transfer system in their generic reference to 'discussions about electrical failures'?

- This question is not relevant to the effectivity of image recorder systems.

7.2 CAA Analysis of Final Reports

7.2.1 Did an Analysis of the Complete Data Set Result in Opinion Changes?

The BFU did not significantly change their statement of probable cause as a result of analysing the complete data set. They did, however, add information that they had gained from analysing the image data.

The BEA made no change at all to their statement of probable cause as a result of analysing the complete data set.

7.2.2 Limitations Imposed by the Supplied Data

The BEA did not supply any specific FDR analyses and so it was not possible to comment on what information was derived from the FDR.

7.2.3 Comparison of BFU and BEA Analyses of Image Data

7.2.3.1 As for each of the previous scenarios, both analyses were detailed and informative but the same difference in approach, highlighted in the analyses of the previous scenarios, can be seen for scenario 4.

The following additional issues were noted:

The BFU image data analysis makes no reference to the flight crew using checklists, however, in contrast to some of the other scenarios, the BEA image analysis does. This supports the BFU's assertions relating to checklists.

The BEA analysis of the image data notes that the APU is started just after the flight crew remove their oxygen masks. This information is not present in the BFU analysis of the image data and its presence in the BEA analysis is difficult to explain, particularly since no other report (including the flight crew ASRs) make any reference to an attempt to restart the APU.

The absence of this information from the flight crew ASRs may be explained by sheer fatigue on their behalf, however, if an attempt was made to re-start the APU it should have been referenced in the analysis of the FDR data.

The reason for this anomaly cannot be determined without answers to the following questions:

a) Did the flight crew actually try to re-start the APU?

b) Were the appropriate parameters recorded on the FDR to determine that an attempt was made to re-start the APU?

c) Could the BEA have mistaken the intent of a flight crew action?

7.2.3.2 The most significant difference between the different analyses of the image data is that the BFU analysis makes direct reference to the presence of smoke. This is something that the BEA analysis failed to do.

This is a surprising difference and it is difficult to precisely determine its cause. The most likely possibilities are:

a) The differing slants of the two analyses resulted in the BFU spotting something that BEA missed; or

b) The BFU already knew that there was smoke in the flight deck as a result of their CVR analysis and so 'went looking' for the smoke during their image data analysis.

The first possibility is plausible, however, given that it was the BEA analyses that focussed more on the system status than the BFU, the difference in slant would suggest that BEA would spot the smoke and not BFU.

The second possibility is more likely. Since the BFU already knew there was smoke in the flight deck it is likely that they would inspect the image data for evidence of this. This provides further evidence that the order in which data is inspected can affect the results that are achieved.

7.2.4 The BFU's General Comment on the Usefulness of Image Data

The BFU made a generic statement (applicable to all scenarios) effectively saying that the image data definitively provided additional information, namely:

a) Actual adherence to checklists (which infers that it would be possible to determine if an inappropriate checklist was used);

b) Crew actions that would not be recorded by the CVR or FDR (including some forms of silent communication - e.g. pointing etc); and

c) The way in which the flight crew handles their workload.

As discussed above, the BEA did make a direct reference to the flight crew using checklists, thus supporting BFU's first assertion. However, since there is only a passing reference to checklists, it is not possible to infer 'actual adherence' to the checklists.

The analyses of the data for this scenario do suggest that some of the flight crew's communication was silent. However, neither report provides enough detail to definitively confirm this.

In common with all the other scenarios, the information available made it obvious that the flight crew had an excessive workload in terms of both physical and mental tasks.

Despite this, none of the investigators reports highlights this fact or the effect it was likely to have on the flight crew actions.

7.2.5 CAA Questions Raised During Analysis of the Accident Data

The additional analysis of the extra data does not provide answers to any of the CAA's previous questions but it has resulted in the additional questions listed below.

Once again, study of these questions showed that some of them related to issues other than image recorder effectivity.

In the interest of providing a complete assessment, all questions raised by the CAA analysis are documented. However, as this report is focussed on image recorder effectivity, detailed answers will only be provided to those questions that relate to the issue being addressed by this research.

a) Did the flight crew actually try to re-start the APU?

- This question is not relevant to the effectivity of image recorder systems.

b) Were the appropriate parameters recorded on the FDR to determine that an attempt was made to re-start the APU?

- This question is not relevant to the effectivity of image recorder systems.

c) Could the BEA have mistaken the intent of a flight crew action?

- This question is not relevant to the effectivity of image recorder systems.

d) Did the BFU see the flight deck smoke solely because they knew it had to be there?

- It isn't possible to provide a definitive answer to this question but it is true to say that previous knowledge of the presence of smoke may have influenced their analysis of the image data.

7.3 Summary for Scenario 4

The analyses of this scenario reinforce the results of the previous analyses, particularly with respect to the uses of the different types of flight recorder.

In addition to this, these analyses make four other significant points.

Firstly, if image data is analysed in isolation from other recorder data, it could be actively misleading. This leads to the conclusion that proposals to use image recorders as a replacement for an FDR and/or CVR should be carefully considered to ensure that any investigations that may be based on a single, image, do not result in spurious findings.

Secondly, the analyses of this scenario would seem to support the theory that image recorder data could show that information that was recorded on the FDR was not displayed to the flight crew. This may lead to a reduction in the number of accidents that are deemed to result from pilot error.

Thirdly the initial analyses of this scenario would appear to indicate that an image recorder is not guaranteed to detect smoke in the flight deck, even if it is visible to the crew. This implies that one of the proposed uses of image recorders cannot necessarily be achieved.

Finally, the analyses of these scenarios strongly suggest that the order in which flight recorder data types is analysed can have a direct effect on the result of the analysis. Although this would appear to be due to a set of human factors relating to accident investigation, it is a point that should be carefully considered when debating the use of any type of flight recorder, including image recorders.

Appendix 5 Flight Recorder Parameter Name Conversion List

NOTE: Data supplied by GECAT.

Variable	Description
RELATIVE TIME	
RAXHP	Pressure Altitude ft
RAXVIADC(1)	Capt Ind Airspeed Kt
RAXVIADC(2)	F/O Ind Airspeed Kt
RAXVC	Calibrated Airspeed Kt
RAXPSI	Heading Radians
RAXYAW	Heading Degrees
RAXAZEAR	Earth Z Axis Accel FT/S**2
RAXTHETA	Pitch Angle RAD
RAXPITCH	Pitch Angle DEG
RAXPHI	Bank Angle RAD
RAXROLL	Roll Angle DEG
TONE	Generated on sim as a timing pulse
RAXDFN(1)	Engine 1 Thrust LB
RAXDFN(2)	Engine 2 Thrust LB
REAOB0	Eng1 Throttle Posn
REAOB1	Eng2 Throttle Posn
DFEF	Effective Flap Angle
RHAO04	Flap Lever Position (range)
RAXDFM	Mean Flap Angle DEG
RAXLEPM	Mean Leading Edge Posn DEG
RAXKGAP	% Autoslat Extension
REXRLA	Reverser Lever Angle (range)
RLXSBHPS	Speedbrake Handle Posn
RAXDSP	Spoiler Angle General
RAXGSPLR	Mean Ground Spoilers DEG
RAXFSPLR	Mean Flight Spoilers DEG

LAXGSPLR	Ground Spoilers Active
RAXTTIND	Indicated TAT Deg C
LQUATARM	A/T Engaged
LQUATEFM	A/T FMC Speed Engd
LQUATEGA	A/T GA Engd
LQUATESP	A/T MCP Speed Engd
LQUATRET	A/T Retard Engd
LQXA270	ARINC 429 Label 270 A/P Modes & Annunciators (36 bits)
RAXAXEAR	Earth X Axis Accel FT/S**2
RAXAYEAR	Earth Y Axis Accel FT/S**2
ELEV	Elevator Angle DEG
DAO	Aileron Angle DEG
RUD	Rudder Angle DEG
RLXACCOL	Column Position (range)
RLXACWHL(1)	P1's Wheel Position (range)
RLXACWHL(2)	P1's Wheel Position (range)
RLXACPED	Pedal Position (range)
STAB	Stabiliser Angle DEG
RAXRAALT(1)	Radio Altitude 1
RAXRAALT(2)	Radio Altitude 2
RRXFDGSD	Glideslope Deviation
RRXGSDEV	Glideslope Deviation
RRXFDVLD	VOR/LOC Deviation
RRXVLDEV	VOR/LOC Deviation
LRXMDVAL	Marker Data Valid
LRXMKVAL	Marker Keying Valid
LBULB2	Master Caution
LHUL23	Fire Warning
LBULA0	Flt Control Wrng
LBULA3	Elec Warning
LBULA1	IRS Warning
LBULA4	APU Warning
LBULA2	Fuel Warning

LBULA5	Ovht/Det Warning
LBULB1	Anti-Ice Warning
LBULA9	Eng Warning
LBULA7	Hyd Warning
LBULB0	Overhead Warning
LBULA8	Doors Warning
LBULA6	Air Cond Warning
LAXAALAW	Altitude Alert
LHUL22	T/O Config Warning
LHUL21	L/Gear Warning
LAWL21_2	Mach/Airspeed Warng
KRXVHFFR(1)	Nav 1 Freq (x 100)
KRXVHFFR(2)	Nav 2 Freq (x 100)
RRXDMERN(1)	DME Range nm
RRXDMERN(2)	DME Range nm
LAXONGND	A/C On Ground
LAWL08	GPWS Inop Valid
LAUS96	Pull Up Warning
LAUSG6	Glideslope Warning
LAWL32	Flap Inhibit
RAXALF	Angle of Attack DEG
LHUL04	Hyd A Low Pressure
LHUL05	Hyd B Low Pressure
LPXL07	L.Bleed Trip Off
LPXL08	R.Bleed Trip Off
LPXL09	L.Pack Trip Off
LPXL10	R.Pack Trip Off
RUXGRSPV	Groundspeed KTS
LHWH23	L/G Lever Up
LHWH24	L/G Lever Below Off
LHWH25	L/G Lever Fully Down
RUXDRANV	Drift Angle DEG
RAXWINDS	Wind Speed KTS

RAXWINDD	Wind Direction DEG
RAXLAT	A/C Latitude RAD
RAXLONG	A/C longitude RAD
RHXBPPOS	Left Bk Pedal Pos (range)
RHXLRMET	Left Bk Pressure Demd
RHXPBMET	Brake Press L.Inbd
RAXDBP(1)	Demanded Brake Force LB
RAXDBP(2)	Demanded Brake Force LB
RAXDBP(3)	Demanded Brake Force LB
RAXDBP(4)	Brakes On
LAXBRAKE	
REXN1(1)	N1 Eng 1 RPM
REXN1(2	N1 Eng 2 RPM
REXN2(1)	N2 Eng 1 RPM
REXN2(2))	N2 Eng 2 RPM
REXIEPR(1)	EPR Eng 1 (ind)
REXIEPR(2)	EPR Eng 2 (ind)
REXIVIB(1)	Vib Eng 1 (ind)
REXIVIB(2)	Vib Eng 2 (ind)
REXIEGT(1)	EGT Eng 1 (ind)
REXIEGT(2)	EGT Eng 2 (ind)
REAOB0	Eng 1 Throttle Posn (range)
REAOB1	Eng 2 Throttle Posn (range)
REWF (1)	FF Eng 1 LB/HR
REWF(2)	FF Eng 2 LB/HR
REAOAO	FCOL Eng 1 (range)
REAOA1	FCOL Eng 2 (range)
KNXTC270	Discrete Word
LAWL75	GPWS w/s alert 1
LAWL76	GPWS w/s alert 2
RQSPHSLE	MCP Baro Alt Error
RQDHSELB	MCP Selected Altitude FT
RQDLVCMD	A/T Speed Reference

RQDLACMD	A/T Mach Reference
RQVSREF	STS Vertical Speed Reference (poss not correct data)
RQPSHENC	MCP Selected Heading
RQFSENC	MCP Selected Course
LAULG8	GPWS DH Reached
JNIBCI	EFISCP L Selected DH
Fixed	Efis Options
LBXGB1	AC Generator Bus 1
LBXGB2	AC Generator Bus 2
LBXMB1	AC Main Bus 1
LBXMB2	AC Main Bus 2
LBXTB1	AC Xfr Bus 1
LBXTB2	AC Xfr Bus 2
LBXACSB	AC Standby Bus
LBXEPB	AC External Power Bus
LBXGSB	AC Ground Service Bus
LBX28MB1	28AC Main Bus 1
LBX28MB2	28AC Main Bus 2
LBX28TB1	28AC Xfr Bus 1
LBX28TB2	28AC Xrf Bus 2
LBX28GSB	28AC Ground Svce Bus
LBXDCB1	DC Bus 1
LBXDCB2	DC Bus 2
LBXHBB	Hot Battery Bus
LBXBB	Battery Bus
LPXH36	Eng 1 Bleed Valve
LPXH37	Eng 2 Bleed Valve
LEXHX3	APU Bleed Air Swth ON
LAMFADC	ADC1 Fail
LAXADCPW(2)	ADC Power Valid
LQMB01	A/T Computer Fail
LGMB04	MCP Fai
LQMB05	FCC !I

REAOB0	Eng1 Throttle Posn
REAOB1	Eng2 Throttle Posn
RAXTHRUD	Thrust Demand To Trim LB
CGBS	Dynamic CofG
RAXCGM	CofG %MAC
RAXWFULW	Wing Fuel Weight LB
RAXWFULB	Body Fuel Weight LB
RAXZFW	Zero Fuel Weight LB
RAXGWKG	Gross Weight KG
RAXGWLB	Gross Weight LB
LAXSSHKR	Stick Shaker On
LRXFDVLF(1)	FD Vor/Loc1 Valid
LRXFDVLF(2)	FD Vor/Loc2 Valid
LRXFDGSF(1)	FD G/S1 Valid
LRXFDGSF(2)	FD G/S2 Valid
LRXDFLG(1	DME1 Valid
LRXDFLG(2))	DME2 Valid
LRXADVAL(1)	ADF1 Data Valid
LRXADVAL(2)	ADF2 Data Valid
LRXHFLG(1)	Heading Valid 1
LRXHFLG(2)	Heading Valid 2
LUXALNCP(1)	IRU(1) Aligned
LUXALNCP(2)	IRU(2) Aligned
RAXWICE	Ice Weight
LAXWAISO	Wing Anti Ice
REXVIB(1)	Eng 1 Vib
REXVIB(2)	Eng 2 Vib
LEXHF1L	Eng 1 Over Temp
LEXHF2L	Eng 2 Over Temp
LEXLU1	Eng 1 Low Oil Pressure
LEXLU2	Eng 2 Low Oil Pressure
REXN1(1)	Eng 1 N1 RPM
REXN1(2)	Eng 2 N1 RPM

JNIEBO	Eng 1 Cont N1 Limit
JNIEBP	Eng 1 Cont N1 Limit
JNIEBQ	Eng 2 Cont N1 Limit
JNIEBR	Eng 2 Cont N1 Limit
JNIEBU	Eng 1 G/A N1 Limit
JNIEBV	Eng 1 G/A N1 Limit
JNIEBW	Eng 2 G/A N1 Limit
JNIEBX	Eng 2 G/A N1 Limit
JNIEBY	Eng 1 Cruise N1 Limit
JNIEBZ	Eng 1 Cruise N1 Limit
JNIECA	Eng 2 Cruise N1 Limit
JNIECB	Eng 2 Cruise N1 Limit
JNIECC	Eng 1 Climb N1 Limit
JNIECD	Eng 1 Climb N1 Limit
JNIECE	Eng 2 Climb N1 Limit
JNIECF	Eng 2 Climb N1 Limit
LEXHX1L	APU Overspeed
RLXRTIMU	Pedal Trim UNITS
RLXRTIMD	Rudder Trim DEGS
RLXATRMU	Aileron Trim UNITS
RLXATRIM	Aileron Trim DEGS
RAXRS	Yaw Rate RAD/SEC
RAXBETA	Sideslip Angle RAD
L83A01	AI Eng 2 Cowl
L83A02	AI Eng 1 Cowl
L83A03	AI Cont Eng 2 & Wing
L83A04	AI Cont Eng 1 & Wing
L83A05	AI Wing Valve
L83C01	Pitot Heat Capt Upr
L83C02	Pitot Heat Capt Lwr
L83C03	Pitot Heat F/O Upper
L83C04	Pitot Heat F/O Lwr
L83D04	Alpha Vane Htr R

L83D05	Alpha Vane Htr L
L83F01	Wind Heat Cont
L83F02	Wind Heat Cont
L83F03	Wind Heat Cont
L83F04	Wind Heat Cont
L6CB07	Window AI
L6CB08	Window AI
L6CB09	Window AI
RHXINDPA	Hyd A Pressure
RHXINDPB	Hyd B Pressure
LPXHCBAL	Cabin Altitude Warning
LPXL19	Pass Oxy On
RLAO70	Stab Trim Position (range)
RLAO21	Aileron Trim Position (range)
RLAO37	Rudder Trim Position (range)
RLXPAFW(1)	Capt Wheel Force (range)
RLXPAFW(2)	F/O Wheel Force (range)
RLXPAFC	Column Applied Force (range)
RLXPAFB	Pedal Force LH (range)
RLXPAFT	Tiller Applied Force (range)
EVENT	Event Marker
(FDR Auto)	Date

Appendix 6 AAIB Report on their Investigation into the BEA and BFU Analyses.

Air Accidents Investigation Branch

Department for Transport

J.R.L. James
Principal Inspector of Air Accidents
Head of Flight Recording

Conduct of the Image Recorder Trials with respect to ICAO Investigation Standards

The International Civil Aviation Organisation (ICAO) provides guidance to Contracting States on investigation team composition, technical competence and the processes involved in order to effectively and competently investigate aircraft accidents. These guidelines are embodied in the working practices of all major investigation authorities including those of the BFU (Germany) and BEA (France) involved in this trial.

In order to preclude inadvertent communication between the BFU and BEA during the trail period and to minimise the manpower impact on already busy investigation authorities, only one person was assigned to the trial by each of the authorities in question. Whilst this achieved the aim of keeping the FDR / CVR evidence separate from that of the Image recordings, the size of each team was at significant variance with that promoted by ICAO which states:

'*Where a large transport aircraft is involved a substantial team of investigators, set up in specialised groups, is usually necessary to cover all aspects.'*

Investigating authorities recognise that, in order to avoid errors of omission or fact, it is important to crosscheck all findings within the investigation team. Thus it can be seen that the method chosen in order to conduct this trial fairly precluded the use of the checks and balances that would routinely have been employed by BFU and BEA participants during a 'real' investigation.

Another of the prime requisites of ICAO is that all the available evidence shall be used during the investigative process. The ICAO Manual of Accident Investigation states:

'Findings which have been arrived at by more than one line of inquiry, by more than one person each reasoning independently, are more likely to be correct than those conclusions arrived at by pursuing one narrow field of activity'.

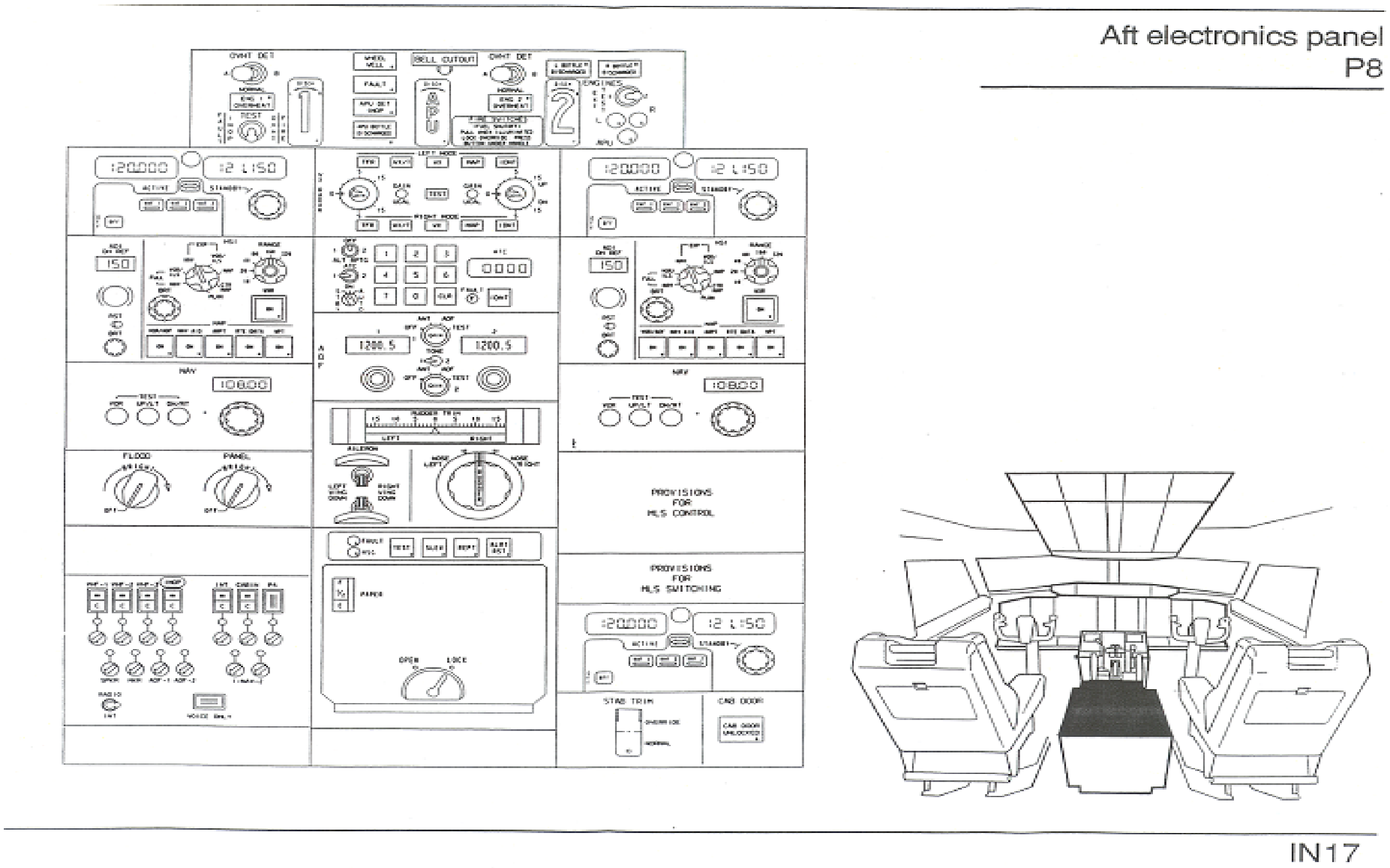
It is recognised by all investigation authorities that information from FDRs etc., although important, forms only a small part of the evidence available during an investigation. Other sources used routinely include engineering evidence, witness statements, air traffic and radar recordings. These were not available to the BFU or BEA participants and hence could not be used to corroborate or refute conclusions drawn from the sole source of the mandatory recordings.

The technical competence of the BFU and BEA is without question and has been demonstrated on many occasions during accident investigation work. The method used to conduct this trial precluded the use of the resources and investigation processes routinely available to them.

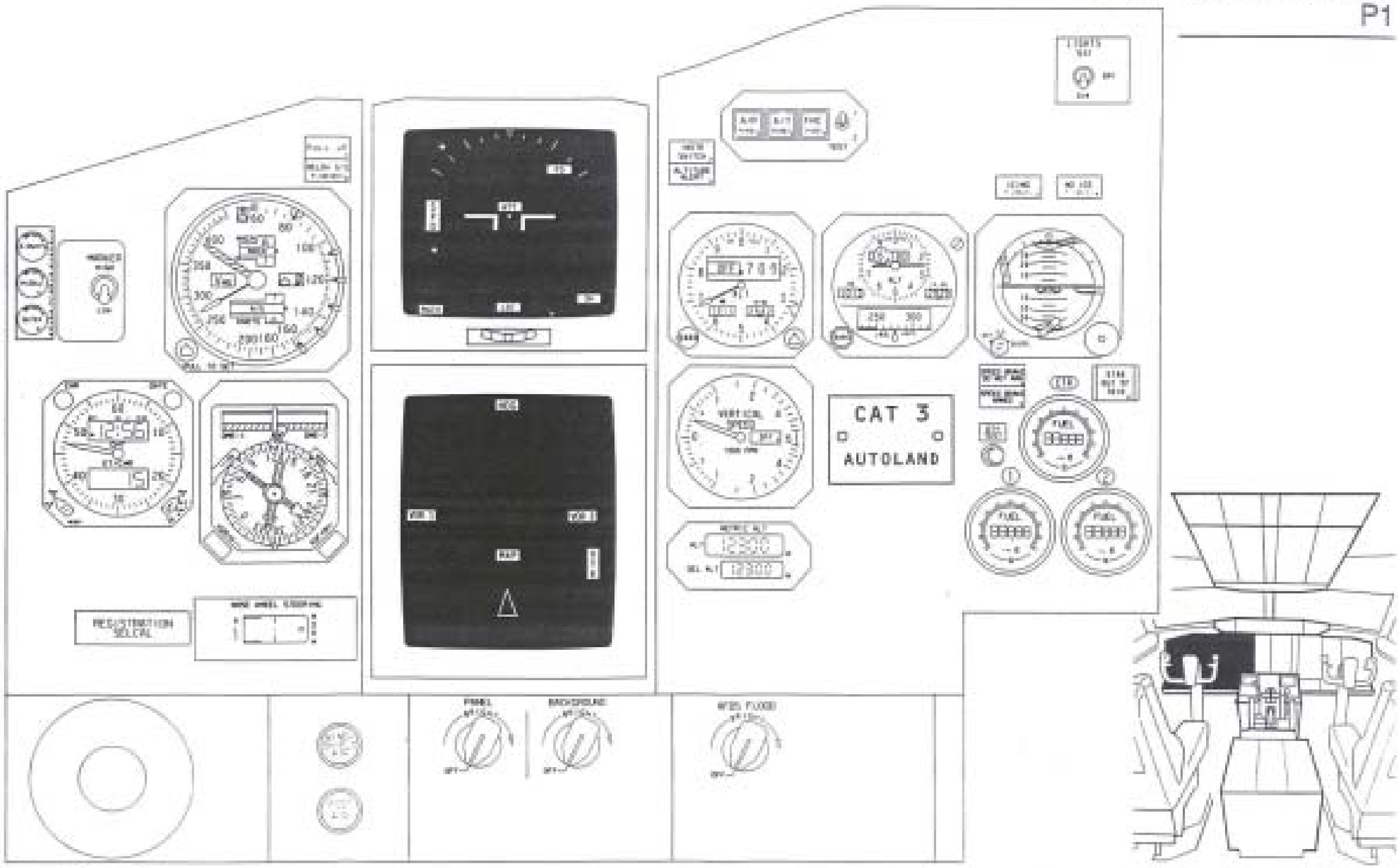
The results of the trial have highlighted areas of great interest to aircraft accident investigators and, in particular, have reinforced the need for, and embodiment of, the organisational guidelines stipulated by ICAO.

J.R.L. James
18th June 2004

Appendix 7 Flight Deck Layout Diagrams

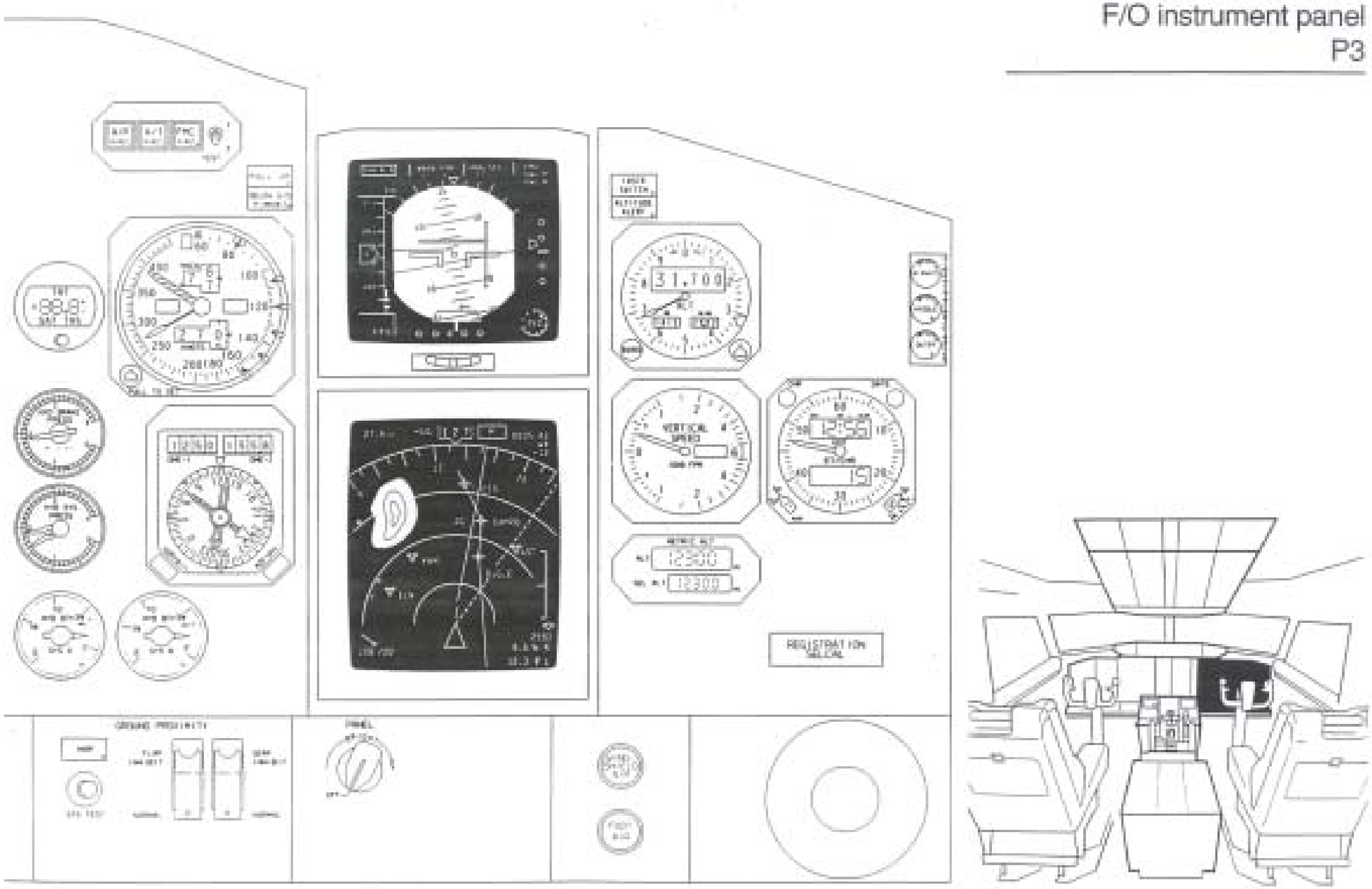


Capt's instrument panel
P1



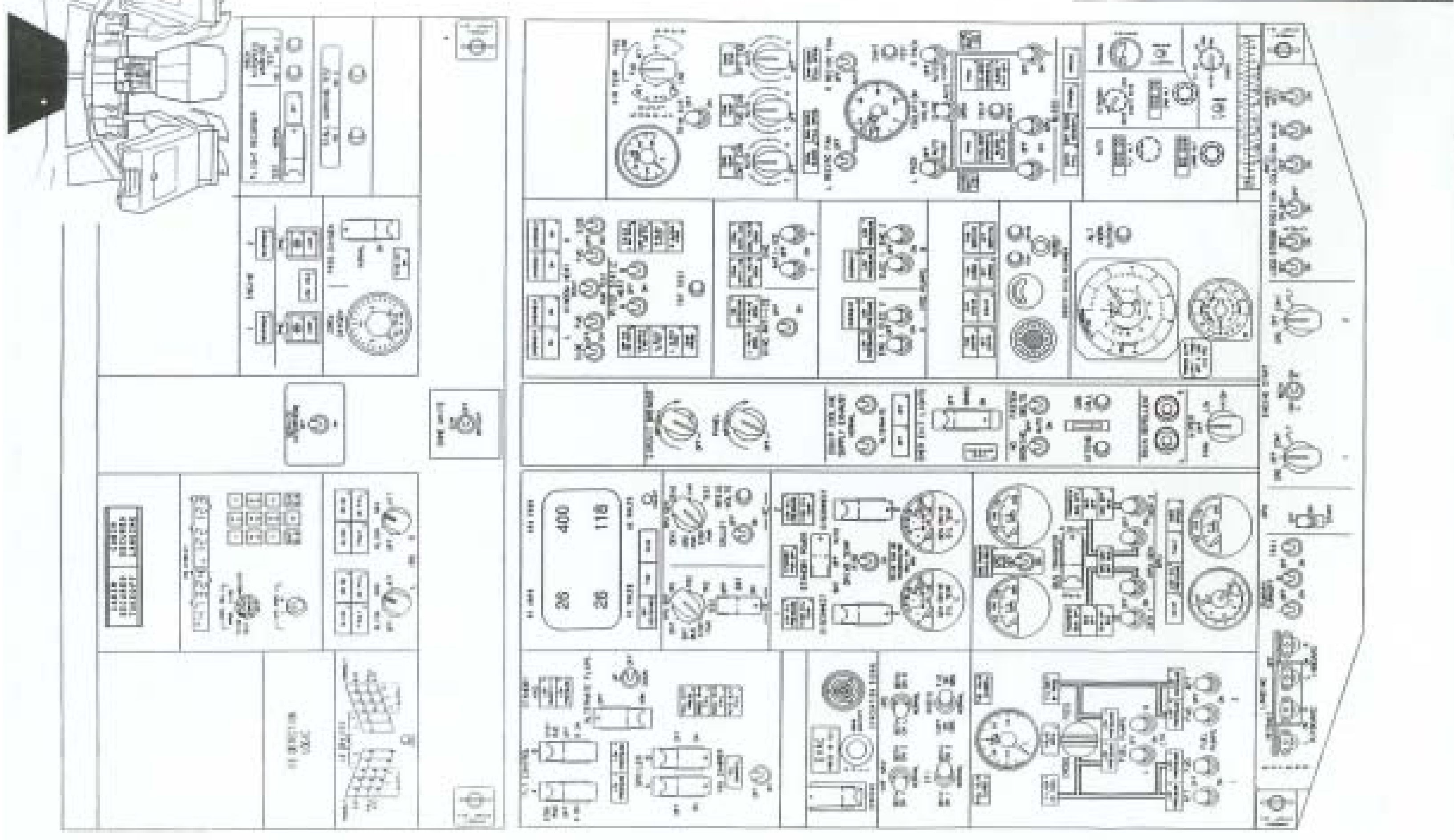
IN18

F/O instrument panel
P3



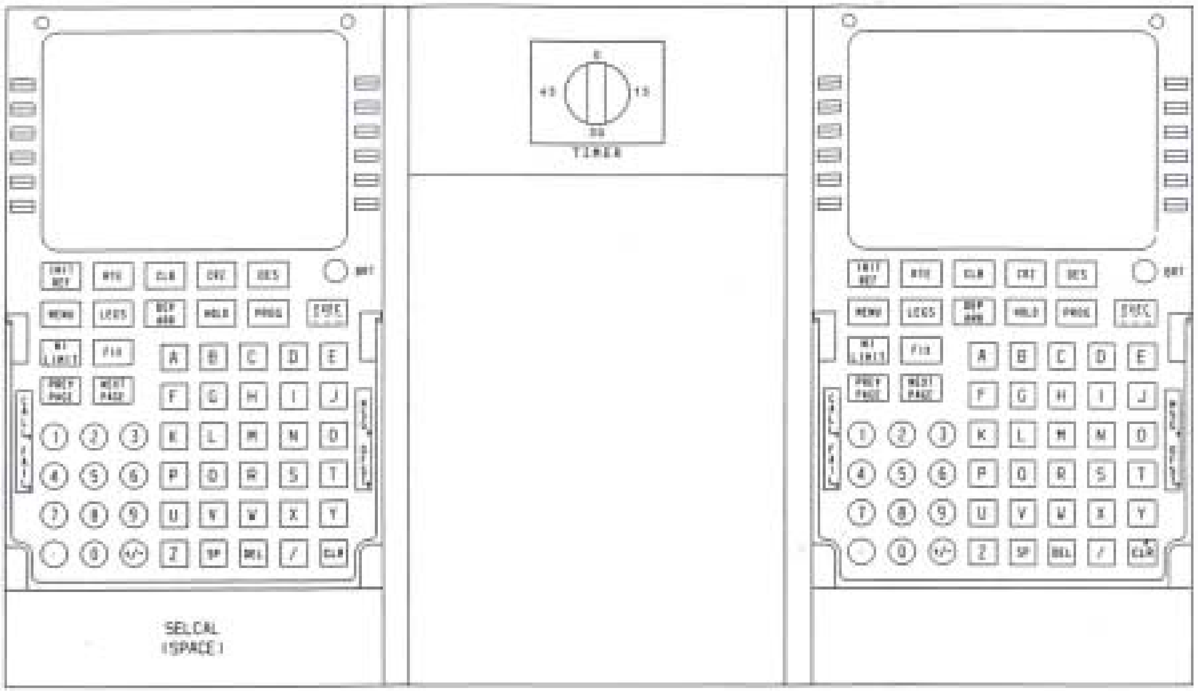
IN 20

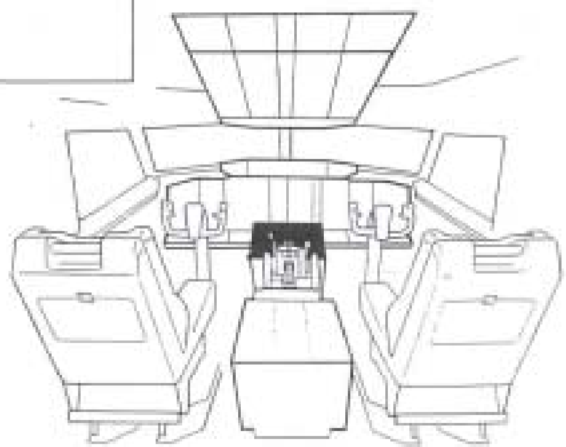
Pilots overhead panel
P5 fwd



IN21

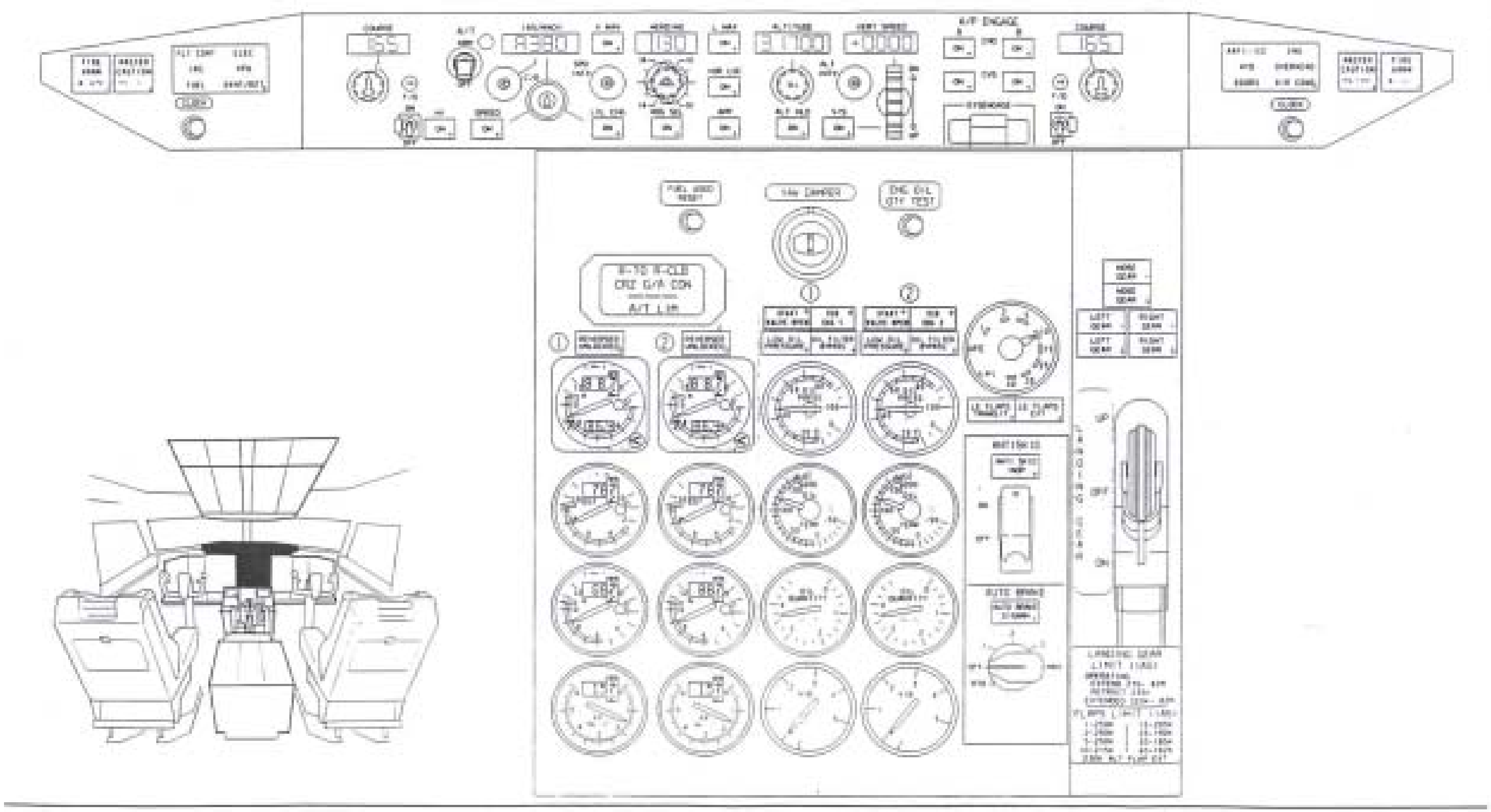
Fwd electronics panel P9





IN22

Centre instrument panel P2 Glareshield P7



IN19

Appendix 8 EUROCAE ED-112 Extract

ED-112 details five separate requirements for Imaging Systems, which results in very different technical solutions:

Type	Image Recording System Purpose
A	Required to capture data supplemental to conventional flight recorders.For example, to capture cockpit Human Factors, movements etc.
B	Would satisfy CNS/ATM (Datalink) Message Display Recording.
C	As a means for recording flight data where it is not practical or prohibitively expensive to record on an FDR, or where an FDR is not required.
D	Required to capture Heads Up Display.
E	Required to capture Other Camera Images presented to the Flight CrewFor example - To capture cargo or cabin views, as selected in the cockpit, which may be achieved by directly recording the images presented to the crew, or indirectly using a camera.

Information Type	Description	Recording Duration	
		Most Recent 30 mins	30 mins - 2 hour
A	General Cockpit View	4 per second	1 per second
B	Datalink data	1 per second	1 per 2 seconds
C	Cockpit Displays	1 per second	1 per 2 seconds
D	Heads Up Display, Display	1 per second	1 per 2 seconds
E	Other Camera Images when presented to the flight crew	1 per second, or the rate provided to the crew, whichever is lower	1 per 2 seconds, or the rate provided to the crew, whichever is lower

1.1 General Flight Deck Area

Coverage areas: All flight crew stations work areas including instruments and controls

Purpose: To determine the following:

Ambient conditions on the flight deck (smoke, fire, lighting, etc.);
General crew activities such as use of checklists, charts, etc, and health and well-being of crew;
Non-verbal communications (hand signals, pointing, etc.);
Cockpit selections within crew reach while seated at duty station (switch/throttle/flight controls, etc).

Resolution: Sufficient to determine status of instrument displays and ambient conditions;

Frame Recording Rate: Sufficient to determine significant crew actions.

Colour: Required.

1.2 Instruments and Control Panels

Coverage Area	Forward Instrument Panel, Overhead Panel, Centre Pedestal and video displays presented to the crew (where installed).
Purpose	To determine the following: Information (including crew selections) not explicitly recorded on the Flight Data Recorder; Status of instrument displays and display modes (blank screen, partial display, automatic display mode changes, etc.);
Resolution	Sufficient to: Determine instrument display status and operational mode of the displays; Determine parameter values whose recording requirements can only be met by image recording.
Frame Recording Rate	As shown in table above
Colour	Required

The General Flight Deck Area requirement is for a wide-angle view, covering the flight deck crew. The Instrument Panel requirement is for a high resolution camera specification, directed solely at the flightdeck instrument panel.

1.3 General Requirements of an Airborne Camera System

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 many failures. Specifically, cameras need to be small, light, and reliable using solid state electronic shuttered light control. They need to take into account the following, which leads to a highly specialized video solution:

Within an aircraft environment, the light range is very wide, even within a single picture, with the brightest scenes, above the clouds for instance, being up to 100,000 times brighter than in a dimmed passenger cabin. For the Camera designer, this leads to either a mechanically driven iris, or to a wide-ranging electronic light control system.

The exterior of an aircraft in flight can be down to -60° Celsius, and just as importantly the interior of an aircraft left parked on an apron, can drop far below zero. Any moving parts will be subject to a great deal of stress and wear, which really leads to a purely electronic solution, using no moving parts, and therefore inevitably to electronic shuttering.

With the intense radiation of the sun during a flight, or within a constrained avionics bay in an aircraft parked in the desert, temperatures can rise to well over 50° Celsius. Heating effects within a camera can lead to "thermal noise" being injected into the picture, which leads to a deteriorating picture, and loss of resolution.

Standard CCTV video cameras "scan" at a field rate of 60Hz. When used to view instruments, this can lead to "beating effects" caused by the scan rate of the tube or LCD display being similar, but out of phase with the camera scan rate. Even more off-putting can be a variable scan rate like those used in radar displays, which can lead to a whole range of different beating effects depending on the phase difference between the signals.

Appendix 9 CAA Analysis of Human Factors Issues Related to this Research

It is not possible to determine how stressed a person is from looking at their face and, although in some cases it can be possible to determine it by listening to their voice, it is very difficult. However, human beings do display predictable behavioural patterns in response to stress and/ or high workload.

The research trials did not specifically address this but, as it offered a potential means of using image recorders to assist in the identification of stress related behaviour patterns, the decision was taken to perform a literature review on this subject (see Chapter 8 paragraph 2.3, Chapter 9 paragraph 1.1, Chapter 9 paragraph 1.2 and Chapter 10 , reference 7 and 8).

The results of this are described below, together with an assessment of whether an accident investigator could detect them using image recorder data.

It should be noted that detection of any of the following behavioural patterns is dependent on a forward facing image recorder system (i.e. one whose cameras point from the rear of the flight deck to the front of the flight deck). This is because detection of these behaviour patterns relies on looking at physical actions performed by the crew together with the relevant flight deck instruments they are interacting with. Views such as these could not sensibly be gained from rear facing cameras.

1 Task Mis-Management

1.1 Explanation

When humans are exposed to stress or a high workload, they tend to mis-manage tasks, either by missing parts of the task out or by performing the different parts of a task in the wrong order.

1.2 Investigator Assessment

An image recorder system would enable investigators to see the flight crew actions. This would enable them to determine whether the flight crew missed checklist items out or got them in the wrong order. In principle, this would allow an accident investigator to determine whether the crew were displaying some of the physical manifestations of stress related behaviour. However, this determination should be made with caution. If a flight crew missed out checklist items it may be because the checklist was not efficient and they were simply streamlining a process to allow faster mitigation of the situation. Equally, a flight crew that appears to be performing tasks in the wrong order may also have been responding to their own personal experience of flying that particular aircraft.

The result of this is that, although an image recorder system will enable an investigator to determine whether a flight crew followed a checklist accurately, any apparent deviations from the checklist should lead to additional questions about the effectivity of the checklist as well as the possible stress levels of the flight crew.

2 Narrowing of Focus / Loss of Perception

2.1 Explanation

Stress and high workload can result in an overly narrow focus, which means that decisions are made without a complete set of data. This can either result from an unconscious desire to focus just on one aspect of a problem or from the physical limitations of the brain preventing the perception/registering of data (e.g. people either just don't hear or don't see the information provided to them).

2.2 Investigator Assessment

The assessment of image data to determine whether the flight crew are displaying the physical manifestations of an overly narrow mental focus or loss of perception should be broken down in to two distinct parts:

a) **No Response To Stimuli**

If members of the flight crew make no response to a stimulus (i.e. a visual or aural alert) an investigator may be able to infer that they are showing the physical manifestations of stress related behaviour. However, once again, this judgement should be made with caution. Although a total lack of response to a stimulus may be a result of stress or high workload, it may also be a result of ineffective alerting mechanisms (e.g. an aural alert may have been masked by other sounds and the crew could fail to register a visual alert due to ineffective colour changes - e.g. green to white).

b) **Inappropriate Response To Stimuli**

An inappropriate response to stimuli could also be used to infer physical manifestations of stress related behaviour. However, an investigator would not be able to prove that the inappropriate response was a result of non-assimilation of data as this is related to a purely mental process about which no recorder could provide information. It should also be noted that the flight crew could have been responding to other, previous experience related to accidents or a particular aircraft idiosyncrasy.

Neither of the symptoms related to this particular behaviour pattern can be definitively assessed using image data alone and any postulated findings related to this should be supported by a detailed examination of the flight deck environment, any aircraft specific idiosyncrasies and the previous experience of the flight crew.

3 Solving Simple Problems

3.1 Explanation

When faced with complex problems combined with high stress levels, people have a tendency to reduce their workload, and stress levels, by dealing with other, possibly non-related, simple problems, even though this may not actually solve the real problem they are faced with.

3.2 Investigator Assessment

This process is predominantly associated with mental processes that would be impossible to assess using camera images, however, reductions in mental capacity may manifest themselves as the physical attributes detailed in Chapter 7 paragraph 1.

The same investigation precautions detailed in Chapter 6 paragraph 2.3.2 should also be employed when assessing this behaviour pattern.

4 Ignoring the Problems

4.1 Explanation

When people are under stress as a result of a complex problem, one response to the situation is to simply try to ignore the problem. This is frequently not a conscious or deliberate decision; rather it is an unconscious reaction to stress.

4.2 Investigator Assessment

This process is predominantly associated with mental processes that would be impossible to assess using camera images, however, it may be manifested as the physical attributes detailed in Chapter 6 paragraphs 2.3 and 2.3.2.

The same investigation precautions detailed in sections Chapter 6 paragraphs 2.3 and 2.3.2 should also be employed when assessing this behaviour pattern.

5 Inability to Reassess Situational Data

5.1 Explanation

Stress or high workload can result in an inability to step back from a situation and reassess whether a previous decision was correct or whether the situation has changed.

5.2 Investigator Assessment

This process is predominantly associated with mental processes that would be impossible to assess using camera images, however, an inability to re-assess a situation may be manifested as the physical attributes detailed in Chapter 6 paragraph 2.3.2.

The same investigations precautions detailed in Chapter 6 paragraph 2.3.2 should also be employed when assessing this behaviour pattern.

6 "It's Always Worked Before!"

6.1 Explanation

A typical reaction to stress/high workload is to resort to tried and trusted methods of dealing with problems and not deviate from them even if they are not working. Where people are subject to very high levels of stress they may actually fail to recognise that their course of action isn't working.

6.2 Investigator Assessment

This particular behaviour pattern could be detected by an investigator, however, image recorder data alone, would not enable them to do this. The additional data required would include both CVR data and knowledge of the previous experience of the flight crew, both actual and perceived (where actual experience relates to things the flight crew have done themselves and perceived experience relates to information the flight crew had heard about but had had no direct experience of).

Although an image recorder system would not provide all the necessary information relating to this behaviour pattern, the crew may react as detailed in Chapter 6 paragraphs 2.3 and 2.3.2. Once again, the same investigatory precautions should be applied.

7 General Observation

One point is common to many of the "Investigator Assessment" sections above. This is that investigators should not rely solely on the evidence provided by the image recorder. They should, instead, seek other information relating to the flight crew's experience, both actual and perceived.

One of the most effective ways to gain an insight into and understanding of this experience would be to generate closer co-ordination between the accident investigation community and the pilot associations. This would enable investigators to gain a far better knowledge of the experience of a flight crew, particularly if that experience is perceived experience.

8 Effect of Cameras on Crew Stress Levels

One of the additional human factors issues that was raised as a result of the analysis of the interim conclusions was that the report did not properly address the effect of cameras on flight crew stress levels. A further analysis was performed as a result of this and the following conclusions were drawn.

There is definitive psychological evidence that monitoring people whilst they perform complex tasks has a negative effect on their ability to perform those tasks. There is also evidence that people perceive having images of their faces and facial expressions recorded to be more personally intrusive than just having their voice recorded. This means that their reaction to cameras recording images such as this are likely to be more pronounced.

Although people can eventually get used to cameras in normal situations, their consciousness of the cameras is likely to be heightened in emergency situations, particularly if they believe that their actions will be evaluated afterwards. The effect of this is particularly pronounced if the camera is facing towards the person's face. It is also possible that a flight crew may 'react for the camera' in this situation, rather than simply performing as they usually would.

This results in the conclusion that cameras can affect the way in which flight crews address situations, and their effect is potentially detrimental should they be rear facing. Since this research has already concluded that rear facing cameras do not provide useful information for accident investigation, this additional finding leads to the conclusion that they should be actively prohibited.

Appendix 10 Glossary

AAIB	Air Accident Investigation Branch (UK Air Accidents Investigation Agency)
A/C	Aircraft
ADC	Air Data Computer
ADI	Attitude Direction Indicator
AGL	Above Ground Level
Air Cond.	Air Conditioning
Amps	Amperes
A/P	Auto Pilot
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio Incorporated
ASAP	As Soon As Possible
ASR	Air Safety Report
AT	Autothrottle
ATC	Air Traffic Control
ATM	Air Turbine Motor
BALPA	British Airline Pilots Association
BEA	Bureau d'Enquêtes et d'Analyses (French Air Accident Investigation Agency)
BFU	Bundesstelle für Flugunfalluntersuchung (German Air Accident Investigation Agency)
Bk	Brake
BUS	Electrical Busbar
CAA	Civil Aviation Authority (UK)
Capt.	Captain
CAVOK	Ceiling and Visibility 'OK'
CC	Cabin Crew
CCTV	Closed Circuit Television
c.g. (or CofG)	Centre of Gravity
CMU	Communications Management Unit
CNS	Continued Navigation Surveillance
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
CWS	Control Wheel Steering

DC	Direct Current
Deg.	Degree(s)
Demd	Demand
DME	Distance Measuring Equipment
EFATO	Engine Failure After Takeoff
EFIS	Electronic Flight Information System
EFISCP	Electronic Flight Information System Control Panel
EGT	Exhaust Gas Temperature
Elec.	Electric/Electronic
Eng.	Engine
Engd.	Engaged
EPR	Engine Pressure Ratio/ External Power Relay
F/A	Flight Attendant
FCC	Flight Control Computer
FCOL	Flight Crew Operating Limitations
FD	Flight Director
FDR	Flight Data Recorder
FF	Fuel Flow
FL	Flight Level
FMC	Flight Management Computer
F/O	First Officer
Freq.	Frequency
G/A	Go-Around
GECAT	GE Commercial Aviation Training
GEN	Generator
GPWS	Ground Proximity Warning System
G/S	Glide Slope
Hyd.	Hydraulics
ILS	Instrument Landing System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
ISASI	International Society for Air Safety Investigators
kts	Knots
lb	pounds (weight)
lb/Hr	lbs/Hour

LCD	Liquid Crystal Display
Ldg	Landing
L/G or L/Gear	Landing Gear
LH	Left Hand
LHR	London Heathrow Airport
Lwr	Lower
MCP	Master Control Panel
N1	Engine Fan Speed (RPM)
N2	Intermediate Pressure Compressor Speed
NITS	Nature Intention Time and Special Instructions
NM	Nautical Miles
Ovht/Det	Overheat/Detection
Oxy	Oxygen
P/A	Passenger/Public Address
Pax.	Passenger(s)
PF	Pilot Flying
PFD	Primary Flight Display
PIC	Pilot in Command
poss.	Possibility/Possible
posn or pos.	Position
QNH	Regional Atmospheric Pressure at Sea Level
QRH	Quick Reference Handbook
Rad.	Radians
Rel.	Relative
RH	Right Hand
RIA	Regulatory Impact Assessment.
RNAV	Area Navigation
RPM	Revolutions per Minute
RT	Radio Telephony
RWY	Runway
SE	South East
Sec	Second
SID	Standard Instrument Departure
Sim	Simulation
STS	Status

TAT	Total/True Air Temperature
T/O	Take Off
Upr	Upper
UTC	Universal Time Constant/Universal Co-ordinated Time
V1	Critical Engine Failure Speed or Take Off Decision Speed
V2	Initial Climb Speed - Engine 1 Inoperative or Take Off Safety Speed
VHF	Very High Frequency
Vib.	Vibration
VOR/LOC	Very High Frequency Omni-Directional Range/Localiser
Vr.	Rotation Speed

EUROCAE	European Organisation For Civil Aviation Equipment - EUROCAE is a European organisation dedicated to developing standards for aeronautical equipment. 102 Rue Etienne Dolet 92240 Malakoff Paris France Website: www.eurocae.org
RTCA	Radio Technical Commission For Aeronautics - RTCA Inc is an association of aeronautical organisations in the United States. RTCA is no longer an acronym and stands on its own as a name, however, the expansion of the acronym has been included for historical reference. 1828 L Street NW Suite 805 Washington DC 20036 USA Website: www.rtca.org
EUROCAE WG-50	EUROCAE WG-50 was a multi-national working group (including specialists from Europe, Eastern Europe, the United States, Canada and Australia) formed specifically to update the technical requirements for flight recorders, including image recording systems.
EUROCAE ED-112	ED-112 is the *Minimum Operational Performance Specification For Crash Protected Airborne Recorder Systems*. It was developed by WG-50 and contains the minimum set of design, installation and maintenance requirements for flight recorders.