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CIVIL AVIATION AUTHORITY

CAA PAPER 95001

THE USE OF EXTERNAL VIEWING SYSTEMS FOR CIVIL AIRCRAFT

CIVIL AVIATION AUTHORITY LONDON PRICE £8.00

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CIVIL AVIATION AUTHORITY LONDON MARCH 1995

ISBN 0 86039 606 1

Printed and distributed by Civil Aviation Authority, Greville House, 37 Gratton Road, Cheltenham, England

Executive Summary

Following an accident to a Boeing 737 aircraft at Manchester Airport in August 1985 the Air Accidents Investigation Branch (AAIB) recommended that research should be undertaken into methods of providing the flight deck crew with an external view of the aircraft, enabling them to assess the nature and extent of external damage and fires. In the report on a further accident to a Boeing 737 aircraft at Kegworth, Leicestershire in 1989 the AAIB recommended that the CAA expedite the research into methods of providing flight deck crews with visual information on the status of their aircraft by means of close circuit television monitoring with a view towards producing a requirement for all UK public transport aircraft to be so equipped.

The CAA initiated a programme of work to investigate the technical feasibility of an external viewing system for aircraft and the need to mandate for such a system. The programme consisted of a review of current technology, an engineering trial on an aircraft conducted in conjunction with a line operator, a study of the Human Factors problems involved and a safety benefit analysis.

The engineering trial demonstrated that it is possible to have a system which can be operated in all the meteorological and atmospheric conditions likely to be experienced. The Human Factors study highlighted many potential problems, in particular the need for a practical evaluation. The safety benefit study identified a number of categories where an external CCTV system could be of value. However, the CAA is of the opinion that such value would be minimal.

The safety benefit analysis highlighted accidents where an external viewing system could be beneficial. However, further analysis by the CAA suggests that these benefits would be marginal. Taking account of the information presently available, coupled with the present limitations of the technology in low level light conditions, the CAA can see no case for taking steps to mandate external viewing systems on UK registered aircraft nor to recommend to the Joint Aviation Authorities that a similar requirement be introduced into the joint Aviation Requirements.

Contents

1 INTRODUCTION

1.1 Following an accident to a Boeing 737 aircraft at Manchester Airport in August 1985 (Reference 1) the Air Accidents Investigation Branch (AAIB) recommended, inter alia, that 'research should be undertaken into methods of providing the flight deck crew with an external view of the aircraft, enabling them to assess the nature and extent of external damage and fires.' In a report on an accident to a Boeing 737 aircraft at Kegworth, Leicestershire, in 1989 (Reference 2) the AAIB recommended that 'the CAA should expedite current research into methods of providing flight deck crews with visual information on the status of their aircraft by means of external and internal closed circuit television monitoring.....................with a view towards producing a requirement for all UK public transport aircraft to be so equipped'.

1.2 In response to the Recommendation in Reference 1 the CAA initiated a programme of work to investigate the technical feasibility of an external viewing system for aircraft and to examine the need to mandate such a system on UK registered aircraft. The CAA took note of the recommendation in Reference 2. The programme consisted of:

(i) a review of current technology;

(ii) an engineering trial on an aircraft, to be conducted in conjunction with a line operator;

(iii) a study of the Human Factors problems likely to be involved; and

(iv) a safety benefit analysis based upon world wide accident records.

2 ENGINEERING TRIAL

2.1 In 1989 the CAA, having initiated a review of available technology, approached British Airways with a view to conducting an engineering trial. The purpose of the trial was to examine the performance of a CCTV system in the conditions of world wide public transport operations. A contract was awarded by the CAA to W Vinten to modify equipment manufactured by them although not designed for an aviation environment, to be installed by British Airways on a line aircraft. The aircraft chosen was a Boeing 747–136. The Boeing 747 was chosen in order to produce as testing a situation as possible in terms of the distances between the cameras and the portion of the airframe being viewed. There was no plan at that stage to provide a CCTV display on the flight deck although the eventual need for such a facility was recognised and the necessary cabling was included in the design installation.

2.2 After discussion between CAA, British Airways and W Vinten it was decided that the optimum configuration of cameras would be:

(i) on the upper fin viewing the starboard wing;

(ii) on the port tailplane viewing the port wing trailing edge; and

(iii) on the aircraft belly, forward of the wing and rearward facing, with a panning capability which allowed a view of an area from No 2 engine inlet to No 3 engine inlet including the main undercarriage bogeys.

Figure 1 shows the configuration.

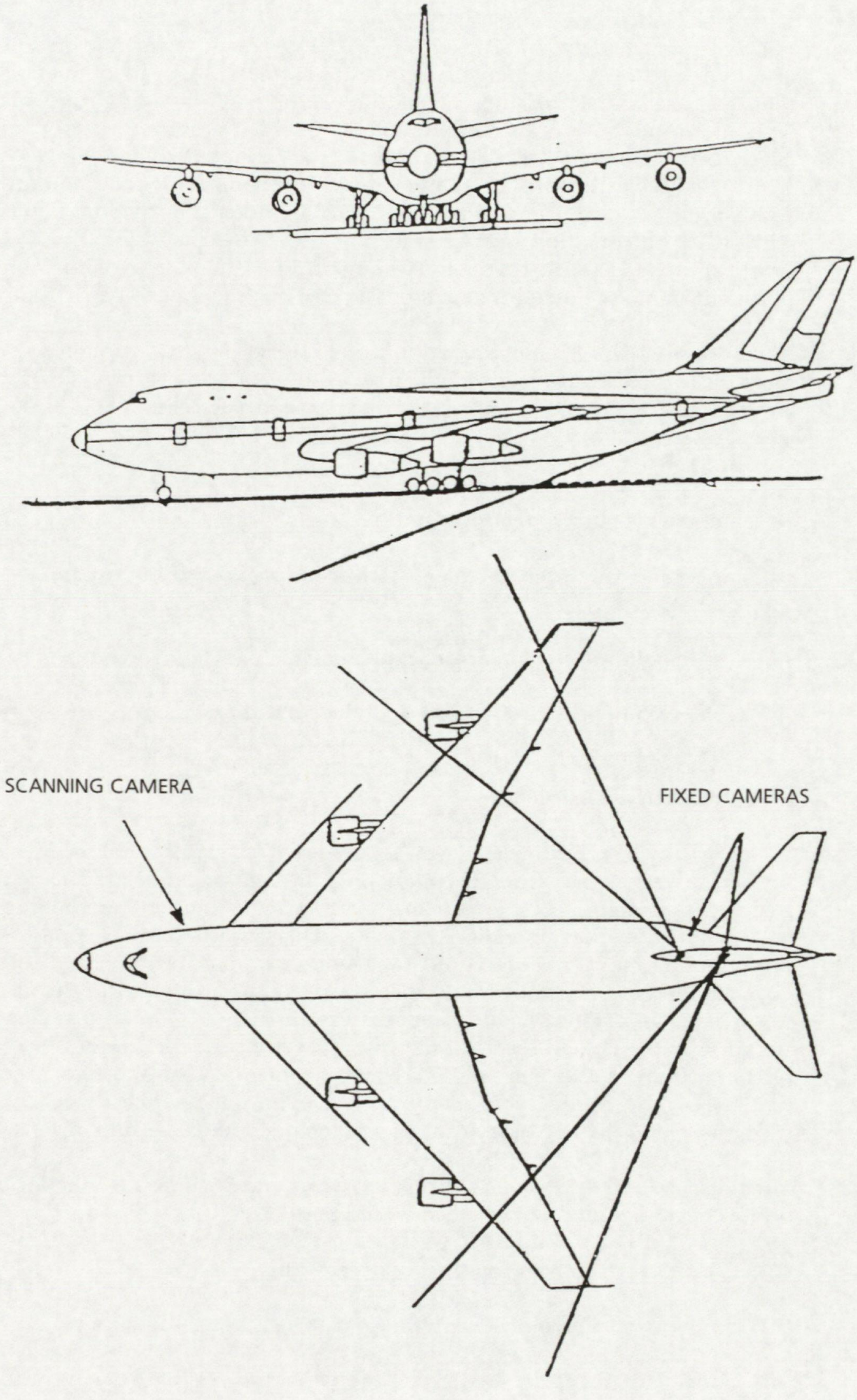

Figure 1 Configuration of cameras on aircraft frames

2.3 Although there was no provision at that time for a cockpit display there was a facility in the upper cabin to view the pictures and to make video recordings. This enabled both CAA and BA staff to observe the system in operation without having to modify the flight deck layout. The aircraft used in the trial was primarily used on transatlantic routes. Experience demonstrated that in general the cameras operated satisfactorily in all the meteorological and atmospheric conditions experienced.

2.4 **Points raised by observers**

2.4.1 The system produced no usable pictures after dusk. Even on a brightly lit apron it was not possible to discern any detail regarding the airframe.

2.4.2 No particular benefits of colour pictures over monochrome were discerned, especially at altitude. Indeed the adjustment of the picture to monochrome produced an improvement in the clarity which outweighed any benefit of colour.

2.4.3 The under belly camera often suffered from misting whilst the aircraft was on the ground and often this did not clear for up to 30 minutes. In addition, whilst on the ground the housing for this camera was prone to the effects of rain and spray, causing the view to be impaired.

2.4.4 The iris control was not sufficiently responsive to cope with the large variations in brightness which occur during flight.

2.4.5 The recorded pictures viewed in flight were inferior in quality to those seen in real time.

2.4.6 Some corrosion of the underbelly camera and mount was seen after about two years operation. The non-continuous use of the heater in the housing, coupled with contamination from the toilet outlet, is thought to be the cause.

2.5 In assessing the points raised in 2.4 above it must be stressed that the trial installation involved components that were not originally designed for aviation use. There is no reason to believe that many of the difficulties could not be overcome, although the problems of night viewing are still a major obstacle to the realisation of a practical system.

3 DRA INVESTIGATION OF HUMAN FACTORS ISSUES

3.1 One of the main concerns about the introduction of CCTV for external viewing is the way in which the crew would use the information provided. The Defence Research Agency (DRA) Farnborough was contracted to investigate the use of such equipment. In their report – 'A Human Factors Investigation into the use of Airborne External Video View Camera Systems' (Reference 3) the DRA considered the following:

(i) the status of the system in operational terms;

(ii) the display of information including character display if alpha-numeric information is required;

(iii) display technology;

(iv) guidelines on monitor position; and

(v) incident reviewing by means of on board recording.

3.2 System status

The way in which the system is integrated into operational procedures will also govern the design. In particular its use as either a primary or secondary source of information will affect the positioning of the monitor screen, the times, if any, during which the displays should be inhibited and the necessary integrity.

3.3 Display of Information

3.3.1 The type of display considered is limited to either Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD) technologies. There are well established parameters applicable to Visual Display Units (VDU) based on CRT technology in terms of luminescence, reflectance, flicker and screen position with respect to the viewer. Less information is available regarding LCD technology. The DRA report stresses, however, that if LCD technology is used, some of the guidelines may need modification and the literature in this area is not comprehensive (at present). Additionally, it is emphasised that provided the contents of the display are of the required clarity for the task to be carried out at a specified eye-screen distance, then the screen size is of secondary importance. If additional alpha-numeric information is required for labelling of pictures the necessary standards for readability are given in BS1990.

3.3.2 The report accepts that the constraints on screen size will probably preclude the showing of more that one camera view at a time. Operational experience will be required before optimum screen content can be fully assessed. However, the possible confusion of viewing pictures from a rear facing camera on a screen facing forward is emphasised.

3.3.3 The CRT is a more mature technology but LCD units have the advantage of needing less depth. This is an important factor when looking for possible locations on the flight deck. Use of a display already provided, such as those found above the centre pedestal has been suggested and it is then likely that for such retrofit applications the existing CRT will be used.

3.3.4 The choice of the focal length of the camera lens is very much dependent on the trade off between field of view and level of detail. Panning cameras can provide a compromise solution but it could not be guaranteed that transient events would be recorded (see para 3.5).

3.3.5 The relative merits of colour and monochrome need to be assessed by operational experience. It is stressed that the potential for night viewing using imagery in the near infra red spectrum needs further investigation.

3.4 Monitor Position

The DRA team examined the flight decks of a number of British Airways aircraft and identified possible locations for a dedicated display. It was apparent that in all cases space was very limited especially for a display regarded as a primary instrument. Modern LCD's, as used in cabin entertainment systems might be one solution on some aircraft types if the sharing of CCTV pictures with other displays proves difficult.

Simulator trials are a means to determine optimum position for each aircraft type depending on the status of the system in operational terms as discussed in para 3.2.

3.5 Incident reviewing

It is likely that some events which the crew may find useful to view using external cameras will be transitory in nature. It is unlikely, therefore, that the crew will be looking at the appropriate part of the airframe at the exact time at which the event occurs. It would be very useful to have the ability to play back recordings of the views from all cameras at a later time. However there are difficulties associated with finding the appropriate piece of recording in a useful time frame using conventional video tape recording techniques. Adequate labelling of the view being shown, time of recording and the facility for inserting event markers would be needed. The use of such a replay system needs to be given an operational status. The search for the relevant incident could become as absorbing as the pictures themselves, to the detriment of the operation.

3.6 Conclusions of the DRA study

The DRA study highlighted many potential human factors problems. In particular, although guidelines can be given based upon good ergonomic and human factors practice, there will be a need for practical evaluation. An initial programme of work on a simulator is suggested.

4 SAFETY BENEFIT STUDY

4.1 The CAA, in considering the AAIB Recommendation to mandate external viewing devices on UK registered aircraft, concluded that a safety benefit analysis based upon previous accident records was necessary. It was thought appropriate that such an analysis should be conducted by an external body. A contract was let to the Department of Air Transport at the College of Aeronautics at Cranfield (now Cranfield University). The report (Reference 4) is given in full at Appendix 1 but is summarised here. It should be stressed that in conducting the study a series of assumptions were made which need to be borne in mind when reading the full report and the CAA's view. These assumptions were:

- Any system would have a 24 hour all weather capability.
- The use of the system would be actioned in the pre-take off check list.
- The system would be capable of showing the presence of ice and snow under all visibility conditions whilst the aircraft is on the ground.

Additionally it was agreed at the outset that the study would make no attempt to decide whether or how any potential benefits might be realised in practice.

4.2 Report summary

4.2.1 The analysis was based primarily on the record of accidents and incidents compiled by the CAA Safety Data and Analysis Unit (SDAU), the Cranfield accident data base and the World Aircraft Accident Summary (WAAS). Supplementary information was also taken from other reputable sources. The incident types as defined in the WAAS were examined to determine if CCTV would be of benefit in either preventing accidents, reducing the effects of an accident or as an aid to accident investigation.

The probability of achieving any benefit was also assessed on a simple ranking scale. It was found that detailed analysis of accidents or incidents relating to the following should be examined further:

(i) failure of some/all power units;

(ii) flying control system malfunction;

(iii) ice or snow accretion on airframe/engines;

(iv) in-flight fire/smoke;

(v) power plant disruption;

(vi) third party (ground manoeuvres); and

(vii) tyre burst.

4.2.2 There then followed a detailed analysis of accidents in all the categories identified in 4.2.1 and the benefits were re-categorised to designate if they would help in either the prevention of an accident, the prevention of a minor incident becoming a major accident, improved accident survivability or as an aid to accident investigation.

4.2.3 A total of 67 relevant accidents were identified and further categorised into the following types:

(i) climate (ice/snow);

(ii) control systems;

(iii) engine fire;

(iv) fire (other than engine); and

(vi) landing gear.

4.2.4 The report stressed that there was no attempt to decide whether or how any potential benefit might be realised in practice. Bearing in mind this constraint it concludes by highlighting the types of accident where external viewing might be of benefit namely:

(i) ground operations;

(ii) ice/snow deposition on aircraft surfaces;

(iii) incorrectly configured landing gear or flaps/slats;

(iv) engine fire/failure; and

(v) during emergency evacuation

5 CAA VIEW OF THE RESULTS OF THE SAFETY BENEFIT STUDY

5.1 The CAA is of the opinion that in practice the value of CCTV will be minimal in a number of the categories identified in the Cranfield report. Tables 1 and 2 below have been derived from the data in Reference 4 with some modifications. In particular the Authority is not convinced of the potential of CCTV to detect ice reliably even in daylight. The concept of using thermal imaging is not thought to be practicable with existing technology and the interpretation of such information by line crews would be difficult. Accidents involving ice on surfaces are therefore not included in Table 1. However, when both snow and ice are mentioned the accident has been included since snow would be visible. If, therefore, the incidents and accidents relating solely to ice are eliminated the potential extent of the safety benefit of CCTV becomes more apparent. Table 1 below classifies by accident type the potential fatalities to be saved.

Table 1 Distribution of numbers of accidents and fatalities by accident type

Accident Type	*No of fatalities*	*No of accidents*
Ground Operations	13	37
Snow on lift surfaces	114	5
Control systems	174	3
Fire in undercarriage area	261	3
Engine fire	105	5
Undercarriage mismanagement	0	3
TOTAL	**667**	**56**

5.2 Table 2 below classifies the potential lives saved according to which part of the airframe the cameras should be viewing.

Table 2 Distribution of numbers of accidents and fatalities according to the part of the airframe that CCTV would need to view to facilitate diagnosis

View	*No of fatalities*	*No of accidents*
Wing (lift devices)	18	2
Wing(snow)	114	4
Wing (ground operations)	0	2
(Total wing)	*(132)*	*(8)*
Engines	50	7
Undercarriage	274	37*
Stabiliser	0	2
Flaps	156	1**
Fuselage	55	1
TOTAL	**667**	**56**

* Including one with 261 fatalities where detailed records show that the situation became catastrophic before an external view would have been helpful – see para 6.1 below.

** These are included in 'Wing (lift devices)' unless there was definite information to say that the trailing edge flaps position was the cause.

6 DISCUSSION OF SAFETY BENEFIT STUDY

6.1 Superficially it would appear that the category of accident resulting in the greatest loss of life is fire in the undercarriage area. There were 3 such accidents. However, all 261 fatalities in that category occurred in one accident (DC8 at Jeddah 1991). The circumstances of this accident were such that, even if the crew had had access to an external viewing device, the sequence of events leading to the outbreak of the fire was such that nothing untoward would have been visible until the situation had become catastrophic.

6.2 The second largest category resulting in fatalities is 'Control systems' (see Table 1). All three cases involved the incorrect setting of flaps/slats. The CAA view is that it would be difficult in the majority of circumstances, using CCTV systems, to ensure that the high lift devices are correctly positioned. The disciplined use of current procedures which use configuration warning systems as a back up for the proper use of the checklist should be emphasised in training. The reasons for crews not responding correctly to, or inhibiting the conventional configuration warning systems would be better addressed by an operational or design solution.

6.3 Snow on lift surfaces is the third largest cause of fatalities mentioned in the safety benefit study. The continuing problems of designing ground deicing systems for aircraft are being addressed separately by the Industry. It has already been stated that the detection of ice on lift surfaces is not practicable using CCTV but that it could possibly be used for detecting snow assuming that there was sufficient ambient lighting. A check list item for snow on lift surfaces will still require a need for an airframe inspection to determine if ground deicing is necessary and there is therefore little value in the ability to determine only the presence of snow using CCTV.

6.4 Ground operations resulted in a large number of incidents although the number of fatalities was relatively small. Ramp safety is being addressed by airlines and airport authorities in terms of ensuring adherence to proper procedures and, if appropriate, revising those procedures. The use of CCTV could produce a small benefit but not sufficient to warrant considering mandatory fit. Furthermore such accidents generally occur whilst the aircraft is being manoeuvred by a ground tug. It is not appropriate to place primary responsibility on the flight crew to ensure third party safety under these circumstances.

6.5 The remaining category causing a significant loss of life is engine fire. On its own an engine fire should not pose a problem to a large public transport aircraft provided that the fire warning is properly actioned. Of the five accidents identified two occurred in the UK and the resultant AAIB reports generated the interest and activity into the potential benefits of external viewing devices. The accident at Manchester in August 1985 took place during the take-off run. In order to be able to benefit from an external viewing system the crew would have had to

- assess the nature of the problem
- decide whether to reject or continue the take-off
- decide where to bring the aircraft to a halt
- instruct the cabin crew on the appropriate exits for evacuation

To perform all of these functions a camera system would have to be active during the take-off run. This is not favoured by the CAA since it can be a source of distraction at a critical stage of flight. The use of a camera system must also be put into the context of the time frame in which the whole accident occurred and other events which took place in parallel. The benefits of external viewing in this case are dubious.

6.6 In the case of the accident at Kegworth in January 1989 there was adequate information to indicate which engine was malfunctioning. The crew misinterpreted this information and convinced themselves that the No 2 engine was the source of vibration. Had they had the benefit of CCTV, it is questionable whether they would have changed this view on receipt of contrary information, even from an external view, unless there was an element of doubt in their minds. There is no evidence from the accident report that any such doubt existed.

7 SAFETY DISBENEFITS

Research has not been conducted into the safety disbenefits of an external viewing system. Before mandating for such a system however they would require careful consideration. The disbenefits would be difficult to determine but the aspects which would need to be examined include:

- visual distraction during critical phases of flight
- distraction from laid down emergency procedures and priorities
- incorrect diagnoses
- information overload
- incorrect camera identification

8 CONCLUSIONS

The safety benefit analysis carried out by Cranfield University has highlighted accidents where an external viewing system might on the face of it have been beneficial. Further analysis by the CAA suggests that in fact the benefits of such a system would be marginal when the accident and an external viewing system are put into a full operational context. The safety disbenefits of such systems have not been fully researched. They would be difficult to determine and the use of the necessary resources is not considered by CAA to be justified in the light of the low level of safety benefit. On the basis of the information to date, coupled with the present limitations of the technology in low light level conditions, the CAA can see no case for taking steps to mandate external viewing systems on UK registered aircraft nor to recommend to the Joint Aviation Authorities that a similar requirement be introduced into the Joint Aviation Requirements.

9 REFERENCES

1 Report on the accident to Boeing 737–236 Series 1 aircraft G–BGJL at Manchester International Airport on 22 August 1985 – Aircraft Accident Report 8/88.

2 Report on the accident to Boeing 737–400 aircraft G–OBME near Kegworth, Leicestershire on 8 January 1989 – Aircraft Accident Report 4/90.

3 A Human Factors Investigation into the use of Airborne External Video View Camera Systems – Dudfield et al. – DRA Technical Report 93021.

4 Safety Benefit of Aircraft External Viewing Systems: A Review of Past Accidents to Identify Possible Benefits: Dept of Air Transport, Cranfield Institute of Technology, July 1993.

Appendix 1

Report for: Civil Aviation Authority

SAFETY BENEFIT OF AIRCRAFT EXTERNAL VIEWING CAMERAS: A REVIEW OF PAST ACCIDENTS TO IDENTIFY POSSIBLE BENEFITS

R Fewings
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1 INTRODUCTION

The flight crew members of current transport aircraft have a very limited view of the aircraft through the cockpit windows and, in those with swept wings and a long forward fuselage, virtually no useful view of the aircraft at all.

The current interest, in the UK, in providing the crew with a view of much of the aircraft, and specifically by means of an external television camera, started with the Manchester B737 accident on 22 August 1985.

In the report on the Manchester accident the Air Accidents Investigation Branch (AAIB) recommended that *'research should be undertaken into methods of providing the flight deck crew with an external view of the aircraft...'* and, following the Kegworth accident in January 1989, called on this research to be expedited. In the meantime certain aircraft have been fitted with external cameras and evaluation trials are continuing.

Acceptance of external viewing cameras by the air transport community is dependent on a safety benefit analysis of such a system, that is, the balance of lives saved, reduced aircraft hull damage and therefore associated insurance costs compared with the costs of system installation and maintenance.

The benefit of any proposed safety measure of most immediate interest to the passenger and the media is that of saving lives. This alone has sometimes been weighed against the cost of introducing the safety measure to produce a quite unrealistic and misleading cost-benefit equation. However, it must be stressed that this study deals with safety benefits alone.

In reality there may be many benefits in addition to that of saving lives, a reduction in structural damage and insurance costs already mentioned above, many of which may be allocated a cost saving in a manner much less controversial than that based on the assessment of the 'value' of a human life. The old cliché that *'if you think safety is expensive, try having an accident'* is still a useful reminder of the many and varied disbenefits of having an accident, all of which may be costed, when assessing the benefit of avoiding the accident.

Furthermore, it is not only accidents that cost money, incidents can also be costly, even if there is no aircraft damage and the only immediate effect is a delay in departure; this in itself can incur the airline in considerable costs which are not covered by insurance.

2 STUDY STRUCTURE

This study is based on an initial research proposal presented to the Civil Aviation Authority by the Department of Air Transport, Cranfield Institute of Technology. The purpose of this study is to review past accidents on a world wide basis to establish the possible safety benefits that might have accrued had external cameras been fitted. That is, it will be necessary to identify accidents where it can be argued that if the crew had additional information available from the external camera they would have been likely to have acted in a different way such as to avoid the accident or its principal effects.

It was intended that the Cranfield accident data base in conjunction with the CAA's data base of incidents and accidents be used to define an initial list of possibly relevant accidents. The list would then be studied and reduced to a more manageable length in stages. The appropriate decision-making process was left open but at the time of submitting the proposal it was, correctly as it turned out, anticipated that little or no justification would be required for eliminating a large proportion of past incidents and accidents in a repetitive and progressively more rigorous 'sweeping' exercise. However, as the list was whittled down, it has also become more necessary to concentrate the thought or decision process on the grey area between relevance and non-relevance.

The work programme was split into three phases. The first phase, described in Section 3 of this report, was the compilation of a comprehensive initial list of possibly relevant incident and accident types using the Cranfield accident data base, the World Aircraft Accident Summary (WAAS) and other information sources. After a review of the initial list, some incident types were eliminated from further consideration.

The second phase was a more detailed examination of the remaining incident types which are discussed in Section 4. On the basis of a final selection of potentially relevant incident types a number of incidents and accidents were identified for further discussion (Section 5) in the third phase of the programme.

The third and last phase of the work programme was the development of an accident data-base on the basis of which a detailed description was made of all relevant accidents to examine the case for fitting Closed Circuit TV (CCTV) systems.

3 IDENTIFICATION OF RELEVANT INCIDENT TYPES

3.1 Introduction

The original intention of the initial phase of the study was to compile a comprehensive initial list of possibly relevant accidents using the Cranfield accident data base and key words. In the event, it was decided that the Cranfield data base contained insufficient detailed information on individual accidents and additional use was made, at an earlier stage than expected, of the WAAS and other information sources including:

- AAIB reports
- Joint Airmiss Working Group
- National Transportation Safety Board
- Flight Safety Digest
- U.S. National Safety Council Newsletter
- Canadian Airlines' Ground Safety Newsletter
- Forum – The International Society of Air Safety Investigators.
- Airliner (Boeing)
- Flight Deck (British Airways)
- Aircraft Support

The WAAS conveniently lists individual incidents/accidents as incident types. There is some duplication with incidents being allocated to one or more incident types. The analysis in the first phase was therefore an identification of accident type and potential benefit and incorporated the elimination from this initial analysis those accidents where CCTV was considered unlikely to have been of benefit either in prevention or diagnosis.

Referring back to the incident types, as defined in WAAS, each was examined for three potential types of benefit, namely:

'A' The prevention of an accident by viewing, check-list process or similar.

'B' The scope or potential for reducing the effects of the incident or accident by the provision of additional knowledge to enable the flight crew to act in accordance with the additional information so made available.

'C' As an aid to the AAIB, or other such equivalent national body, to determine the causal factors behind each individual incident or accident.

Each of the benefit types was then ranked, in the following fashion:

• Most unlikely	0
• Possible but improbable	1
• Probable	2
• Almost certain	3

Although this ranking may appear rather simplistic, it was applied in a manner which would tend to retain borderline cases for further consideration.

Table 1 shows an initial attempt at benefit ranking that was made for the individual incident types from the WAAS. Reference to Table 1 enabled the last step of the first phase to be made, namely, to eliminate from further analysis those incident types where CCTV was considered unlikely to have been of benefit either in prevention or in diagnosis.

It should be noted at this early stage that a sweeping overview of incident types, and the elimination of certain incident types from further analysis, may have led to a relevant incident 'slipping through the net'. Again, an initial 'trawl' is subjective and dependent on the level of descriptive material included in WAAS. Some incident reports covered many paragraphs; other incidents were 'dismissed' within a single line. It was noted that the most descriptive material available comes from the United Kingdom and the United States. While there may be some function of traffic levels in this, it is unlikely that only a few 'relevant' incidents have occurred elsewhere in the world.

During the second part of the study, cross reference was made to the more detailed AAIB, and other reports. These tended to confirm our views which were based on the synopsis abstracted from the WAAS.

3.2 Elimination of incident types

To return to those incident types eliminated from further analysis, it is important to give reasons as to why these incident types merited no further study in terms of the benefits that might be provided by CCTV.

Aircraft shot/forced down

Control of events taken away from aircrew although there is the possibility of damage assessment to aircraft structure if the aircraft is still controllable. The most likely benefit of CCTV may be as a source of information to accident investigators – if the aircraft (wreckage) was readily accessible.

Aquaplaning/hydroplaning

Control of events taken away from aircrew but with some similarity to 'overrunning of runway'.

Table 1 Potential CCTV benefits (source WAAS)

	Incident Type	*Benefit*		
		A	*B*	*C*
	Aircraft shot/forced down	0	1	3
*1	Airframe failure (excl. sabotage)	1	1	3
	Aquaplaning/hydroplaning	0	1	2
*2	Bird strike, ingestion	0	2	3
	Cargo breaking loose	0	0	0
	Collision (high ground)	0	0	1
	Collision (water)	0	0	2
	Crew incapacitation	0	0	2
	Crew shot	0	0	2
*3	Doors, windows opening/failing	1	2	3
	Electrical system failure	0	0	0
*4	Failure of all power units	0	1	2
*5	Flying control system malfunction	0	1	2
	Fuel contamination	0	1	1
	Fuel exhaustion, starvation	0	1	1
*6	Hail damage	0	1	1
*7	Ice/snow accretion on airframe/engine	2	2	3
	Inflight accidents (sabotage)	0	1	2
*8	Inflight fire/smoke	0	2	3
	Instruments	0	1	2
*9	Lighting strike	0	1	2
*10	Power plant disruption	0	2	2
	Mid-air collisions	1	1	2
*11	Overrunning of runway	0	1	2
*12	Third party (ground manoeuvres)	2	1	2
*13	Tyre burst	1	1	2

Cargo breaking loose

Applies to internal CCTV only (in cargo hold), although is possibly some linkage to in-flight fire/smoke in inaccessible areas (again in cargo holds).

Collision (high ground/water/mid-air)

Control of events taken away from aircrew, however, note linkage to other incident types.

Crew incapacitation/shot

Control of events taken away from aircrew. There is a potential benefit of internal CCTV as a useful source of information to accident investigators.

Electrical system failure

Only possible use of CCTV would be to confirm the effects of system failure on the major moveable aircraft components, therefore diagnostic.

Fuel exhaustion, starvation

Only possible use of CCTV might be to confirm that engine separation, fire or other damage has not occurred, therefore, diagnostic.

In-flight accidents (sabotage)

Diagnosis of external damage.

Instruments

No apparent immediate benefit or relevance to CCTV.

Mid-air collisions

Control of events taken away from aircrew, although, in the 'glancing blow' scenario, CCTV would be useful to ascertain damage to the aircraft structure. Note that with modern aircraft there are large volumes of airspace (apart from the aircraft surface itself) which are out of view from the cockpit. However, a more sensible alternative is for all aircraft to be fitted with an airborne collision avoidance system.

4 DISCUSSION OF RELEVANT INCIDENT TYPES

4.1 Introduction

The remaining incident types (*Table 1) were then examined in greater detail. Each incident type was reviewed and classified on the following basis:

- Those incidents in which there was some evidence that CCTV might possibly have changed the course of events, ie by supplying the aircrew with useful visual and/or diagnostic information.
- The incidents were selected on the basis of the benefit ranking shown in columns A and B of Table 1.

- There are many other incidents where the installation of CCTV would have been useful to the appropriate national Accident Investigation Authority.
- Within this Section of the report, it is not the intention to discuss individual incidents in detail but to give an initial indication of the appropriate components of the aircraft whose failure created the incident and which, in turn, could be viewed by a CCTV system.

Comments on the incident types that were re-examined are made below. On this basis, a final selection of incidents was made for detailed examination and which are discussed in Section 5.

4.2 Incident types re-examined

4.2.1 *Airframe Failure [*1]*

From an analysis of the incidents listed in the WAAS under this category, there appeared to be insufficient initial evidence that CCTV would have changed the course of events.

However, there are a number of incidents in which it is possible that visual information from CCTV may have enabled the flight crew to diagnose problems more quickly.

Aircraft component failures included in this incident type include engines, elevators, flaps, rudder, structure damage and fire. Note a previous comment that many incidents are classified under more than one incident type; this is particularly true for this incident type.

4.2.2 *Bird strike/ingestion [*2]*

There appeared to be insufficient evidence that CCTV would have changed the course of events.

However, there are a number of incidents in which information from CCTV may possibly have provided, to the flight crew, a visual assessment of damage.

In view of the nature of the incident type, this would be limited to the engines, flaps, leading edges and elevators.

4.2.3 *Doors, windows opening or failing in flight [*3]*

The failure or opening of doors and windows in flight can have dramatic effects due to decompression. CCTV could be used to ascertain both what has happened and also possibly provide diagnostic information for the purposes of damage assessment to other parts of the airframe.

4.2.4 *Failure of some/all power units [*4]*

There have been a number of incidents in which the visual information provided by CCTV may have changed the course of events. The most significant of these will be discussed in Section 5 of the report.

In addition, there are a number of other incidents in which CCTV may have provided diagnostic information to the flight crew.

Within this group, incidents have included engine failure, loss of aerodynamic performance due to ice formation, fuel leakage and structural damage.

4.2.5 *Flying control system malfunction [*5]*

There have been a number of incidents in which the visual information provided by CCTV may have changed the course of events; in other incidents CCTV may have provided diagnostic information to the flight crew.

Within this group incidents have included damage to flaps, slats, engine loss, undercarriage, fuel leakage, fuselage damage, rudder, elevators and stabilizer.

4.2.6 *Hail damage [*6]*

A review of incidents, in which hail damage was cited as being a causal factor, has led to the conclusion that there is insufficient evidence that CCTV would have changed the course of events but there is the possibility that under such circumstances CCTV would enable the flight crew to make an assessment of damage.

4.2.7 *Ice, snow accretion on airframe, engines [*7]*

There have been many recorded incidents attributed to ice and snow on the airframe and engines. There are two significant points of interest:

- Ice related incidents are prevalent during the take-off phase and, not surprisingly, occur in the winter months of the northern hemisphere.
- There seems to be some indication that, particularly for jet aircraft, ice-related problems have been prevalent to the F28, DC9/MD–80 aircraft types. This would suggest that the aerodynamic performance of these aircraft may be particularly sensitive to the formation of ice.

National regulations, in one form or another, specify restrictions or limitations on aircraft taking off when frost, ice or snow is adhering to the wings, control surfaces, propellers, engine inlet or other critical surfaces of the aircraft.

If the hypothesis is put forward that CCTV would have changed the course of events then this must be based on the following assumptions:

- CCTV would be used within the pre take-off check list to check that there was no frost, ice and snow adhering to the aircraft structure.
- CCTV would be capable of picking up ice and snow under low visibility conditions – possibly by thermal imagery.

Alternative ice detection systems are presently available, or under development, and therefore the possible use of CCTV should be seen as a potential additional source of information to the flight crew on ice formation.

4.2.8 *In-flight fire/smoke [*8]*

There have been a number of incidents in which the visual information provided by CCTV may have changed the course of events or at least alleviated damage and/or injury. It should be said that this could apply to both internal and external CCTV. The most significant of these incidents will be discussed in Section 6.

In addition, there have also been a number of other incidents in which CCTV may have provided diagnostic information to the flight crew.

Within this group, incidents have included engine fire, passenger evacuation, landing gear and undercarriage fire.

4.2.9 *Lightning strike [*9]*

There is little evidence that CCTV would have changed the course of events. In any case, it is quite probable that any CCTV system would be knocked out by a lightning strike on the aircraft.

However, in the event that the CCTV system would still be functioning, then diagnostic visual information of damage could be available to the flight crew.

The list of incidents indicates that lightning strike has caused damage to landing gear, wings, flaps, leading edge, tail, rudder, elevator and fuselage. Radome damage could not be picked up by a CCTV system.

4.2.10 *Power plant disruption [*10]*

There have been a number of incidents in which the availability of CCTV may have changed the course of events and many other incidents in which CCTV may have been useful for diagnostic purposes.

Within this group, incidents have included engine fire, engine separation, damage to the wing, undercarriage/landing gear and fuselage.

4.2.11 *Overrunning of runway [*11]*

A small number of incidents were identified in which the use of CCTV may have either influenced the course of events or have been useful for diagnostic purposes.

The point to be made is that CCTV is unlikely to prevent the initial incident. This may be caused by one of:

- pre touch-down mechanical failure
- climatic and runway conditions
- post-flare mechanical failure.

Where CCTV would probably be most useful is to provide an aid by which a situation may be diagnosed in the post-incident scenario. For example if an aircraft catches fire then, ideally, the selected emergency evacuation routes used should avoid the fire if possible.

The overrunning of a runway is linked to a number of causal factors which have been covered by other incident types.

4.2.12 *Third party (ground manoeuvres etc) [*12]*

This incident type was classified in the WAAS as third party (but including ground manoeuvres). Analysis of the incidents showed that these could either be re-classified as other incident types or the incident could be re-classified as ground manoeuvres.

This reinforces a point that has been already made, that is, the lack of visibility of almost all the aircraft structure from the cockpit.

4.2.13 *Tyre burst [*13]*

On the basis of the incidents examined, there appears to be no significant evidence that the installation of CCTV would have changed the course of events.

It would appear, however, that there are potential benefits in the installation of CCTV within, or adjacent to, the undercarriage bays to enable the flight crew to make damage assessment.

5 DETAILED ANALYSIS OF ACCIDENTS

5.1 Introduction

At this stage of the study it was considered appropriate to attempt a classification of potential benefits that is wider than that used so far. Our initial classification was:

A Prevent accident (check list process)

B Reduce effects of incident or accident (additional knowledge)

C Aid to air accident investigation.

This limited classification proved to be useful in the initial analysis of accidents but, as soon as different types of accident were examined more closely, it became apparent that a more detailed break-down would be helpful.

It is clear that the original 'A' could be subdivided and that there might sometimes be an overlap with 'B'. For example, use of the appropriate check list which included looking at the aircraft exterior might show that a significant piece of the flap was missing, sufficient to cause an accident due to asymmetrical control difficulties at normal approach speeds. This knowledge should alert the crew to take appropriate action, such as approaching and landing at a higher speed and perhaps with a more appropriate flap setting. Such an event could be interpreted as a class 'A' benefit since an accident has been prevented or as class 'B' because additional knowledge has prevented an incident from becoming an accident, ie the effect of the incident has been reduced.

The proposed new classification would put such an event firmly into class 'A' but perhaps as an 'A2', leaving 'A1' for avoidance of the original damage to the flaps if, for example, this were achieved by noticing an obstruction on or close to the taxi-way and stopping in time.

Under this system if the aircraft were to land short, either out of control or fast, damaging an engine or fuel line with a subsequent fire, then the view of the aircraft exterior, showing the otherwise out of sight fire, could help the crew to decide where and how to stop and evacuate the passengers. Any potential reduction in aircraft damage on the number of casualties remains a class 'B' benefit.

Since any exterior view of the aircraft during the above event, at whatever stage it reached, would be of use to the accident investigation, a class 'C' benefit is to be expected in most cases.

The revised classification (based on a rationalisation of WAAS incident types), and used in the spreadsheet discussed later in this Section, is as follows:

A1 *Prevent accident*

- ground operations
- ice/snow deposition on aircraft surfaces
- high lift devices and control surfaces during take-off
- landing gear

A2 *Prevent incident or minor accident becoming a serious accident*

- power plant
- fuselage fire

B *Improve survivability*

- emergency evacuation from aircraft

C *As an aid to air accident investigation*

It was also agreed that, although there would be no attempt to decide whether or how any potential benefit might be realised in practice, it would nevertheless be useful to give an indication of the part or area of the aircraft that would need to be viewed for the potential benefit to be even possible. The camera or cameras may therefore be considered as an extra pair of eyes, coupled with a perfect memory, that may be consulted either during or after an 'event'.

The final review of the accidents considered most relevant to this study has resulted in the development of a data-base which is reproduced in Table 2 as a spreadsheet. The next section of this report will discuss the spreadsheet indicators. Many of these are self-evident. However, a deliberate attempt has been made to reduce the number of key words as this will help to rationalise the discussion on CCTV location and purpose.

5.2 Spreadsheet indicators [Refer Table 2]

(a) *Aircraft type [AIRCRAFT]*

Passenger carrying capacity of 30 passengers (or equivalent in freight).

(b) *Date of accident [DATE]*

Data from 1976 to 1992 have been examined in detail.

Table 2 Spreadsheet of accident indicators and the potential application of CCTV

	AIRCRAFT	DATE	LOCATION	P	F	I	D	TYPE	FACTORS	A1	A2	B	C	VIEW	O	L	AXIS
1	BRITANNIA	1976	LUTON	0	0	1	1	GROUND OPERATIONS	Collision with ground equipment	3	0	0	0	ENGINE	F	F	UR
2	DC9	1976	VANCOUVER	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
3	DC8	1977	ANCHORAGE	1	5	0	3	CLIMATE	Ice on airframe	1	0	0	1	WING	R	F	STF
4	B747	1977	HONOLULU	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
5	DC9	1978	NEWARK	1	0	0	1	CLIMATE	Ice on wing	1	0	0	1	WING	R	F	STF
6	B737	1978	HYDERABAD	1	4	15	3	CONTROL SYSTEM	Leading edge not configured	2	0	0	1	WING	R	F	SF
7	A300	1978	MIAMI	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
8	NORD262	1979	CLARKSBURG	1	2	8	3	CLIMATE	Snow on wing	2	0	0	1	WING	R	F	SF
9	L1011	1979	ATLANTA	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
10	DC8	1979	MIAMI	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
11	A300	1979	DUSSELDORF	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
12	BRITANNIA	1980	BILLERICA	1	7	1	3	CLIMATE	Ice and snow on airframe	2	0	0	1	WING	R	F	SF
13	DC10	1980	NEWARK	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
14	A300	1981	MIAMI	0	1	0	0	GROUND OPERATIONS	Ground crew / nose-gear door	3	0	0	0	UNDERCARRIAGE	F	F	UR
15	DC10	1981	MIAMI	0	1	0	0	GROUND OPERATIONS	Pushback / ramp worker	3	0	0	0	UNDERCARRIAGE	F	F	UR
16	B707	1981	ST. LOUIS	0	0	1	0	GROUND OPERATIONS	Ground crew / landing-gear door	3	0	0	0	UNDERCARRIAGE	F	F	UR
17	B737	1982	WASHINGTON	1	78	5	3	CLIMATE	Snow / ice on airfoil surface	2	0	0	1	WING	R	F	SF
18	A300	1982	CASABLANCA	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
19	B737	1983	PHOENIX	0	0	1	0	GROUND OPERATIONS	Jet blast	3	0	0	0	ENGINES	F	F	UR
20	B747	1983	KUALA LUMPUR	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
21	B727	1984	GENEVA	0	0	1	0	GROUND OPERATIONS	Jet blast	3	0	0	0	ENGINE	F	F	UR
22	DC9	1985	PHILADELPHIA	1	0	2	3	CLIMATE	Ice on wing	1	0	0	1	WING	R	F	SF
23	DHC6	1985	ALASKA	1	0	2	2	CLIMATE	Ice on leading edge	1	0	0	1	WING	R	F	SF
24	B737	1985	MANCHESTER	1	55	15	3	ENGINE FIRE	Evacuation / fire	0	0	2	1	FUSELAGE	F	F	SR
25	DC8	1985	GANDER	1	256	0	3	CLIMATE	Ice on wing	1	0	0	1	WING	R	F	STF
26	B747	1985	AMSTERDAM	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
27	B737	1986	HEATHROW	1	0	0	2	FIRE	Wheel well / evacuation	0	1	0	1	UNDERCARRIAGE	F	F	UR
28	DC7	1986	DAKAR	1	3	1	3	ENGINE FIRE	Incorrect diagnosis	0	1	0	1	ENGINE	F	F	SR
29	METRO	1986	SANTA BARBARA	3	0	1	2	LANDING GEAR	Warning horn disarmed	2	0	0	0	UNDERCARRIAGE	F	F	UR
30	L1011	1986	HEATHROW	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
31	CARAVELLE	1987	STOCKHOLM	1	0	0	3	CLIMATE	Ice / snow on stabilizer	2	0	0	1	STABILIZER	R	F	TF
32	DC9	1987	DETROIT	1	156	2	3	CONTROL SYSTEM	Flaps / slats not configured	2	0	0	1	FLAPS	R	F	SF
33	DC9	1987	DENVER	1	28	28	3	CLIMATE	Ice on wing	1	0	0	1	WING	R	F	STF
34	BEECH	1987	ALASKA	3	18	3	3	CLIMATE	Ice on leading edge	1	0	0	1	WING	R	F	SF
35	B727	1988	SARASOTA	0	0	1	0	GROUND OPERATIONS	Refueller / slat retraction	3	0	0	0	WING	F	F	UR
36	B727	1988	DALLAS	1	14	26	3	CONTROL SYSTEM	Flaps / slats not configured	2	0	0	1	WING	R	F	SF
37	B737	1988	TULSA	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
38	B737	1989	EAST MIDLANDS	2	47	74	3	ENGINE FIRE	Incorrect diagnosis	0	2	0	1	ENGINE	F	F	SR
39	F28	1989	DRYDEN	1	24	19	3	CLIMATE	Ice on wing	1	0	0	0	WING	R	F	SF
40	A300	1989	SAN JUAN	0	1	0	0	GROUND OPERATIONS	Pushback / ramp worker	3	0	0	0	UNDERCARRIAGE	F	F	UR
41	B767	1989	CHICAGO	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
42	F28	1989	KIMPO	1	0	6	3	CLIMATE	Ice on wing	1	0	0	1	WING	R	F	STF
43	DC9	1989	ORLANDO	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
44	B727	1990	INDIANAPOLIS	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
45	DHC7	1990	HEATHROW	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
46	B757	1990	GLASGOW	0	0	1	0	GROUND OPERATIONS	Pushback / groundcrew	3	0	0	0	UNDERCARRIAGE	F	F	UR
47	DC10	1990	MEMPHIS	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
48	B767	1990	MELBOURNE	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
49	BAe146	1990	CHRISTCHURCH	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
50	SA226	1990	IDAHO	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
51	B747	1990	GATWICK	3	0	0	2	ENGINE FIRE	Diagnosis / status	0	1	1	1	ENGINE	F	F	SUF
52	B757	1991	MANCHESTER	0	0	0	2	GROUND OPERATIONS	Collision / structure	2	0	0	0	STABILIZER	F	T	TF
53	CITATION	1991	HATFIELD	3	0	0	2	LANDING GEAR	Warning horn inoperable	2	0	0	0	UNDERCARRIAGE	F	F	UR
54	DC9	1991	CLEVELAND	1	2	0	3	CLIMATE	Ice on wing	1	0	0	1	WING	R	F	SF
55	B727	1991	TAEGU	3	0	0	2	LANDING GEAR	Incorrect GPWS	2	0	0	0	UNDERCARRIAGE	F	F	UR
56	DC8	1991	JEDDAH	1	261	0	3	FIRE	Burst tyre / landing gear bay	0	1	0	1	UNDERCARRIAGE	F	F	UR
57	MD80-B737	1991	NEWARK	0	0	2	2	GROUND OPERATIONS	Collision / other aircraft	2	0	0	0	WING	F	T	TF
58	A300	1991	MADINAH	0	1	0	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
59	B737	1991	ALBUQUERQUE	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
60	B727	1991	ONTARIO	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
61	MD80	1991	COPENHAGEN	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
62	MD80	1991	STOCKHOLM	1	0	8	3	CLIMATE	Ice ingestion by engines	1	0	0	1	WING	R	F	SF
63	B757	1992	PHOENIX	0	0	1	0	GROUND OPERATIONS	Pushback / ramp worker	3	0	0	0	UNDERCARRIAGE	F	F	UR
64	F28	1992	NEW YORK	1	27	24	3	CLIMATE	Ice / snow on wings	2	0	0	1	WING	R	F	SF
65	B757	1992	HAYDEN	0	0	1	0	GROUND OPERATIONS	Pushback / ground crew	3	0	0	0	UNDERCARRIAGE	F	F	UR
66	B737	1992	HEATHROW	0	0	1	0	ENGINE FIRE	Evacuation / incorrect warning	0	1	0	1	ENGINE	F	F	STR
67	L1011	1992	NEW YORK	1	0	1	3	FIRE	Evacuation / visibility	0	1	1	1	UNDERCARRIAGE	F	F	UR

(c) *Location of incident/accident [LOCATION]*

Note that a majority of incidents and accidents occur in North America and Europe. This is probably due to a number of factors:

- traffic levels
- climate
- data sources readily available

(d) *Flight phase [P]*

The following indicators have been adopted:

'0' Ground operations

'1' Take-off/climb out

'2' En-route

'3' Final approach/landing

(e) *Fatalities [F]*

As recorded in the WAAS

(f) *Serious injuries [I]*

As recorded in the WAAS

(g) *Damage to aircraft [D]*

The following indicators have been adopted, based on those used in the WAAS:

'0' None

'1' Minor

'2' Substantial

'3' Destroyed

(h) *Incident type [TYPE]*

The key words below have been selected on the basis of the review of accidents listed in the WAAS and which were selected for further analysis.

- CLIMATE
- COLLISION
- CONTROL SYSTEM
- ENGINE (or other) FIRE
- GROUND OPERATIONS
- LANDING GEAR

(i) *Causal factors [FACTORS]*

Linked to indicator *'TYPE'* above, the causal factors indicate the aspect of the incident or accident to which the potential benefits of CCTV are particularly related.

(j) *Indicator 'A1', prevention of accident [A1]*

The following indicators have been used:

'0' Most unlikely

'1' Possible but improbable

'2' Probable

'3' Highly likely

(k) *Indicator 'A2', prevent incident becoming accident [A2]*

Refer to 'j' above for the indicators.

(l) *Indicator 'B', improve survivability [B]*

Refer to 'j' above for the indicators.

(m) *Indicator 'C', aid to aircraft accident investigation [C]*

Refer to 'j' above for the indicators.

(n) This indicator *[VIEW]* shows the major component of the aircraft structure which would have to be viewed by CCTV if the hypothesis were to be adopted that the presence and use of CCTV would either have been preventive, an aid to survivability or an aid to aircraft accident investigation.

As the result of the initial analysis and review of individual accidents it has been decided to limit the number of components which could most usefully be viewed to one of the following:

- ENGINE(S)
- FLAPS
- FUSELAGE
- STABILISER
- UNDERCARRIAGE
- WING

(o) This indicator [O] shows the direction in which the CCTV would have to be orientated in order to view the aircraft component described in the previous indicator. No assumptions have been made on any limitations to the angle of view of the camera. Therefore, only the following indicators have been considered:

'F' Forward facing

'R' Rear facing

(p) The next pair of indicators show the location of the CCTV in order to view the aircraft component described in *[VIEW]* above. Again, no assumptions have been made on any limitations to the angle of view of the camera. These indicators (as was the previous indicator) are sensitive to the design and layout of the aircraft, in particular the location of engines.

The first indicator *[L]* is based on the camera location on the aircraft structure. Three indications have been considered:

'F' Fuselage

'T' Tailplane

'W' Wing

The second indicator *[AXIS]* is based on geometric orientation and the following indications have been considered:

'F' Front

'R' Rear

'S' Side

'T' Top

'U' Underneath

5.3 Discussion

5.3.1 *'A1', accident prevention*

CCTV is considered to have potential safety benefits for four categories of accident type. These are discussed below.

(a) *Ground operations.* A significant number of accidents have occurred resulting in death or injury to ground crew and others. Other incidents include collision with other aircraft and airport structures. This problem may get worse with airports becoming more crowded and the introduction of larger aircraft in the future.

From Table 2, the following accidents have been identified as being caused by some form of communications breakdown during ground operations in which CCTV may have a potential safety benefit. Note that 'No.' refers to the chronological listing of the accident (on an annual basis) in table 2.

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'A1'*
1	1976	Luton	0	1	Minor	3
2	1976	Vancouver	0	1	None	3
4	1977	Honolulu	1	0	None	3
7	1978	Miami	1	0	None	3
9	1979	Atlanta	1	0	None	3
10	1979	Miami	1	0	None	3
11	1979	Dusseldorf	1	0	None	3
13	1980	Newark	0	1	None	3
14	1981	Miami	1	0	None	3
15	1981	Miami	1	0	None	3
16	1981	St. Louis	0	1	None	3
18	1982	Casablanca	0	1	None	3
19	1983	Phoenix	0	1	None	3
20	1983	Kuala Lumpur	0	1	None	3
21	1984	Geneva	0	1	None	3
26	1985	Amsterdam	0	1	None	3
30	1986	Heathrow	0	1	None	3
35	1988	Sarasota	0	1	None	3
37	1988	Tulsa	0	1	None	3
40	1989	San Juan	1	0	None	3
41	1989	Chicago	0	1	None	3
43	1989	Orlando	1	0	None	3
44	1990	Indianapolis	1	0	None	3
45	1990	Heathrow	1	0	None	3
46	1990	Glasgow	0	1	None	3
47	1990	Memphis	0	1	None	3
48	1990	Melbourne	0	1	None	3
49	1990	Christchurch	0	1	None	3
50	1990	Idaho	1	0	None	3
52	1991	Manchester	0	0	Substantial	2
57	1991	Newark	0	2	Substantial	2
58	1991	Madinah	1	0	None	3
59	1991	Albuquerque	0	1	None	3
60	1991	Ontario	0	1	None	3
62	1991	Copenhagen	0	1	None	3
63	1992	Phoenix	0	1	None	3
65	1992	Hayden	0	1	None	3
TOTAL			13	24		

Individual ground operation accidents involving ground crew, ramp workers etc result in 'almost' a single figure fatality or injury but little or no damage to the aircraft. The two cases in which substantial damage to the aircraft occurred were as the result of collision with either another aircraft or ground structures.

(b) *Ice/snow deposition on aircraft surfaces.* Icing has been recognised as the cause of a significant number of accidents although certain aircraft types seem to be particularly susceptible.

The United States National Transportation Safety Board have recently identified 15 major air carrier accidents in the last 23 years which were attributable to failure to de-ice and/or anti-ice the aircraft adequately before take-off.

In response to these accidents the FAA have issued an interim regulation that requires specified aircraft operators to either have an approved de-icing/anti-icing programme, or perform a pre take-off contamination check from *outside* the aircraft not more than five minutes prior to take-off.

From Table 2, the following accidents have been identified as being caused by ice or snow contamination:

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'A1'*
3	1977	Anchorage	5	0	Destroyed	1
5	1978	Newark	0	0	Minor	1
8	1979	Clarksburg	2	8	Destroyed	2
12	1980	Billerica	7	1	Destroyed	2
17	1982	Washington	78	5	Destroyed	2
22	1985	Philadephia	0	2	Destroyed	1
23	1985	Alaska	0	2	Substantial	1
25	1985	Gander	256	0	Destroyed	1
31	1987	Stockholm	0	0	Destroyed	2
33	1987	Denver	28	28	Destroyed	1
34	1987	Alaska	18	3	Destroyed	1
39	1989	Dryden	24	19	Destroyed	1
42	1989	Kimpo	0	6	Destroyed	1
54	1991	Cleveland	2	0	Destroyed	1
62	1991	Stockholm	0	8	Destroyed	1
64	1992	New York	27	24	Destroyed	2
TOTAL			447	106		

Accidents due to icing and/or snow have nearly always resulted in both loss of life and injury in addition to complete destruction of the aircraft. The financial implications of such accidents on the air transport industry, whether operators or insurers, are such that if these accidents can be prevented then the potential benefits may well outweigh the costs.

Inclusion of these accidents is conditional on the hypothesis set out in Section 4.2.7. That is, firstly there would be an appropriate procedure in which CCTV were used as a check for the presence of ice and snow. Secondly, that CCTV technology would be available to distinguish the presence of ice and snow, in particular, on wing surfaces.

(c) *High lift devices and control surfaces during take-off.* A few accidents have occurred due to the incorrect configuration of flaps and/or leading edges. In most cases there was a failure of the primary information system and therefore the installation of CCTV would be on the basis that information would be provided which was already available, in theory, to the flight crew.

From Table 2 the following accidents have been identified:

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'A1'*
6	1978	Hyderabad	4	15	Destroyed	2
32	1987	Detroit	156	2	Destroyed	2
36	1988	Dallas	14	26	Destroyed	2
TOTAL			174	43		

In the first accident, the cause was attributed to the non-availability of leading edge devices. In the second accident, the cause was attributed to improper configuration of the flaps and slats for take-off. In addition, a known causal factor was *'the absence of electrical power to the aircraft take-off warning system'*.

In the Dallas accident, similar to Detroit, take-off was attempted without the wing flaps and slats properly configured and *'the failure of the take-off configuration warning system to alert the crew that the airplane was not properly configured for the take-off'*.

(d) *Landing gear.* Perhaps surprisingly, some accidents have been recorded where aircraft have landed with the landing gear up. Similar to high lift devices and control surfaces, the accidents have occurred as a result of the failure or lack of primary information systems. The safety benefit of CCTV would, again, be to supplement information already available in another form.

From Table 2 the following accidents have been identified:

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'A1'*
29	1986	Santa Barbara	0	1	Substantial	2
53	1991	Hatfield	0	0	Substantial	2
55	1991	Teugu	0	0	Substantial	2
TOTAL			0	1		

Accidents with landing gear up have not proved to be serious in terms of loss of life and injury. The damage to the aircraft structure has been classified as substantial; this assumes that the aircraft is repairable. There is no obvious pattern as to why this type of accident should occur but the following extracts from the WAAS summaries serve to give an indication as to where the primary information systems or procedures failed on these occasions:

- *'landing gear warning horn disarmed/silenced'*
- *'failed to check gear-down command complied with'*
- *'forgot to lower the gear'*
- *'GPWS circuit breaker pulled after landing gear warning'*

5.3.2 *'A2', prevention of incident becoming an accident*

The following incident types have been identified on the basis that CCTV may have reduced the chances of the initial incident developing into the eventual accident:

(a) *Power plant.* This includes engine separation and/or fire. For example, an incident may start with an engine fire warning. There may be uncertainty as to which, if any, engine is on fire. A spurious fire warning or other flight deck indicators may induce the flight crew into commencing an inappropriate set of control actions. Alternatively, engine separation may not be initially apparent, again, with inappropriate control actions on the part of the flight crew.

From Table 2 the following accidents have been examined

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'A2'*
28	1986	Dakar	3	1	Destroyed	1
38	1989	East Midlands	47	74	Destroyed	2
51	1990	Gatwick	0	0	Substantial	1
67	1992	New York	0	1	Destroyed	1
TOTAL			50	76		

The above accidents were, with the exception of Gatwick, catastrophic both in terms of human loss and hull destruction. The common link is that an initial problem with the power plant was the first step in a chain of events.

The Dakar incident, although featuring a turboprop, is a simple example of smoke seen from one engine, a fire alarm but no fire from another engine with the result that the wrong engine was shut down and the aircraft crashed.

Two years later almost the same sequence of events occurred with an almost new B737–400 but with far more tragic results. The accident near East Midlands airport has been well documented (AAIB AAR 4/90). However, the following extract from the WAAS emphasises the potential benefit of a suitably located CCTV system; ...*'they* (the flight crew) *were not informed of the flames which had emanated from the No. 1 engine and which had been observed by many on board'...*

The Gatwick incident, in which tailpipe fires were observed on all three engines, resulted in a safety recommendation being repeated (source: WAAS) concerning the provision of outside viewing facilities from the flight deck. To quote ...*'when the Gatwick Ground Controller first noticed and informed the aircraft of an engine fire he initiated an Aircraft Ground Incident and the fire and rescue services were alerted. The flight deck crew could see no signs of fire and had no fire warning indications except the over-temperature exhaust gas warning lights on Nos 2, 3 and 4 engines'...* No. 4 engine was shut down initially, Nos 2 and 3 were shut down after ... *'the commander had received further information of the situation from outside the aircraft'*... Lastly, ... *'with no evidence of fire visible from the flight deck, the commander had to rely on information from outside sources'*... the above extracts are reproduced from AAIB Bulletin 11/90.

Interest in the last accident (New York) comes from a safety recommendation by the National Transportation Safety Board from which the following extracts are reproduced:

... *'the flight attendant who was responsible for the L–2 emergency exit was unable to assess conditions outside the exit using the exit door's prismatic window because the window's outside pane was either scratched or crazed'*...

... *'the Safety Board believes that door windows must be properly maintained in order to provide flight attendants the best possible view of the exterior of the airplane through the door......if window panes are scratched or crazed, flight attendants may not accurately assess the conditions outside a door'*....

In the above example, a case could be made for an alternative means of establishing external conditions before opening cabin doors under declared emergency evacuation conditions.

(b) *Fuselage Fire.* Fire in the cargo hold and the landing gear bay have resulted in a number of major incidents. Although the use of internal viewing cameras is not within the remit of this study it is appropriate to note cargo hold fires as being examples where the availability of CCTV may have prevented the chain of events continuing.

Often, the first indication of an incident has been smoke in the passenger cabin and/or cockpit. It is suggested that, along with other measures, suitable CCTV may have given more advanced warning and thus allowed more time for alternative options of action by the flight crew to be considered. The following accidents have been identified from Table 2:

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'A2'*
27	1986	Heathrow	0	0	Substantial	1
56	1991	Jeddah	261	0	Destroyed	1
TOTAL			261	0		

The Heathrow incident was a fire in the wheel well. The appropriate fire warning system was activated but, almost immediately and perhaps fortuitously, the aircraft behind transmitted the warning that smoke and flames were visible. The Jeddah accident showed some similarity, again with a fire in the wheel well (attributed to a burst tyre) but in this case there was no possibility of a fire warning from a third party source.

5.3.3 *'B', improve survivability*

The comments made in Section 5.3.2 are equally applicable to indicator 'B' which is related to the safe evacuation of passengers from aircraft.

Emergency evacuation from aircraft. CCTV can be used as part of a two stage process. Firstly, to determine the need for emergency evacuation (spurious indications of engine fire, for example). Secondly, if so then CCTV may be used to ensure that evacuation can proceed in such a way as to minimise the chances of injury. The following accidents have been examined:

No.	*Date*	*Location*	*Fat.*	*Inj.*	*Damage*	*'B'*
24	1985	Manchester	55	15	Destroyed	2
51	1990	Gatwick	0	0	Substantial	1
67	1992	New York	0	1	Destroyed	1
TOTAL			55	16		

The B737 at Manchester suffered an uncontainable failure of the engine with resultant fire. Initial diagnosis was either a tyre-burst or bird strike. Confirmation of the fire came several seconds later after confirmation from Air Traffic Control. In this example, the availability of CCTV would possibly have enabled an earlier diagnosis of the initial incident to be made and also assisted in the passenger evacuation process (on the basis of procedures outlined in Section 6.4). Under the circumstances, substantial damage to the aircraft would still have occurred but a substantial reduction in the number of fatalities and injuries might have occurred.

The Gatwick and New York accidents are included, although discussed in Section 5.3.2, because the flight and cabin crew experienced difficulty in ascertaining what was happening outside of the aircraft when the circumstances suggested that an emergency evacuation would be a prudent course to follow. Fortunately, on these two occasions, there were few injuries.

5.3.4 *'C', as an aid to accident investigation*

CCTV could be a potential aid to the accident investigator but an unresolved question is whether a specific CCTV system should be set up for this purpose only or use be made of a CCTV system that might be set up for, say, the monitoring of ice formation or ground operations. In terms of the 'C' ranking, CCTV has not been considered as an potential aid to accidents involving ground operations (where there are usually witnesses) and landing gear.

6 INSTALLATION OF CCTV

6.1 Views of the aircraft structure

It would not be practical to have a multitude of CCTV systems on each aircraft. Selectivity is necessary to limit the number of cameras that could usefully be installed on each aircraft.

Two major parts of the aircraft structure have initially been identified. Firstly, the area beneath the fuselage is blind both from the flight deck and the passenger cabin. there have been many incidents linked to both undercarriage problems and ground operations. Therefore, underneath the aircraft fuselage is the most appropriate location for an extra (one or more) 'pair of eyes'.

Secondly, in terms of incidents/accidents, the other critical component of the aircraft structure is the wing and, for most modern jets, the engines. The two components could be viewed together for the majority of aircraft types where the engine is mounted beneath the wing.

6.2 Location

CCTV location at this level of analysis has been examined in very general terms and is very dependent on aircraft geometry. The following parameters have been considered:

- the direction of camera view, either forward or rearward.
- the location on the aircraft structure; consideration has been limited to fuselage (in the vast majority of cases), wing and tailplane.
- the location relative to the fuselage cross-section, side, top or underneath, (alternatively, the top of the tail-fin).
- no attempt has been made to quantify the number of cameras required.

Some basic patterns, in terms of direction of camera view, have been established. For ground operations and views of the landing gear, a forward facing camera mounted below the aircraft belly (and located towards the rear of the aircraft) would possibly suffice.

To view ice build-up on wing surfaces and a forward view of the engines then, on each side of the fuselage, this would require a rear facing camera mounted at about the sill level of the forward door (except for high wing aircraft).

To view the rear of the (wing-mounted) engines would require a forward facing camera, mounted at a similar level and located towards the rear of the aircraft (again one on each side of the aircraft).

Tail-mounted engined aircraft (now declining in numbers) would require a different camera location; views of such engines by CCTV would be difficult to achieve.

6.3 Camera characteristics

The use of CCTV has been based on the assumption that the appropriate camera technology will be available to fulfil the perceived requirements of the camera.

Any installed CCTV system must be capable of operating 24 hours a day, therefore, day and night and all climatic conditions, including within cloud.

The camera view has been defined as either rear or forward facing. In addition to the general orientation of the camera, the view from the camera should encompass as much of the aircraft structure as possible. However, a balance has to be struck between image detail, distortion, perspective and field of view. This is a compromise that would have to be tested in the field and under different lighting conditions.

The hypothesis has been postulated in Section 4.2.7 that CCTV could be used to 'view' ice formation on the wing structure and, in particular, the rubber de-icing boots for turboprops. In this example, de-icing equipment is switched on depending on how thick the ice layer is judged to be. Under many light conditions ice layers are all but invisible to the naked eye. CCTV could possibly differentiate between the ice layer and the bare wing metal possible by comparing ice/non-ice profiles or surface temperature differences between bare metal and ice-covered surfaces.

6.4 Procedures

This section will deal briefly with specific aircraft operation procedures involving the use of CCTV.

Six procedure types have been identified as being most appropriate to be used with CCTV. Five of these are preventive, one diagnostic. These are summarised as follows:

- Use before push-back or commencement of other ground manoeuvres [Section 5.3.1 (a)].
- Use as a pre take-off check to confirm absence of ice, correct configuration of control surfaces [Section 5.3.1 (b)].
- Use to confirm configuration of high lift devices and control surfaces [Section 5.3.1 (c)]
- Use to confirm undercarriage status at take-off and landing [Section 5.3.1 (d)].
- Use for diagnostic purposes, for example, engine problems [Section 5.3.2 (a), (b)].
- Use in the event of aircraft emergency evacuation with possible selective use of escape chutes due to external factors [Section 5.3.3]. Note that in the Manchester accident the CCTV system would have had to be activated automatically in the event of an aborted take-off; this would require a link to the aircraft flight management system.

7 SUMMARY AND CONCLUSIONS

An evaluation has been made of the potential benefits of CCTV with reference to reported aircraft incidents and accidents that have occurred since 1977.

Specific scenarios of aircraft operation have been selected on the basis of incident frequency and the applicability of CCTV. For each scenario a number of incidents and accidents have been examined. Each of these have been assessed based on a judgement of the likelihood that CCTV would provide a safety benefit.

Rather than concentrate on individual accidents in great detail (although all selected incidents and accidents are documented in the spreadsheet) this report has highlighted the specific areas of aircraft operation in which CCTV appears, in conjunction with current warning systems, to have the potential to prevent accidents or reduce the level of injuries and fatalities.

The safety of ground operations would benefit from the availability of CCTV. Typical incidents usually result in a single fatality or injury and slight (if any) damage to the aircraft.

Accidents resulting from ice accumulation on the airframe have resulted in fatalities, injuries and the complete destruction of the aircraft. Although the technical practicality of using CCTV is very uncertain, and other techniques for ice detection are available, the potential safety benefits are significant.

A number of incidents have occurred in which the landing gear has not been extended prior to landing or high lift devices not configured correctly prior to take-off. A revision to the appropriate procedures to include the use of CCTV as a supplementary source of information may be worth considering.

A potential safety benefit of CCTV is to provide diagnostic information to the flight crew that would prevent an incident developing into an accident. A typical incident can include engine failure, fire or separation. The mishandling of such incidents has resulted in major accidents with loss of life, injury and aircraft destruction. One example (Kegworth) has indicated that CCTV might have changed the course of events.

Another potential benefit of CCTV is as an aid during emergency evacuation from an aircraft in the post accident phase. Again, one example (Manchester) has highlighted the possibility that CCTV could have prevented an initial incident developing into a major accident. Other incidents have occurred where the crew were uncertain of external conditions when there was a possible need for emergency evacuation.

In order to achieve the benefits identified above it is essential that the use of CCTV can be properly integrated into operating procedures.

There is less evidence that CCTV would have been a potential aid to the accident investigator in previous accidents although, again, CCTV could act as a supplementary source of information.