AIRCRAFT ACCIDENT REPORT 5/83

Accidents Investigation Branch

Department of Transport

Report on the accident to BAe HS 748 G-ASPL at Nailstone, Leicestershire on 26 June 1981

LONDON
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Department of Transport
Accidents Investigation Branch
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7 November 1983

The Rt Honourable Nicholas Ridley MP
Secretary of State for Transport

Sir

I have the honour to submit the report by Mr L S H Shaddick, an inspector of Accidents, on the circumstances of the accident to BAe HS 748 G–ASPL which occurred at Nailstone, Leicestershire on 26 June 1981.

I have the honour to be
Sir
Your obedient Servant

G C Wilkinson
Chief Inspector of Accidents

Accidents Investigation Branch

Civil Aircraft Accident Report No. 5/83
(EW/C755)

Owner and Operator:		Dan-Air Services Limited
Aircraft:	*Type:*	British Aerospace HS 748 series 2A
	Nationality:	British
	Registration:	G–ASPL
Place of Accident:		Nailstone, Leicestershire 52° 40'N 001° 22'W
Date and Time:		26 June 1981 at 1811 hrs
		All times in this report are GMT

Synopsis

The accident was notified to the Accidents Investigation Branch by the London Air Traffic Control Centre and the investigation was commenced the same day.

The aircraft was engaged on a mail carrying freight flight. During the initial descent in preparation for landing at its destination, the attendant in the cabin reported that the mechanical indicators on one of the cabin doors were showing an unlocked condition. Shortly afterwards the right hand rear door (baggage door) came open, detached from its hinge mountings and became lodged on the leading edge of the right horizontal tailplane. The aircraft became uncontrollable and went into an increasingly steep dive which terminated in several abrupt pitch oscillations. Both the mainplanes and the horizontal tailplanes were subjected to overstressing in upload which resulted in their detachment from the fuselage.

The report concludes that the accident was caused by the baggage door becoming lodged on the leading edge of the right tailplane after it had opened and detached in flight. This produced changes in the aerodynamic characteristics of the aircraft which rendered it uncontrollable resulting in overstressing of the wings and tailplane leading to an in-flight structural failure. A contributory factor was the mis-rigged state of the door operating mechanism which allowed the top and bottom pairs of claw catches to lose synchronisation. The failure of the door warning arrangements to give adequate warning of door safety was a further contributory factor.

1. Factual Information

1.1 History of the flight

The aircraft was operating Dan-Air Flight 240 and was flying from Gatwick to East Midlands Airport (Castle Donington) on the first leg of a night mail carrying flight. On board were two pilots plus an attendant in the cabin. (It was the airline's policy to carry an attendant, known as a Postal Assistant (P A), on mail flights. His duties are described in paragraph 1.5.3). The aircraft departed Gatwick at 1728 hrs and climbed under Air Traffic Control (ATC) instructions to flight level (FL) 100 which was its planned cruising flight level. The estimated time of arrival (ETA) at its destination was 1825 hrs.

The aircraft was equipped with a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR) and it was thus possible to follow the progress of the last 30 minutes of the flight in some detail, (for the three-dimentional plot see appendix C). There is no evidence of any untoward event in the first part of the flight and the crew performed their routine duties in a competent and conscientious manner. At 1739 hrs the co-pilot reported that the aircraft was serviceable when he passed the flight's details to the Company's ground control on their frequency.

At 1757 hrs the PA asked the two pilots whether they would like tea or coffee to drink. This is the first occasion on which the PA's voice is heard on the CVR and presumably it marks his arrival on the flight deck for a visit he was making from his normal seated position in the rear of the cabin. Two minutes later the aircraft left FL 100 having received clearance to descend to FL 60 in anticipation of its landing at Castle Donington. An analysis of the sounds on the CVR tape indicates that there was no adjustment in engine power at this time with the result that the indicated airspeed built up to 210 knots during the descent. At 1802 hrs the PA served the pilots their drinks, and 1 minute 38 seconds later the following conversation took place:

"PA	THE INDICATORS ON THE REAR PORT DOOR ARE SHOWING RED (1)
PI (Commander)	SHOWING RED (?)
PA	YEAH IT LOOKS AS IF THE IT LOOKS AS IF THE HANDLES (possibly 3 or 4 unintelligible words) ON IT ARE SHOWING RED NOT NORMAL

(1) The rear port door is commonly called the passenger door; the rear starboard door is known as the baggage door; the investigation established that the baggage door opened later in the flight.

PI	PASSENGER DOOR SORRY
PA	YEAH
PI	OH "

The clarity of the PA's voice on the recording while he was talking about the condition of the door is poor and some of the words he used could not be deciphered.

At the time the PA was reporting his observations to the commander the aircraft was still in the descent and flying at 210 knots. Shortly afterwards engine power was reduced and the aircraft levelled off temporarily while the speed was allowed to decrease to 140 knots. While this was happening the co-pilot made a comment about a "STRONG UPDRAUGHT" to which the commander replied "NO THE REAR PASSENGER DOOR . . . . . PORT PASSENGER DOOR'S SHOWING UNLOCKED". The Commander's comments and actions at this time show that he was very concerned about the security of the door and the effects of cabin pressurisation upon it. As a result he ordered the rate of cabin depressurisation, which was already taking place in preparation for the landing, to be increased. He also told the PA to remain in the front of the aircraft in case the door came off. It is clear that he hoped his actions would lessen the risk of this happening but at the same time he took the precaution of reducing speed to minimise any impact damage the door might inflict on the tailplane should it come free. At 1806 hrs the aircraft levelled off at FL 60 in accordance with its ATC clearance.

At 1808 hrs the aircraft was instructed by ATC to change to Castle Donington Approach on 119.65 MHz. Having established contact with Castle Donington, it was cleared to descend to 3,000 feet on QNH 1017 and given the latest aerodrome weather. Its speed at this time was 135 knots and the commander decreased engine power and established a descent while maintaining 150 knots. The background noises on the CVR tape changed at 1809:30 hrs as the aircraft was passing through 5,450 feet. The change was sudden and marked by a transient noise typical of a rapid cabin decompression which is consistent with one of the doors opening. (Subsequently it was established that the baggage door had come open in flight). The background noises then increased gradually in a way which corresponds to an increasing airspeed. A number of unusual sounds could also be heard including sounds of severe vibration. The recordings of both the FDR and the CVR continued for seventy seconds from the time the decompression occurred and it is presumed that their cessation coincided with the fuselage hitting the ground. A plot of the aircraft's flight path constructed from the evidence provided by the flight recorders indicates that the cabin decompression occurred when the aircraft was in the vicinity of Market Bosworth.

Comments made by the commander indicate that almost immediately after the decompression something very violent was happening to the aircraft and after only eleven seconds he asked the co-pilot to transmit a 'MAYDAY'. He also told the PA to strap himself in. In his distress message the co-pilot told the Castle Donington controller: "WE'D LIKE TO COME STRAIGHT IN WE'VE ER HAD A VIOLENT DEPRESSURISATION ER IT LOOKS AS THOUGH WE'VE LOST OUR BACK DOOR AND HAVING A SEVERE CONTROL PROBLEM". He was told to descend to 2,000 feet and to steer 360 degrees for a two mile final approach. He acknowledged this and in a broken transmission asked for the emergency services to stand by.

As soon as ATC received the distress message they alerted the aerodrome emergency services and also informed the police. Shortly afterwards the radar controller noticed that the aircraft was turning right beyond its assigned heading but although she called the aircraft on several occasions she received no reply and no further radio contact was made with it. When the aircraft disappeared off the controller's radar screen at a range of 8 miles south south west of the aerodrome she asked the crew of another aircraft which was in the area to make a search of its last known position. Approximately 3 minutes after the broadcast of the distress message, reports began to reach ATC from the police of an aircraft crash and when this was confirmed the aerial search was discontinued.

A large number of eye witnesses saw the final stages of the flight. The weather conditions were bright although there were occasional light showers. A large black cloud was in the vicinity and some witnesses saw the aircraft either coming out of the cloud or from behind it. The consensus of opinion indicates that the aircraft was lower than those normally going to Castle Donington and was also still losing altitude. It was oscillating both in pitch and roll. As it recovered from one fairly steep dive the aircraft momentarily banked almost vertically but opinion varied as to whether this was to the left or the right. As it regained a fairly level attitude both wings folded upwards almost simultaneously and detached from the fuselage. A number of other pieces of structure also separated from the main body of the aircraft. The wreckage was spread over several fields (see plan appendix D) in a position about one mile north east of the village of Nailstone. There were fierce fires in both wings which apparently started before they struck the ground but there was no evidence of fire in the fuselage. Several small pieces of plastic internal door trim together with a small cardboard box and a Dan-Air bar box tag were later recovered from a grass field approximately $2\frac{1}{4}$ miles south south west of the crash site and one mile north of Market Bosworth.

The FDR shows that the aircraft experienced a slight right yaw and a small pitch-up when the decompression occurred. It also assumed a bank angle of between 6° and 8° right wing down and after ten seconds began a gradual turn to the right which continued until the aircraft started to break up. After the decompression the aircraft maintained its height for 20 seconds and during this time the speed decayed to 140 knots. It then began to nose over into an increasingly steep dive and the speed built up to a peak of 230 knots. Twenty seven seconds before impact with the ground, there was a marked change in pitch which, over a 4 second period went from 8° nose-down to 24° nose-down with a momentary pause at 17½°. The aircraft then rapidly in 1½ seconds pitched up to 6° nose-down. This was the first of three pitch oscillations, the last of which began 9½ seconds before impact when in 5½ seconds the aircraft went from 16° nose-down to 34° nose-up. The CVR evidence indicates that the mainplanes detached seven seconds before the final impact of the fuselage with the ground which occurred at 1810:39 hrs.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	3	—	—
Serious	—	—	—
Minor/None	—	—	—

1.3 Damage to aircraft

Destroyed.

1.4 Other damage

Some damage to standing cereal crops.

1.5 Personnel information

1.5.1 Commander

Age:	36
Licence:	Airline Transport Pilot's Licence valid to 26 May 1986

Aircraft ratings:	Aircraft Part 1: Piper PA34, Comet Variants, BAe 748
Instrument rating:	Instrument rating valid to 17 December 1981
Last medical examination:	16 June 1981, Class 1 valid to 31 December 1981
Last certificate of test:	16 June 1981
Flying experience:	
Total flying hours:	8,418
Total flying hours on BAe 748:	1,393
Total flying hours in last 28 days:	34
Rest period prior to duty period which commenced at 1645 hrs on the day of the accident:	10 days

The commander was an authorised training captain on BAe 748 aircraft with Dan-Air.

1.5.2 Co-pilot

Age:	29
Licence:	Airline Transport Pilot's Licence valid to 28 February 1989
Aircraft ratings:	Aircraft Part 1: Piper PA23, BAe 748
Instrument rating:	Instrument rating valid to 22 May 1982
Last medical examination:	19 February 1981, Class 1 valid to 28 February 1982

Last certificate of test:	23 April 1981
Flying experience:	
Total flying hours:	5,611
Total flying hours on BAe 748:	1,711
Total flying hours in last 28 days:	38
Rest period prior to duty period which commenced at 1645 hrs on the day of the accident:	12 hours

1.5.3 Postal Assistant

A cabin attendant, known as a Postal Assistant (PA), was carried on all Post Office mail flights. His main duty was to monitor the cabin in case of fire, but he was also responsible for ensuring that the doors were shut and locked and he was expected to look after the loading and security of the freight. The PA's duties were set out in writing and included the following:- "8. Close doors and check door locks report closure to the Captain". His duty station was in the rear of the cabin where a seat was provided for his use. This was normally the rear-facing folding seat beside the baggage door but because G–ASPL carried a fixed forward-facing pair of passenger seats immediately in front of this, it is considered that the PA on the accident flight would have used one of these seats as his seated position in preference to the folding seat (see section 1.6.4).

The PA's were used solely on the mail flights and were employed by the airline on a temporary basis. Many of them were either attending university or waiting for their courses to begin. Their training consisted of one day in ground school covering safety equipment and procedures plus three days in ground school and static aircraft covering loadsheets, weight and balance, aircraft loading and equipment including practical demonstrations in the aircraft in the operation of the doors. Inflight training consisted of a minimum of two flights (total eight sectors) under supervision.

The PA on the accident flight, age 20, had been employed as such by the airline since February 1981. He was awaiting to attend university to study Aeronautical Engineering and Avionics. He satisfactorily completed his safety training course on 14 March 1981. Pilots with whom he had flown reported that he was keen and conscientious and carried out his duties in a capable manner.

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer:	A V Roe and Co Ltd, Manchester (latterly Hawker Siddeley Aviation Ltd, now British Aerospace, Manchester Division)
Type:	Manufactured as an HS 748 series 2 model 108. Subsequently converted to series 2A standard
Engines:	Rolls Royce Dart 533–2/534–2
Date of Manufacture:	1964
Previous operators:	1964 BKS Air Transport 1967 Skyways Coach-Air Ltd 1972 Dan-Air Skyways Ltd 1975 Dan-Air Services Ltd
Certificate of Airworthiness: (C of A)	UK Transport Category (Passenger) last renewed: 7 May 1981 valid to: 6 May 1982
Certificate of Maintenance:	issued: 28 April 1981 valid to: 24 September 1981, or until the aircraft had completed 34,732 hours, whichever was the sooner
Total airframe hours:	34,592
Maximum certified take-off weight:	20 182 Kg
Approximate weight at time of accident:	19 094 Kg
Centre of gravity (CG) range:	Index –5.1 to –26.7
Centre of gravity at time of accident:	Index –15.6

1.6.2 *Door description*

The BAe 748 is equipped with 3 doors (see appendix E for diagram of aircraft configuration). At the front of the cabin on the left hand side just rear of the flight deck is the crew/freight door. The other two doors are located at the rear of the cabin. On the left hand side is the passenger door and opposite to it on the right hand side is the baggage door. All three doors open outwards.

The baggage door, when open, is carried on its mid-point by an articulated hinge and held approximately parallel with the fuselage side by two parallelogram links. The door is secured in the closed position by four claw-type catches which act upon fretting pads on the inside of the door aperture. These catches have a geometry which causes the door to be drawn into the aperture during closure and then held in position by the overcentring action of links attached to the claws. In addition to the overcentring effect of the closure claws, their movement once the door is closed is prevented by the engagement of plungers, known as secondary locks, which prevent any further angular movement of the links attached to the primary lock claws. Thus, opening and closing of the door lock mechanism involves rotary movement of the primary claws and linear movement of the secondary plungers, the two motions being carried out in a controlled sequence. (The door operation is shown diagramatically in figures 3–6).

All baggage doors have an additional locking system which is known as the barometric lock. It consists of a barometric capsule which is connected to a static vent on the outer skin of the door. Whenever cabin differential pressure exceeds approximately 0.5 pounds per square inch (psi), collapse of the capsule moves a small lever into position above the top end of one of the secondary lock plungers. This prevents the secondary locks from disengaging and thus prevents a door opening sequence from starting. The lever may only move into place, however, if the secondary locks are fully engaged. Some baggage doors are fitted, in addition with a speed lock which engages when the aircraft's speed rises above 90 knots but this was not required to be fitted to the door on G–ASPL because of its internal lay-out.

On aircraft having the modification state of PL, the baggage door is fitted with two levers (handles) which can be used to operate the door mechanism. One lever is located on the inside of the door and the second one is positioned on the outside; the two handles, however, do not share the same pivot point. Opening of the door from inside involves movement of the handle away from the door and inwards to the cabin which withdraws the secondary locks, followed by downward-rotary movement which opens the primary claw catches. The correct sequencing of these operations during both opening and closing is controlled by a fixed cam under the inner handle. The profile of this cam controls the locus of movement of the handle

and thereby the relationship between in and out (secondary mechanism) and up and down rotary (primary lock mechanism) movement. There is normally a hinged transparent cover attached to the door trim which covers the inner handle when the door is closed.

The outer handle possesses only up and down rotary movement. When the outer handle is used to open the door, a lost-motion link arrangement ensures that secondary lock movement takes place before the primary lock motion begins. This secondary lock motion is transmitted from the shaft of the outside handle via a lever and cable to the secondary lock drive mechanism at the top of the door. During door closure using the external handle, rotation of the handle towards the closed position drives the primary claw mechanism to the 'claws overcentre' position. The final part of the handle motion slackens the cable which in turn allows the secondary plungers to move into the locked position under spring pressure.

The other two main doors on the aircraft are somewhat different in design to the baggage door. The passenger door opens outwards on an articulated hinge and is retained parallel to the fuselage side in a similar manner to the baggage door. It is, however, larger and is secured in the closed position by six claw catches and their associated secondary lock plungers. The crew freight door is attached at the top by two piano type hinges. It is also secured in the closed position by six claw catches and secondary locks similar to those used on the other two doors.

1.6.3 Doors locked indications and warning systems

a) 'Door unsafe' warning light

Aircraft which have the same modification state as G--ASPL are equipped with an electrical 'door unsafe' warning system which is designed to operate a single red warning light on the commander's instrument panel when any door is not closed and locked correctly. The light illuminates on the closing of a relay which is held in the open position when the door warning circuit is completed and energised.

The circuit includes nine micro-switches, three positioned on each door. In the case of the baggage door, one micro-switch is positioned on the bottom of the door and closes when the door is fully into its aperture. The other two switches are positioned on the lower ends of the bottom pair of secondary locking plungers. Hence any movement of the secondary lock plungers away from the locked position or any movement of the door out of its aperture will break the warning circuit allowing the relay to close and causing the warning light to illuminate. The three micro-switches in each of the other doors perform similar functions and because all the nine micro-switches are in series, the single warning light will only extinguish if all

three doors are closed and locked correctly. Any discontinuity in the main warning circuit which prevents current flowing will allow the relay to close and the warning light will remain on regardless of the positions of the doors and the door mechanisms. The warning light incorporates a 'press to test' facility to enable the functioning of the bulb filament to be checked.

(b) Mechanical indicators

It is not possible to see the secondary locking plungers on an in-service door. However, two mechanical indicators are positioned in the lower half of the baggage door. The bottom pair of secondary lock plungers are driven by rods and idlers from the two top secondary plungers and these rods revolve two indicator drums. The surface of each drum facing the inside of the aircraft is divided into a lower red section and an upper diagonally striped green/yellow section. The drums are set up in such a way that only the striped section is visible when the secondary lock mechanism is safely locked and the red section comes into view when the mechanism is unlocked. The indications change progressively so that varying portions of both sections are visible for a period while the secondary locks are being withdrawn.

The indicator drums are viewed through small plastic windows in the internal door trim. In the correct method of installation, the transparent section of the window is recessed into the door trim with its convex face outwards (see figures 8, 11 and 13). The viewing window is thus close fitting to the face of its indicator drum. However, it was possible to mount the window with the concave face outwards and with the transparent section protruding from the profile of the door trim (see figure 14). Although the correct fitment of the window was shown on illustrations in the maintenance manual, and also in the overhaul manual and the illustrated parts catalogue, there were no specific written instructions detailing which orientation it was intended the windows should have.

The indicator drums were originally designed to exhibit a locked/unlocked indication on the outside of the aircraft in addition to that visible from within. This was achieved by means of small viewing windows in the outer skin of the door through which the outward facing sides of the indicator drums could be seen. These were painted in a similar manner to those visible from within the aircraft. After a number of incidents regarding doors, however, it was decided that correct closing of the doors could best be achieved if it was only carried out from within the aircraft. To this end BAe 748 aircraft were subsequently manufactured without the viewing windows in the outer skin and without any instructions for door closure on the outside of the aircraft. An Advisory Service Bulletin was circulated in 1968 by the manufacturer to users of existing aircraft which, amongst other things, recommended the removal of any external markings relating to door closure and also the painting-over of the external viewing windows in the door skin. This action had been carried out on G–ASPL so it was no longer possible to ascertain the condition of the door locks from outside the aircraft.

(c) Claw catches and barometric locking lever

The position of the claw catches on the fretting pads during closure of the door changes very little from the time that they start to grip the pads until they are geometrically locked in position. Small transparent covers are positioned over the claw linkages but these are not capable of being used as viewing windows and for practical purposes it is not possible to check visually on in-service aircraft whether the claw linkages have overcentred.

Although there was a small plastic window in the internal trim of PL's baggage door in the vicinity of the barometric locking lever, it was not possible under normal conditions to view the lever and ascertain its position. In any case deployment of the lever only occurs after the aircraft becomes airborne and the cabin differential pressure exceeds approximately 0.5 psi.

1.6.4 *Cabin configuration*

The interior lay-out of BAe 748 aircraft can be varied and the following is a description of the cabin configuration on G–ASPL on the accident flight (see appendix E).

A folding canvas seat was available to allow a supernumerary crew member to sit on the flight deck between the two pilots. The seat was attached to a pillar and was normally stowed against the rear of the bulkhead at the front of the cabin on the left side adjacent to the freight door. No flight deck door was fitted and when the seat was required it could be pivoted round and secured in the entrance to the flight deck.

The forward facing passenger seats had been left on the aircraft but they were of a type in which each pair of seats could be folded outwards. When mail was being carried the seats were stowed against the side wall of the fuselage leaving the centre of the cabin free for the mail bags. The bags were held in place by nets and lashings which were secured to the cabin floor. A bulkhead was located behind the last row of seats on the right side and a folding, rearward-facing, double crew seat was positioned on the rear of this bulkhead adjacent to the baggage door. The rearmost pair of folding seats just in front of this bulkhead had been replaced by a pair of fixed passenger seats.

The front end of the cabin on the right hand side was normally reserved for baggage but a five space bar box stowage unit had been positioned in this area. The box containing the crew catering on the accident flight was located in one of the stowage spaces. The galley itself was situated on the left of the cabin aft of the passenger seats and just forward of the main passenger door. The rear of the cabin aft of the two doors was occupied by a toilet on the left side and a baggage stowage area on the right.

No attempt was made to retain a gangway to the rear of the cabin and when the amount of mail was large, as on the accident flight, access could be gained only by crawling over the top of the mail bags. This lack of easy access to the back of the aircraft in case of an emergency was one of the reasons for the decision to carry PAs on mail flights. Their normal seating position was on the rear-facing folding seat beside the baggage door. However, this seat on PL was found in the stowed position, and it is probable that the PA on the accident flight, when he was seated, used instead one of the two fixed passenger seats just forward of the baggage door because it was more comfortable.

1.7 Meteorological information

An aftercast prepared by the Meteorological Office, Bracknell, showed that an unstable and rather cold north north easterly airflow covered the area in the vicinity of East Midlands Airport. Cloud cover was fairly extensive although broken in places and light showers were reported in several areas.

The following actual observation for the airport was passed to the aircraft at 1808 hrs:-

Surface wind :	020° at 15 knots
Visibility :	15 kilometres
Cloud :	4 oktas at 2,500 feet 6 oktas at 4,500 feet
QNH :	1017
QFE :	1006
Temperature :	Plus 13°C

The accident occurred in daylight.

1.8 Aids to navigation

Not relevant .

1.9 Communications

Radio telephony (RTF) communications throughout flight were normal. Transcripts of recordings of the ATC frequencies used by the aircraft were prepared.

1.10 Aerodrome and ground facilities

Not relevant .

1.11 Flight recorders

1.11.1 Flight data recorder

The aircraft was fitted with a Normalair Garrett Midas CMM/3B frequency modulated flight data recorder. The unit was fitted in the tail cone of the fuselage, aft of the pressure bulkhead and was recovered undamaged from the wreckage. The following parameters were recorded against elapsed time:

Pressure altitude; indicated airspeed; pitch attitude; roll attitude; normal acceleration (g); magnetic heading; flap position

Under scale P(f) of the Air Navigation Order 1980, engine power is required to be recorded only if the equipment fitted in the aeroplane will enable this to be done. On G--ASPL, engine power was not a recorded parameter.

A good replay was obtained using the Dan-Air Midas display equipment under the supervision of the Accidents Investigation Branch. The accuracy of the recorded parameters, after correction is estimated to be as follows:

Altitude:	± 100 feet
Airspeed:	± 5 knots
Heading:	± 5°
Pitch attitude :	± 2°
Roll angle:	± 2°
Normal acceleration:	Not known

The accuracy of the normal acceleration is not known because of a known problem with the Midas system in that normal acceleration often shows little activity. This is possibly due to the response time of the replay system which damps out the higher frequency oscillations. During highly dynamic manoeuvres the accuracy of the manometric parameters is likely to be degraded due to unknown position error effects.

Despite the loss of both mainplanes the recording continued until the fuselage struck the ground. The flap signal was lost at impact – 6 seconds which was the approximate time that other information indicates the wings detached. From this point on, due to disrupted wiring, the heading recordings are invalid. The altitude and airspeed readings would also be meaningless over this final period because of unknown PE effects. Data plots for the final 100 seconds of flight are shown in appendix F–1; the dotted lines on the 'g' trace are the result of calculations carried out by British Aerospace to deduce normal acceleration from the other recorded parameters. The significant information from the FDR is summarised below.

The aircraft was in a steady descent at a speed of approximately 150 knots. At impact – 70 seconds, when it was passing 5,450 feet (amsl), its pitch increased by 2° and it started to develop a starboard bank of about 4° accompanied by a small amount of right yaw. The aircraft maintained height and remained fairly steady for approximately 20 seconds although it was banked up to 9° to the right. It was also turning gradually to the right and continued to do so until the wings detached at which point it was heading 048°(M). While the aircraft was level its speed decayed to 140 knots. At impact – 50 seconds the aircraft entered a gradually steepening dive during which the speed increased to a peak of approximately 230 knots. There is evidence that at about impact – 33 seconds, the aircraft appeared to enter either an unstable region or an area of severe control difficulties. At this time it was passing 4,600 feet with its speed 170 knots. The rate of descent was approximately 6,000 feet per minute and the aircraft's pitch attitude was 10° nose-down. At impact – 27 seconds, the pitch suddenly decreased in two steps from 8° nose-down to 24° nose-down and then abruptly increased to 6° nose-down. Two further pitch oscillations followed culminating at impact – 9½ seconds in a violent pitch-up from 16° nose-down to 34° nose-up over a five second period. During this pitch-up the flap signal disappeared and the aircraft's roll attitude indicated momentarily 60° of right bank. The aircraft's altitude at the assumed time for the mainplane's detachment was about 1,500 feet amsl (900 feet above the ground).

1.11.2 Cockpit voice recorder

The aircraft was equipped with a Fairchild type A100 cockpit voice recorder although there was no legal requirement for a CVR to be fitted. It was located in the tail cone of the fuselage and had been torn loose complete with a portion of honeycomb structure and had suffered some damage in the impact. However, a good replay was obtained with the following track allocation:

Track 1	Captain's RTF and Intercom
Track 2	Crew Hot-microphones
Track 3	Area microphone
Track 4	Co-pilot's RTF and Intercom

The recording covered approximately the last 30 minutes of flight and terminated at impact. A transcript of the full 30 minutes was prepared at the AIB facilities at Farnborough and this was then time correlated with the FDR data and transcripts of the various ATC frequencies.

At 1739 hrs the co-pilot made a routine radio call to the company's movement control and reported that the aircraft was serviceable. The flight continued without incident and at 1800 hrs the aircraft was cleared to descend to FL 60. At 1757 hrs the PA asked the two pilots whether they would like tea or coffee to drink and delivered the drinks to the flight deck at 1802 hrs. One minute 38 seconds later the PA made his report on the condition of the indicators on the 'REAR PORT DOOR'. He was not using the intercom and the clarity of his comments on the handle was so poor that possibly three or four words could not be deciphered even after intensive examination.

At 1809:30 hrs there was a sudden increase in the background noises on the CVR which started with a transient noise typical of a rapid cabin decompression. The noises continued with sounds of severe vibration and increased in level in a way that is normally associated with increasing airspeed. At 1809:41 hrs, 11 seconds after the decompression, during which period several exclamatory remarks were made, the commander asked the co-pilot to transmit a 'MAYDAY'. The co-pilot's voice during the distress message transmission was also indicative of the presence of severe vibration. At 1810:32 hrs there were loud sounds of structural failure and the sounds of the engines disappeared from the recording which terminated at 1810:39 hrs.

Engine rpm settings were obtained from an analysis of the background noises on the CVR tape. These indicated that cruise power was maintained during the initial stages of the descent but that power was reduced progressively to 10,800 rpm after the problems with the door had been reported. The engine frequencies finally disappeared off the analyser at 1810:32 hrs indicative of the loss of the mainplanes.

1.12 Wreckage information

1.12.1 On site examination

The wreckage of the aircraft was dispersed over several fields of level arable farmland in a position 10 nautical miles south south west from Castle Donington aerodrome. A re-construction of the wreckage indicated that all significant components were present within the site. The main wreckage area included the fuselage, the vertical fin and rudder, and the right hand horizontal tailplane and elevator. Ground marks indicated that the fuselage was upright with only moderate nose-down pitch when it struck the surface. Its heading was 023°(M) at the time of impact but its direction of travel was 080°(M). It came to rest 40 yards from its initial impact point. Both the freight door and the passenger door were found adjacent to but detached from the fuselage. The right hand tailplane and elevator were detached from the main fuselage. All the mail bags on board the aircraft were collected, weighed and examined. There was no evidence of an explosive device or fire in either the freight or the fuselage.

Both wings and their associated engines were lying in a field approximately 300 yards north west from the main wreckage site. They had both suffered extensive fire damage. The left tailplane and elevator were found approximately 440 yards south west from the fuselage. The baggage door lay 90 yards closer to the fuselage and had fallen into a hedgerow. There were indications, which are discussed fully later, that it had struck the right tailplane. Numerous items of wreckage were found further south west of the main site. These included a section of left inboard flap, a section of inboard wing skin, a nose gear door, and pieces of blue plastic trim from the baggage door.

Several significant items were discovered in fields approximately $2\frac{1}{4}$ miles south south west of the crash site. These included a small cardboard box, a Dan-Air bar box tag and several small pieces of plastic internal door trim later identified as part of the baggage door. An aerial search by helicopter along the aircraft's assumed flight path failed to reveal any further pieces of wreckage. However, some time later a large section of trim from the baggage door was found approximately one mile from the accident site.

1.12.2 Subsequent examination

(a) Wings and tailplane

A detailed examination showed that both wings had detached due to overstressing in upwards deflection. The left wing had separated at the inboard wing/nacelle station and the right wing had detached at its root.

The left tailplane detached due to overstressing of its root in an upwards/aft deflection. Inspection of the right tailplane revealed evidence of an overstressing pattern very similar to that on the left tailplane. There was evidence, however, that the right tailplane deflected upwards and lay against the side of the fin. The ground impact of the fuselage then caused the tailplane to rotate downwards and forwards and to separate from the main structure. The leading edge of the right tailplane suffered severe distortion when it struck the ground and, although the evidence on the baggage door indicated that it had struck some part of the tailplane, this distortion made it impossible to identify the area where the strike had occurred.

The evidence indicated an in-flight structural failure due to a massive aerodynamic overload in upwards deflection. At the time the flaps and undercarriage were both retracted.

(b) Fuselage structure

The complete fuselage structure, apart from the baggage door, was found at the main crash site. The evidence indicated that both the freight and passenger doors although detached on site, were in position and locked when the fuselage struck the ground. The position of the baggage door in the wreckage distribution, however, indicated that it had fallen as a free object sometime earlier. No evidence was found to suggest that either of the two rear door apertures failed because of anything other than ground impact induced overload. A detailed examination of the rear fuselage area did not reveal any evidence of pre-existing cracking or failure which could have caused the in-flight release of the baggage door.

The baggage door aperture was extensively damaged although its inside face had suffered no significant impact damage at the four points where the door's claw catches bear on the structure. There was no evidence on this structure or on the four fretting pads that any abnormal opening or closing operation had taken place. The lower rear fretting pad was secured by only one screw, although the second screw was present in its hole in the structure. There was clear evidence that the associated claw catch had been bearing directly on the structure of the door aperture.

(c) The baggage door

(1) General

The baggage door had suffered severe damage at approximately mid-height which included crushing and fracture of the edge members and the compression and folding of the outer skin. There was no evidence to suggest that this damage was due to impact with the ground but it was consistent with an impact of considerable force by

an object of greater length than the width of the door and having a height of approximately 4 inches. Deposits of rubber were present on the damaged area of the outer skin which chemical analysis showed to be similar to that used on the leading edge de-icing boot on the tailplane. It was clear from this evidence that the door, following its detachment, had struck the tailplane. The line of the impact was at an angle of approximately 25° to the horizontal axis of the door. The remainder of the door structure was undamaged apart from light nicks and dents.

The door's main articulated hinge assembly was found, still attached to a broken fragment of its associated door aperture, lying close to the rear fuselage at the main wreckage site. Examination revealed that the outer door attachment pivot points had failed in overload allowing the door to separate from the hinge.

Most of the plastic interior door trim was missing although some small sections adjacent to the securing screws were still attached. As stated earlier, fragments of the missing trim were recovered some distance from the main accident site.

(2) Mechanical indicators

Examination of the operation of the mechanical indicator drums on G–ASPL showed that there was considerable backlash in their drives. (It should be noted, however, that this did not significantly exceed that found in new doors.) The red sections on the faces of PL's drums had been painted over at some time with another layer of red paint which extended for approximately $\frac{1}{8}$ inch over the striped green/yellow markings on the upper part of the drum faces. This paint layer had been partly worn away revealing some of the original green and yellow stripes thereby making the boundary between the red and striped sections indistinct. (See figures 7–14 for details of the drums and the viewing windows.)

The indicator viewing windows were found to have been installed in a manner that was not the one that was intended. Examination of the windows also revealed scouring marks on their exposed faces. When the windows were removed during the investigation and offered up in the normal orientation to their mounting brackets, it was discovered that they fouled the drums even with the correct thickness of interior trim interposed between the windows and their brackets. The evidence indicated that at one time the windows had had the normal orientation. During this period contact between the windows and the drum faces had caused the partial wearing away of the layer of the red over-paint and the scouring of the viewing window faces.

(3) Door operating mechanism

Initial examination of the door operating mechanism revealed considerable wear of the profile of the fixed cam. (See section 1.17.4.) The inner door skin was removed in order to examine the remainder of the operating mechanism. There was no evidence of any damage that did not appear to have occurred at the same time as the structural damage (for example there was bending of the vertical rods in the secondary lock mechanism where they had been forced out of shape by the deflected outer skin and buckled intercostals.) All the rod end fittings of the primary mechanism were correctly wire-locked. However, the locking wire of the top end fitting of the vertical rod connected to the upper star lever was of a different diameter to all the other locking wire in the door and its appearance suggested that the locking had not been carried out in the same way as all the other wire locking in the door. The end fitting in question was one of the few parts of the primary mechanism accessible without removing the door from the aircraft and unriveting the inner door skin.

(d) Flight deck warning system

No fault was found in those parts of the electrical warning system which were recovered and the relay in the system was found to be serviceable. The 'door unsafe' warning light from the pilot's instrument panel could not be identified in the wreckage. The wires in the terminal block situated on the fuselage adjacent to the baggage door aperture were correctly installed but the wiring between this terminal block and the one within the door itself was not recovered. The rest of the wire within the door was intact. All nine micro-switches in the warning system operated satisfactorily.

(e) Seats

The framework of the supernumerary's seat which could be swivelled into position on the flight deck, was broken at several places. There was evidence that the seat was locked in position across the flight deck entrance at the time of the impact and that it was occupied. Marked distortion of the right hand lap-belt anchorage also indicated that at least this part of the harness was in use at impact. A double fold-down seat for use by cabin attendants was mounted on the rear side of the bulkhead which was positioned just forward of the baggage door. This was found secured in the folded position.

1.12.3 Trajectory and wind drift plots

Wind drift calculations were made for the small pieces of interior door trim from the baggage door which were found approximately $2\frac{1}{4}$ miles south south west from the main accident site. These indicated that the fragments detached from the door when the aircraft's height was approximately 3,300–3,500 feet amsl. The calculations therefore showed that the pieces could not have detached as late as the final structural break-up sequence.

The main structural break-up occurred at approximately 900 feet above the ground and the high weight of most of the major structural parts that detached would result in negligible drift in the prevailing wind conditions. The trajectories of these components would be mainly dictated by their ballistic characteristics. It is considered that the break-up occurred over the field that contained the earliest items in the main wreckage trail, that is some 500–600 yards from the fuselage site (see appendix D) and that the baggage door did not fall free before the aerodynamic overload was experienced by the wings and tailplanes.

1.13 Medical and pathological information

There was no evidence that any medical factor contributed to the accident.

1.14 Fire

The only evidence of fire was that associated with both detached wings and engines. This occurred subsequent to the ground impact although it is possible that some fire may have started after the structural failure occurred while the wings were still in the air. There was no evidence of fire in the main fuselage wreckage.

1.15 Survival aspects

The accident was non-survivable.

1.16 Tests and research

1.16.1 Baggage door reconstruction

Because of the unusual circumstances associated with the opening of the baggage door for which there seemed no ready explanation, it was decided to attempt a reconstruction of the door structure so that the complete operating mechanism could be functioned and its operation investigated. To achieve this the original manufacturing jig was utilised at British Aerospace premises. Certain parts of the mechanism were removed and the mid-section of the door was cut away. The claw catches and their associated linkages were removed and this enabled the two structural elements to be offered up to the jig. Reconstruction of the mid-section

was then carried out by introducing sections cut from a new edge member pressing which were butt-jointed to the cut ends of the existing edge members. Replacement intercostals and brackets were installed in the same way that is normally done during manufacture. A new section of skin was riveted in position and lap-jointed to the existing skins, a small packing piece being introduced where some skin distortion was noted to have occurred. The vertical rods in the secondary lock mechanism were straightened and tests were conducted which confirmed that there was insignificant alteration in the lengths of the secondary rods as a result of bending in the accident and subsequent straightening. All mechanical items were re-installed in their original positions.

When the reconstruction was complete, it was found that the various rods constituting the primary lock mechanism could not be joined together with all the four claws in the locked position without disturbing the existing rod length adjustments. In order to join all the drive rods, it was necessary for the top pair of claws to be opened until the gaps between the claw levers and their stops were approximately 0.3 inches, while the bottom claws were still at the fully closed position.

A rig was constructed at the AIB premises, Farnborough, to enable the mechanism of the rebuilt door to be functionally tested with varying amounts of packing under the claw catches. The tests showed that under all normal conditions of packing, the door could be fully closed using the internal handle, provided that sufficient force was exerted. When lighter forces were applied, the bottom pair of catches geometrically locked in the normal way, but the top pair of claws failed to over-centre. Similarly the top pair of catches remained unlocked when the outside handle was used regardless of the amount of force applied. In this case the outer handle moved easily through its full travel into the normal locked position and the bottom catches became locked. With the primary mechanism in this partially locked condition it is not possible to drive the secondary lock plungers into engagement, nor into a position to operate the micro-switches to extinguish the door unsafe warning.

1.16.2 Tests to establish the door's reaction to pressurisation loads

In order to preserve the evidence within the rebuilt door, a second door was rigged with its mechanism set to a similar geometry. This door was then subjected to load tests in a rig specially constructed by British Aerospace. This rig applied forces to four points on the door structure adjacent to the claw catches in order to simulate the loading in the catches resulting from cabin differential pressure acting on the door. Deflection gauges were installed on each rod of the primary mechanism and the vertical rods were also strain gauged. This enabled the behaviour of the mechanism to be studied during load application and removal. Loads were applied incrementally

through the test rig and then reduced progressively. During each test run the peak load reached was increased. On reaching a peak load equivalent to 2.5 psi cabin pressure, it was noted that the behaviour of the mechanism began to alter significantly as the loading was reduced. It was found that the bottom pair of claw catch levers moved by approximately 0.004 inches away from their stops during the final stage of load removal.

This trend was observed increasingly during the load reduction part of the cycle as the peak load was increased. Finally, a loading cycle was carried out whose peak load was equivalent to 3.0 psi. During load reduction, the complete door locking mechanism suddenly opened, releasing all four catches and allowing the door to drop clear of the rig. This release of the catches occurred at a loading equivalent to 1.0 psi cabin differential pressure.

1.16.3 Movement of secondary lock plungers

The structures department of British Aerospace, Woodford, was requested to investigate the movement of the secondary lock plungers of a baggage door under the influence of varying cabin pressure differentials. It was considered that elastic deformation of the door structure under pressure loads could result in some movement of the top and bottom plungers since they are connected by rigid drive rods. This could conceivably result in initially engaged plungers moving to a disengaged position in flight, thus rendering the door less safe. The tests were carried out on an instrumented aircraft with the primary locks engaged and the secondary locks partly disengaged. This latter position was achieved by means of packing placed under the inside handle. No significant movement was detected at any of the four plunger positions throughout the full range of cabin pressure differentials. There was therefore no evidence that movement of this sort played a part in the opening of the door in the accident.

1.17.1 Interpretation of wind tunnel results and FDR data

1.17.1.1 Aerodynamic effects

Special wind tunnel tests were carried out after the accident by the manufacturer as part of the investigation (for a summary of the results see appendix A.) These indicated that an aircraft with a door lodged on the tailplane leading edge would suffer pitch control difficulties accompanied by severe buffet and vibration due to adverse aerodynamic effects. The tests that examined elevator hinge moments revealed additional problems for someone trying to fly the aircraft. Initially, according to the tests, an aircraft flying at a speed similar to PL's when the door opened, would pitch nose-up when the door became attached to the tail. If the speed was then increased, progressively more nose-down elevator would need to be

applied to prevent the aircraft from pitching further upwards. At the same time, however, the stick force necessary for a given forward control column position would decrease. Finally, if the aircraft reached a speed such that the area of discontinuity was entered, it would suddenly pitch nose-down. At this point, the tests indicated the aircraft would enter a region of violent longitudinal instability and reversal of elevator effectiveness.

Wind tunnel tests as performed for the benefit of this inquiry are subject to uncertainties from a variety of sources. These include:-

(a) A difference in Reynolds number between the model tests and the full-scale situation.

(b) The use of a half model to simulate an unsymmetrical full-scale situation in the hinge moment tests.

(c) Use of a tunnel model without any propeller slipstream effect giving somewhat unrepresentative airflow conditions over the tailplane.

Even allowing for these reservations, however, the tests showed sudden step changes in pitch trim and in elevator hinge moments at particular values of co-efficient of lift (C_L.) The behaviour in pitch of an aircraft is the result of changes in overall trim and in elevator angle. The latter are the product of elevator hinge moment changes and also pilot control inputs. Clearly the C_L values at which the sudden changes would have occurred on the aircraft would not have been exactly the same as those values at which the changes occurred in the model tests, because of the usual problems of experimental error. Since the exact C_L values at which the pitch trim step changes and the major changes in elevator hinge moment occur can only be approximately established, it is not entirely clear what exact sensations of control force and pitch changes the pilot would experience with changing C_L values. What is evident, however, is that the changes in pitch trim and elevator forces would be large and in unexpected directions and would occur suddenly with changing airspeed. There is no doubt that this would in due course render the aircraft uncontrollable leading to divergent pitch oscillations.

The tests suggested that if 22½° of flap was lowered while the aircraft's speed was above that at which the discontinuity occurred, then the aircraft might escape the region of the pitch instability. However, since the precise behaviour of an aircraft so affected cannot be predicted, it is considered impractical to devise a drill which would assist in the situation where the door had already become attached to the tail-plane.

1.17.1.2 Consideration of the aerodynamic information and FDR data

The evidence on the FDR trace shows that at about the time that the door came open, a very slight pitch-up occurred. This was accompanied by a small degree of right roll and yaw. It is evident that the pilot was able to control the aircraft's tendencies for a while although the comments which appear on the CVR show that it was not easy. The aircraft maintained height for approximately 20 seconds during which time the speed decreased slightly probably due to additional drag from the door. It then pitched forward into an increasingly steep dive accompanied by a steady increase in airspeed. At approximately 180 knots there was a sudden decrease in pitch which went in two steps from 8° nose-down to 24° nose-down. This was followed by an abrupt pitch-up and the aircraft began a series of pitch oscillations until it could no longer withstand the stresses placed on it.

There is a general agreement between this behaviour of the aircraft and that predicted for it by the wind tunnel tests if a baggage door was attached to the leading edge of the tailplane. Considering the aerodynamic consequences of such an event it is surprising and creditable that the pilot succeeded in maintaining some degree of control for as long as he did.

1.17.2 Door mechanical indicators and viewing windows

(a) Interpretation of the condition as found on PL

There was considerable backlash in the drives of the mechanical indicator drums on PL's baggage door and the viewing windows did not have their normal orientation. An investigation was therefore carried out to determine what effects this condition could possibly have on the indications displayed by the indicators themselves.

A viewing window when it is correctly installed, is normally close fitting to the face of its indicator drum. In the case of PL the windows and the drums had actually been in contact with one another and this condition is significant when the backlash in the drum drives is taken into consideration for movement of the drums which this allows gives a range of indications for any given position of the secondary locks. During door closure the drums are driven down to reveal the upper striped section. Friction between the drums and the windows, however, has the unintentional effect of restricting free movement of the drums. This consequently retards the disappearance of the red sections thereby achieving the beneficial effect of retaining a 'door unsafe' indication until a late stage in the operation. The re-orientation of the windows into the position found on PL, however, introduces a space between

them and the drums and consequently the drums are free to move down under the effects of gravity to the limit permitted by the backlash in their drives. This has the effect of revealing more of the green/yellow striped sections for any given position of the secondary lock mechanism and as a result the 'door safe' indications become visible at an earlier stage in the door closure cycle. The orientation of the windows as found on PL, therefore, gives a less sensitive warning of door insecurity than when the windows are installed correctly.

The general effect of having the windows installed as on PL is to make it less easy to distinguish the drum indications. This is partly because the distance between the windows and the drums creates large parallax errors which are sensitive to the position of the observer's eye. It is also partly because there is less light falling on the drum face making viewing difficult. The concave curvature of the visible faces of the windows also creates shadows and reflections which tend to obscure the lower (red) sections of the drums without similarly affecting the upper (green/yellow) sections.

The combination of all these factors, therefore, serves not only to reduce the amount of red warning visible but also to make the red more difficult to discern in contrast to the more readily apparent green and yellow stripes. In the case of PL this problem was aggravated by the indistinct boundary between the two sections.

(b) As fitted on other aircraft

The above effects would apply to any BAe 748 aircraft which suffered the same window orientation as PL. An examination carried out shortly after the accident of a number of aircraft in the fleets of both this and another operator revealed a significant number of instances where the windows on the baggage door were installed in this manner. There was also widespread confirmation from other aircraft whose windows were installed normally, of fouling between the windows and the drum faces. This had caused scratching of the painted surface of the drums which in some cases had erased the boundary between the two coloured sections.

1.17.3 Examination of an in-service BAe 748 aircraft

An in-service BAe 748 aircraft having a similar lay-out as the accident aircraft was examined to assess what factors could affect the appearance of a baggage door, particularly one in the condition of PL's. It was first noted that with the two rear doors closed, the cabin lighting did not illuminate very effectively the vestibule area at the rear of the cabin. Close examination of the baggage doors caused the observer to position himself between the nearest light and the door, making both the door handle and the mechanical indicators somewhat difficult to see. When the mechanical

indicator viewing windows were re-fitted in the same way as PL's, it was noted that the poor lighting made the lower part of the indicator drums more difficult to see than the upper part. In addition, with the observer's eye in certain positions, a shadow was cast over the lower part of the window further obscuring the bottom part of the drum's face.

The secondary lock mechanism on the door was then positioned to give the indicator drums a similar appearance to those on PL when its bottom claw catches were closed and the top claw catches unlocked. Because of the lighting conditions in the vestibule, the indicators appeared from most normal eye positions to be exhibiting only the green/yellow striped surface. Close and careful examination, preferably using a torch, was required to confirm that the red sector was visible at the bottom of the transparent section.

The considerable distance between the transparency and the face of the drum at its lower part (see figure 14), created parallax problems and made it difficult to decide when the red section was in the 'unexposed' position. The fact that the face of the drum and the face of the transparency were at some 45 degrees to one another at the point where the colour of the drum changed from green/yellow stripes to red accentuated the problem (see figure 14). It was noted that the aircraft examined had bright red sections to its indicator drums and a straight distinct boundary between the red and green/yellow sections, unlike the blurred and indistinct boundary visible on PL's indicators.

1.17.4 The fixed cam

As stated in the door description, a profiled cam is fitted on the inside face of the door below the inner handle (figure 4), which controls the sequence of primary and secondary lock movement by guiding the locus of movement of the door handle. Each cam has a unique profile to allow for the effects of the cumulative tolerances in manufacturing dimensions and door mechanism rigging. Wear on this cam disrupts the operating sequence causing the secondary lock plungers to contact elements of the primary mechanism during door operation and the resulting friction increases the forces needed to operate the door mechanism. If sufficient wear is present, interference between primary and secondary locks may completely prevent movement of the mechanism. Examination showed that there was sufficient wear on the cam of PL's baggage door to have caused severe stiffness of operation even without the additional problem brought about by the mis-rigging of the primary mechanism.

The manufacturer's maintenance manual made no reference to the effect of wear in this component and gave no criteria by which the extent of the wear could be judged. At the time of the accident, the procedure for changing a worn cam was not described in either the maintenance or overhaul manuals even though installation of the cam is a selective fitting operation as the required profile differs on each door. The maintenance schedule devised by the manufacturer, on which the operator's maintenance schedule was based, made no reference to examination of the cam profile.

1.17.5 History of door defects on G–ASPL

(a) General

The technical log records for G–ASPL show a continuing history of door defects which, however, are mainly confined to the passenger and baggage doors. The majority of the entries refer either to complaints of noise coming from the area around a particular door which at times was so loud as to cause concern to the passengers and which seems to have been caused by damaged seals, or to the illumination of the door warning light on the commander's instrument panel. Occasionally both the doors were difficult to open or close and the fretting pads and shims were adjusted several times. Comments have been received that similar defects were not uncommon on other BAe 748 aircraft.

According to the aircraft's defects log the door warning light illuminated in flight on a number of occasions. The top and bottom edges of the doors move slightly outwards under pressurisation loads and this can cause the sill micro-switch to open and interrupt the warning light circuit. The aircrews have apparently found that the light can often be extinguished by reducing the cabin differential pressure. The cause of the problem was often traced to inaccurate adjustment or damage to the sill micro-switch striker plate on one of the doors. The cabin passenger door system seems to have been particularly troublesome in the middle of 1979 at a time which coincided with a number of door seal problems. In April 1980 several sectors were flown with the light continuously illuminated, as permitted by the Minimum Equipment List (MEL) until finally the fault was traced to a defective micro-switch in the crew freight door.

Although many of the defects were rectified while the aircraft was on the ground after the relevant flight, some, particularly those involving the seals or the warning light were transferred to the deferred defect list ('B' defect list) presumably because they were thought to be of a minor nature. Others were rectified but were left on the 'B' defect list until further crew reports confirmed that the system was operating

satisfactorily. The cause of many of the spurious light warnings was difficult to identify simply because the single warning light served all three doors. However, one feature of the log entries is the way in which a defect would keep on appearing; the defect was often recorded as having been rectified only for the symptoms to recur on subsequent flights.

(b) Baggage door

In October 1980 a leak was reported from around the baggage door seal which was sufficiently serious to limit the cabin differential pressure to about 2 psi and this was subsequently cured by carrying out repairs to the seal. In the period following the aircraft's last major inspection in April 1981 there were several complaints about noise from the baggage door and these appear to have been cured when the seal was repaired on 17 June 1981. As part of the attempt to stop the noise the claw abutments were repositioned on 22 May 1981. During this period a damaged sill micro-switch striker plate appears to have caused the warning light to illuminate in flight on several occasions. On 20 June 1981, the door's external handle was broken and the door was reported as being jammed shut the following day. A new shaft and handle assembly was fitted and the door operated satisfactorily. On 22 June 1981 the door was reported as being difficult to lock and also noisy. Rectification was carried out on the next day by tightening the nut on the main hinge bottom bolt when it was found to be loose.

There is no record of any work having been carried out on the operating mechanism within the door and the personnel responsible for changing the handle's spindle stated that they did not disturb any part of the mechanism within the door. At the time of the aircraft's last flight there were no outstanding 'B' defects relevant to the door or the warning system.

1.17.6 History of BAe 748 door opening incidents

(a) Incidents prior to the accident

The manufacturer's records disclosed a number of instances of doors coming open in flight. The passenger door was recorded as having opened on four occasions, all of them occurring when the aircraft was at altitude. The first three occurred in 1962 before the introduction of the modifications which incorporated the secondary locking plungers. There was, however, evidence that on the third occasion the opening occurred while someone was unofficially testing the responses of the door warning light system. On each of these incidents the door separated from the fuselage. The fourth instance took place in 1978 when a defect resulted in two of the claw linkages not being correctly over centred causing the door to open partially and suffer structural damage.

In contrast to the history of the passenger door, the manufacturer's records show that from 1962 onwards there have been 35 instances when a baggage door has come open. Of these 28 opened during or shortly after take-off, two occurred when the aircraft was at altitude (3000 metres and 7,000 feet), and the details of the others are unknown. Unfortunately, there are very few details about the two events which occurred at altitude except that the first one occurred before the introduction of the secondary lock modifications. Of the 31 instances for which details are available, 13 doors separated from the aircraft and five of these struck the tailplane occasionally causing considerable damage. Vibration was reported on a number of occasions even when the door remained attached to the aircraft. At the commencement of three flights, the aircrew disarmed the flight deck warning system or part of it when the unsafe warning remained after a visual check on the doors had been completed. In 16 reports the crew alleged that the warning light illuminated at about the time the door opened. Only 3 of the 35 incidents occurred to a United Kingdom operated aircraft; the remainder concerned overseas operators.

Another incident, of which the manufacturer had no knowledge, occurred overseas in 1978 when a door opened shortly after take-off but did not detach from the aircraft. It was later discovered that during servicing maintenance personnel had inadvertently made an incorrect connection of the two conductors of the main warning system at the terminal block adjacent to the baggage door. This completed the warning circuit and cancelled the flight deck warning irrespective of whether any of the micro-switches within the baggage door were in the open position.

Since the accident one further incident has been reported. In May 1982 an overseas operator of the BAe 748 experienced the opening of a baggage door shortly after the aircraft had taken off. The door fell into the sea but was later recovered.

(b) Occasions when a door has attached to the horizontal tailplane

The report on the third incident in 1962 involving a passenger door revealed that the door separated from its hinge assembly and then became fixed on the leading edge of the tailplane. The pilot experienced considerable control difficulties and he was obliged to make an immediate forced landing. The landing was successful and there were no injuries.

In 1968 a baggage door detached shortly after take-off and then wrapped itself around the tailplane. The pilot made an immediate circuit and landed safely. It is not known whether the opening occurred before or after the pilot had retracted take-off flap.

After the accident to G–ASPL, evidence came to light in the aviation press of three other occasions when a door had become lodged on the leading edge of a tailplane after coming open in flight. These incidents did not involve BAe 748 aircraft and on each occasion the pilot made a successful landing in spite of having considerable difficulty in retaining control of the aircraft.

1.17.7 History of development to door mechanism

The BAe 748 aircraft was originally manufactured with all doors having a simple system of geometrically overcentring claw catches. Experience with the first batch of production aircraft, however, indicated that these doors did not perform satisfactorily in service. Accordingly modifications were introduced on all doors to incorporate the secondary lock system complete with mechanical position indicators. Certain aircraft were fitted with a thumb-catch arrangement to operate the secondary locks from within although most aircraft were modified so that both the primary and secondary locks were operated by a single lever. Subsequently, all aircraft were produced with the latter single internal handle.

An electrical warning system was introduced to give a cockpit indication of a 'door unsafe' condition. Subsequently, barometric locks were introduced on all doors in the aircraft. Certain aircraft were built with a different lay-out at the rear of the cabin, where the toilet was repositioned so that the baggage door opened from within the toilet compartment. The baggage doors on these aircraft were therefore equipped with a speed-lock to prevent inadvertent opening by the occupant of the toilet compartment during unpressurised flight.

As a result of persistent problems with inadvertent opening of the baggage doors, later versions of the aircraft were equipped with two flight-deck warning lights to alert both crew members to any unsafe door condition. In addition on some aircraft, an audible warning was introduced to indicate a 'door unsafe' condition.

Late production aircraft had the external windows for viewing the mechanical indicators deleted and instructions on closing the baggage doors previously painted on the outside, were eliminated. A service bulletin to all operators advised them to delete the external markings on earlier aircraft (except those showing how to open the door) and to paint over the external viewing windows.

G–ASPL had a baggage door which was originally manufactured without secondary locks. It was, however, modified at the manufacturer's premises before initial delivery of the aircraft, to incorporate the secondary locks system. At the time of the delivery, its baggage door had secondary locks operated by the single internal handle, and

incorporated the barometric lock. The toilet compartment arrangement was such that incorporation of the speed lock was not required and none was fitted. The flight deck warning system was the early arrangement with a single light on the commander's panel and no audible warning. The external marking of the baggage door conformed to the advisory information in service bulletin 52/27 i.e. the indicator windows were painted over and the only instruction took the form of an arrow indicating the 'open' direction of the handle.

1.17.8 Post-accident actions

It is not possible because of continuing review and action, to give a complete account of everything that has been done since the accident concerning BAe 748 doors. However, both the technical aspects and crew operating drills have received attention. Numerous mandatory and optional modifications have been developed, certain existing optional modifications have been declared mandatory, and sections of the manufacturers maintenance manual have been re-written. Other actions are still being introduced and implemented in order to improve door operation and reliability, and to make maintenance manual instructions easier to follow. The following is a summary of the main actions taken during the immediate period after the accident; more complete details of these instructions are given in appendix B.

On 9 July 1981 British Aerospace sent, by telex, an Alert Service Bulletin No A52/90 to operators. The contents of the Bulletin were declared mandatory by the United Kingdom Civil Aviation Authority (CAA). Towards the end of July 1981, examination of the baggage door recovered from G–ASPL highlighted the problems with the mechanical indicators detailed in section 1.12.2. In view of their possible significance to other BAe 748 aircraft the details were at once conveyed to the CAA and the manufacturer. The latter issued an alert telex reference PSM/509/3816, classified mandatory by the CAA, to operators detailing checks and rectification action to be carried out where necessary on the positioning of the indicator windows. Service Bulletin A52/90 was then produced incorporating the contents of the two above telex messages and this was posted to operators. Subsequently a series of design changes were developed to improve door operation and warning system functioning.

1.17.9 Activities prior to the departure from Gatwick

The aircraft arrived at Gatwick from its previous flight at 0300 hrs and because there was no cargo on board, it taxied directly to a stand at the Company's engineering base. On arrival the incoming PA opened both the right and left rear doors as was his normal custom and the engineers servicing the aircraft confirmed that both rear doors were open. There is no record of any work being done on the baggage door during the turn round. After the servicing had been completed, the aircraft remained at the base during the rest of the day and during this period all the doors appear to have been shut. At approximately 1500 hrs the aircraft was towed to its departure stand 48 and all the doors were checked shut prior to the towing. When the aircraft was on stand the engineer who was manning the brakes left it by the rear left hand door. Loading of the mail for the accident flight started shortly after this and the sacks were loaded through the front and rear left hand doors. The right rear door appears not to have been used during the dispatch of the aircraft and the general consensus of opinion is that it was closed all this time. Only one person considered that this door was open but no confirmation of this could be established. The ground engineer who attended the dispatch of the aircraft examined the baggage door at some time after the mail had been loaded and stated that he checked that the door was properly locked and secured. When the loading was completed the rear left door was closed by an unknown person. The catering was received on board by the PA through the front left door and placed in the stowage on the right side behind the flight deck. The catering included flasks of hot water, coffee and tea ingredients, soft drinks and meals for the crew. The commander appears to have been the last person to board the aircraft and he entered through the front left door which he closed at about 1718 hrs. The ground crew assisting with the departure made a visual external check that the doors were closed. Start up clearance was requested from ATC at 1721 hrs and the aircraft taxied at 1723 hrs.

1.17.10 Operational procedures

The following extracts are taken from various manuals and concern procedures which are relevant to door operations.

1.17.10.1 Flight Manual

"INTERNAL CHECKS
PORT INSTRUMENT PANEL
Door Warning Light: ON, if 'OFF' operate PRESS-TO-TEST

PRE-STARTING CHECKS

Door warning light:	OUT (operate PRESS to TEST)
Door visual indicators:	Check safe

TAXYING AND TAKE-OFF CHECKS

Door warning light:	Out. Operate press to test
Door visual indicators:	Check SAFE i.e. green/yellow stripes
Forward freight	completely fill the viewing aperture
Rear port side passenger	
Rear starboard side baggage doors	
Door inner handle:	Check that inner handles on all doors are in the fully closed position".

1.17.10.2 *Operations Manual*

"INTERNAL CHECKS (Expanded Check List)

21 Warning Lights	4 Hydraulic Panel
	1 Door Warning
	6 FFPS
	8 Generator, Oil Pressure, Inverter, Alternator
	2 Pitot Heaters

PRE-START CHECKS

Door warn light:	Out Press/Test"

1.17.10.3 Cabin staff manual

"2.3.5.1 Electrical

(1) Doors unsafe: indication is by the illumination of a red indicator lamp on the first pilot's instrument panel.

(2) Doors safe: indication by light not being lit.

2.3.5.2 Mechanical

(1) Doors unsafe: indication is by a red area visible from the inside of the aircraft through view panels on the doors.

(2) Doors safe: Green and yellow stripes visible through view panels.

(3) Check 'claw' catches are in locked position round door.

(4) Ensure door handle is firmly pushed up and in, fitting firmly into its recess".

1.17.10.4 Minimum Equipment List (MEL)

The following item was part of Dan-Air's MEL at the time of the accident

"Door warning lights	Acceptable inoperative provided mechanical indicators serviceable and doors closed and locked under Captain's supervision".

2. Analysis

2.1 Introduction

The aircraft suffered a major in-flight structural failure and a detailed examination of the wreckage revealed that this occurred when both mainplanes and the left horizontal tailplane detached as a result of being overstressed in upload. The right tailplane also suffered overstressing but folded up against the fin and did not separate until the fuselage impacted the ground. There was no evidence that the failures were the result of any pre-existing structural weakness nor that the weather was a factor in the accident. The wreckage showed no evidence of damage from an explosive device.

The on-site examination of the aircraft showed that the fuselage structure was intact when it struck the ground except for the absence of the baggage door from its aperture. It was evident from the door's position in the wreckage distribution that it had started to fall as a free object at about the time that the major structural failure occurred. However, the discovery over two miles from the main wreckage of pieces of interior door trim and small articles from the cabin indicated that the door had not been in the closed position for some time before this. It is in fact reasonable to assume from the evidence on the CVR tape of a sudden cabin decompression 63 seconds before the wings detached, that the door actually opened at this time.

Since it did not immediately fall free two things could have happened. The door could have either remained secured to its hinge assembly and was hanging in the airstream until it finally detached at about the time the wings folded up, or else it must have separated immediately on opening or shortly afterwards and in some way then became re-attached temporarily to the rest of the structure.

The commander's comments showed that the aircraft became very difficult to handle almost immediately after the door opened and this suggested that the position that the door assumed after it opened had drastically affected the aircraft's flying characteristics. It then seemed possible that the massive aerodynamic overload which the aircraft later suffered was a consequence of that change.

2.2 Events subsequent to door opening

The rubber deposits on the creased area of the baggage door skin indicated that the door had struck the tailplane after becoming detached. Moreover, the general shape and position of the deep indentations on the door's outer skin were also consistent with it having struck the tailplane leading edge. However, the deformation suffered by the right hand tailplane when it later struck the ground crushing its leading edge, obscured any evidence on the tailplane of contact between it and the door. There is therefore no direct evidence from the wreckage as to the extent and duration of the contact between the two.

There is no evidence from the records of the 36 previous instances of baggage doors coming open that any pilot experienced serious control difficulties on the occasions when the door either remained attached to the hinge assembly or was lost overboard completely. There was no evidence either from the wind tunnel tests carried out by the manufacturer after the accident, that an open door would create handling problems. This indicates that something more unusual occurred to the door.

The wind tunnel tests in which the fixing of a baggage door on the leading edge of the tailplane was simulated, revealed a significant modification to the tailplane's aerodynamic characteristics giving rise to unexpectedly large effects on the aircraft's pitching characteristics including a region of violent instability. A comparison between these effects and the FDR data shows that there is a consistency between the predicted results of attaching a door to the tailplane and the actual behaviour of the aircraft after the door opened. The commander's comments also confirm that something violent and unusual was happening which was outside his normal flying experience.

In the light of this very strong circumstantial evidence, it is concluded that the baggage door was very quickly torn from its hinge assembly after it opened and that it then struck and remained lodged on the leading edge of the right tailplane. It is likely that the force of impact between the door and the tailplane was sufficient to distort both in such a way that the two became keyed together. Because the damage to the door edge members had robbed the door of its vertical stiffness, it is probable that the air pressure on its forward facing side then caused it to flex rearwards above and below the tailplane thereby pinching the tailplane and making the door more secure until it became dislodged during the break-up of the aircraft at the end of the flight.

This attachment of the door to the tailplane was, therefore, the direct cause of the accident and everything which followed, including the involuntary manoeuvres which subjected the structure to loads beyond its design strength, was the result of that event. The door created a greatly modified airflow over the right hand side of the tailplane which produced effects which were totally outside normal flying conditions. No pilot could have handled the situation in the short time before the aircraft hit the ground and in the circumstances there was nothing the crew could have done to save the aircraft. Although the lodging of a door on a tailplane may seem an unlikely occurrence, it is interesting to note that it had happened twice before to BAe 748 aircraft. On the first occasion the pilot was able to maintain some control over the aircraft and he carried out a successful forced landing. The second opening occurred shortly after take-off and the aircraft made a circuit and landed. There were apparently no serious control problems but it is possible that the airspeed was low and that take-off flap had not been retracted. Three other instances have also been recorded involving different types of aircraft and their pilots also encountered considerable control difficulties.

2.3 The reasons why the door opened

It has not been possible to visualise any sequence of events that would permit a correctly rigged and correctly closed door to open of its own accord in flight unless the door or its aperture was grossly damaged. Since however, there was no evidence of significant pre-impact damage in this area on PL it must be assumed that the door catches released and thereby permitted opening of the door. Such release could only have occurred for one of the following reasons:

1) Someone in the aircraft released the door lock mechanism.

2) The door had been closed without fully overcentring the door catches.

3) Some abnormal condition existed within the door.

These possibilities are discussed below.

1) The door lock mechanism can only be released by operating the handle, and the handle cannot be operated in pressurised flight since the barometric lock prevents movement of the secondary locks and hence stops the door mechanism sequence from beginning. Post accident tests confirmed the correct operation of the barometric lock. If, however, for some reason (such as the secondary locks not being quite fully home) the barometric lock lever had failed to engage correctly and had permitted movement of the handle, cabin pressure would have forced the door open immediately the door catches had ceased to be geometrically locked. Since all three occupants were on the flight deck at the time the rear door opened, it is possible to eliminate the hypothesis that it opened because someone tampered with the handle in flight.

2) It is possible when closing a door to leave all four claw catches not properly overcentred. In such a condition increasing cabin pressure would cause the claw catches to move suddenly and rapidly away from the on-centres position to either the fully open or fully closed position. If the latter occurred there is no reason why the door should not then remain fully closed throughout the flight, but if the catches moved to the open position then the door would open. Clearly this would occur during the early stages of cabin pressurisation (ie initial climb), since the very high forces generated by the pressure differential being fed into the catch mechanism are only resisted by friction of the mechanism and of the claw catches on the fretting pads. In the majority of recorded cases where the baggage door has opened on BAe 748 aircraft it has occurred shortly after take-off, strongly suggesting that in these instances the doors were not correctly closed.

   The possibility has been suggested that a baggage door with a very slight loss of synchronisation of the claw catches could be closed incompletely so that one or more claws was positioned just overcentre and the remaining claws remained just

on the 'open' side of centres. The kind of balance thereby created could possibly permit the door to resist some degree of pressure differential without opening. Such a condition is, however, highly unstable. Although a condition could be created where the forces tending to open the claw catches which are on the unsafe side of centres exactly balances the forces tending to close the overcentred claw or claws, the door would only remain closed as long as the opening and closing forces increase at exactly the same rate with rising pressure differential. In practice, the elastic deformation of the door and of the cabin structure, although small, will cause non-linear changes of these forces with increasing pressure differential. A pressure will then be reached at which the total out of balance claw catch forces will exceed the frictional forces and when this happens, the primary mechanism will either move to the fully closed position or to the open position. In the latter case, the door will then open. There is no reason to believe that the mechanism will remain closed throughout the climb and cruise phase of flight, and yet open during descent.

In both these examples, the opening of the unsecured door would take place sometime during the early stages of cabin pressurisation. In contrast to this, PL's door remained attached throughout the rising pressure cycle and the steady pressurisation phase of the cruise and then only opened when the cabin pressure had been almost exhausted. This behaviour is most unexpected and inconsistent with the above hypotheses and it was concluded, therefore, that the explanation for the door's opening lay in something more unusual than just being improperly closed.

3) A decision was taken to rebuild the damaged door in order to try to re-establish the pre-crash condition of its operating mechanisms to see if this could give some indication of the cause of the door's opening.

An examination of the accident door before it was rebuilt revealed no pre-impact damage or excessive wear in its operating mechanism, with the exception of the condition of the fixed cam. On completing the reconstruction, however, it was discovered that the movements of the top and bottom pairs of claws were not synchronised and because of this, when the outside handle was used to close the door mechanism, the lower two catches geometrically locked but the top pair failed to overcentre. With the linkages in this condition the secondary lock plungers could not engage on any of the claws. It was also found that the same effect could be achieved by closing the door using the internal handle but without applying any great force to the handle. However, it was still possible to lock the door mechanism securely by the inner handle provided that sufficient force was applied to the handle because some elastic deformation of the structure and mechanism was taking place.

In order to preserve the evidence within the accident door, another door was rigged with its primary locking mechanism in the same adjustment state and this was then subjected to tests in a specially devised rig to see what would happen when loads simulating cabin pressurisation were placed upon it. The door was set with its claw linkages in the unsychronised condition which was associated with closure by the outer handle or incomplete closure using the inner handle. It was found that the door remained closed during a series of loading cycles with a steadily increasing peak load until a load cycle with a peak of 3.0 psi was applied. During reduction of loading from this figure, all four catches suddenly released and the door mechanism suddenly opened at a load equivalent to a 1.0 psi pressure differential.

The positions taken up by the claw linkages in the rebuilt door when closure was made using the outside handle or the inside handle with light forces, represents in terms of the total angular travel of the linkages, a difference in the movements of the top and bottom pairs of claws which is far beyond what could be expected to result from normal wear. Although there may be some reservations as to whether a damaged structure can be rebuilt to reproduce its exact pre-damage dimensions, the errors which were introduced during this reconstruction were not sufficient to produce the loss of synchronisation in the linkage's movements which appeared necessary to cause the unusual door behaviour. It is considered therefore, that the reconstructed door did reflect its pre-accident condition. The different diameter and appearance of the locking wire at the end of an operating rod in the only part of the door mechanism accessible without removing the door from its hinge and the inside skin from the door, could be significant. It suggests that an adjustment may have been made to that rod length subsequent to the previous setting up of the mechanism.

To summarise, it can be said that the last of the series of rig tests produced a loading cycle on the door which approximately reproduced the loading cycle estimated to have been applied to the door of PL by the cabin pressurisation system during the accident flight. During this test the door in the rig behaved in the same unexpected manner as did the door on PL, that is, it remained closed during application of the highest loading, but opened as the loading decreased and at a load corresponding closely to that believed to have been acting on PL's door when it opened. This unusual behaviour of the door in the test rig was the result of the incompletely locked and unsynchronised state of its mechanism which in turn was largely the result of the incorrect state of adjustment of that mechanism. This setting had been copied from the settings of the corresponding parts of the reconstructed door from PL. In the absence of any other reasonable explanation, therefore, it is considered that the door of PL opened because it was in an incompletely locked condition with the bottom pair of claws geometrically locked and the top pair unlocked. This condition was the result of the mis-rigging of its locking mechanism and the manner in which the door was

closed which failed to ensure full engagement of the locks. The unlocked condition must have existed at the time of take-off from Gatwick.

2.4 Door unsafe indications

Although the mis-rigging in the primary locking mechanism was indirectly responsible for the partially locked condition of the door, the factor which was the primary reason why the opening occurred was that the aircraft was allowed to start the flight without the door being properly locked. If the door's condition had been detected prior to take-off then the subsequent events would have been avoided. It is possible, at any time, for a door to be closed but not properly secured before the start of a flight and this is one of the reasons why the BAe 748, in common with most other types of aircraft, is equipped with warning devices. These, in conjunction with specially devised procedures, are intended to alert crews to the presence of an unsecured door.

The baggage door warning arrangements on the BAe 748 relied on the secondary locking plungers being in the closed position for the 'door unsafe' warnings to disappear. In the case of PL, the secondary locks could not have been engaged and therefore, before the aircraft departed Gatwick, the crew should have been alerted to the fact that the baggage door was not properly locked. Clearly, however, the circumstances at that time failed to arouse them to the presence of this condition for they would not have knowingly accepted the aircraft with the door not fully secured. The warning systems on PL have therefore been examined in conjunction with the operating procedures used by the crew, to assess just how effective they might have been in actual operational conditions.

2.4.1 Mechanical indicators

Given the improperly locked state of the baggage door at take-off and the insecure secondary locks, the mechanical indicators would normally have been expected to show a predominantly red aspect with some of the green/yellow section also visible. However, several significant factors came to light during the investigation concerning the appearance of the indicators on PL. These were that the viewing windows were not positioned with their normal orientation; the presence of the considerable amount of backlash in the drives of the indicator drums (as typically found on BAe 748 aircraft); the scratching away of some of the red over-paint on the drums which allowed some of the green/yellow section previously covered to become visible again making an indistinct boundary between the two sections, and the poor lighting condition in the rear vestibule. The effects of these factors have been discussed in sections 1.17.2 and 1.17.3 but the overall result is that the mechanical drums were capable of giving a misleading appearance in which the presence of the red indication became less pronounced if not totally obscured. It also came to light during the investigation that

crews flying BAe 748 aircraft had come to accept the presence of a small amount of red in an indicator window as a not 'unsafe' indication. The reason for this was that experience had shown that BAe 748 aircraft door indicators occasionally exhibited some small amount of red indication although their secondary lock plungers were fully engaged.

The fitting of windows, as installed on PL, in removing a source of friction from the indicator drums, allowed them to move freely within the limits of their backlash. Thus in flight, under even slight conditions of turbulence, there is reason to believe that the indicators would have occasionally moved some distance upwards revealing more of the red section. Therefore, with different lighting conditions and with a different position of the observer's eye, it is conceivable that it would be possible to detect a 'door unsafe' condition in flight which was not evident on the ground although no secondary lock movement had taken place between the two viewings.

It is not known for how long the orientation of the viewing windows as found after the accident had been in existence. The windows would have had to be removed when the external handle's spindle was replaced 5 days before the accident and it is probable that they were re-installed with their accident orientation on completion of that work.

To sum up therefore, it is considered that the mechanical indicators could have given either a completely green/yellow striped appearance to the person checking the door or one in which the amount of red which was visible was not sufficient to cause any alarm to the observer. The probable reasons why the PA noticed in flight that the indicators were showing red were that the drums had moved upwards due to turbulence or vibration and that he was looking at them from a different eye position and in different light conditions.

2.4.2 *Flight deck warning system*

The warning light on the commander's instrument panel and the warning system appear to have been serviceable prior to the accident flight and it would have become apparent during the pre-start checks on the accident flight whether the bulb was broken and needed replacing. The light should have remained illuminated after all the doors had been shut because the failure of the baggage door secondary plungers to engage would have meant that their associated micro-switches would not have closed. This matter would then have been discussed by the crew but it is not known whether such a conversation took place because the CVR retained only the last 30 minutes of flight. However, the interval between the time that the commander closed the front freight door and that when a radio request to ATC for engine start-up clearance was made, appears to have been only approximately three minutes. Considering that the commander had to settle in his seat and perform the pre-start checks, this does suggest that any delay to the crew's normal duties was not of a prolonged nature. Later in the flight, the pilots did not refer to the light during any of their discussions after the conditions of the mechanical indicators had been reported but it is not possible to deduce from this whether it was illuminated at the time nor whether it had been at any other period in the flight.

The warning circuit is so arranged that any failure of continuity in the circuit causes the light to remain 'on' regardless of door mechanism position. A failure within the warning system relay could possibly cause the light to remain extinguished even though a door was unsafe. The relay from PL was recovered undamaged from the wreckage and found to be functioning correctly. The possibility of the light being extinguished from some other reason was the subject of further consideration. The theory was advanced that a short-circuit between the two adjacent conductors of the warning system in the section where they pass from the fuselage to the baggage door, could cause the light to extinguish irrespective of whether all or any of the micro-switches within the door were in the open position. In this area the conductors pass from a terminal block on the fuselage onto the door hinge and through a conduit attached to the underside of the hinge before passing into the door and connecting with a further terminal block. To achieve the short-circuit, the covering around both conductors would need to be damaged in order to allow them to come into contact with each other. If contact was made then a circuit could be completed which would by-pass the micro-switches within the door, enabling the warning light to extinguish even though the affected door was incorrectly locked. The relevant section of PL's wiring was not recovered from the wreckage and there is therefore no evidence to assess whether such a short-circuit could have occurred.

There is, therefore insufficient evidence to reach a conclusion about whether PL's door warning light was illuminated when the aircraft departed Gatwick. The hardware evidence indicates that it should have been but the possibility that it was extinguished cannot be eliminated. Without that warning the crew would not have been independently alerted to the unsafe state of the baggage door.

2.4.3 Appearance of the handles and the claw catches

It was established during the investigation that the external handle on the baggage door took up its 'locked' position when the door operating mechanism was in the partially locked condition with only the bottom pair of claws geometrically locked. The external appearance of the door, therefore, would not have looked unusual to anyone on the ground making a visual inspection of the aircraft. The ground crew assisting with the departure did in fact make a visual external check that the doors were closed. The aircrew would check the internal appearance of the door as part of their own pre-departure procedures. In practice this means ensuring that the inner handle is stowed correctly and that the claw catches are in position. After the handle has been rotated upwards to engage the primary claw catches its final movement, which operates the secondary locking mechanism, is towards the door. The range of this movement is small and changes in the handle position are difficult to detect. When the internal handle of the reconstructed door was set in the 'pre-departure' condition, it was found that it had nearly completed its full travel and that a standard transparent hinged cover could be fully closed over it. It is considered that in this position, the handle could have had every appearance of being stowed according to where the observer was standing.

There is very little movement of the claws from the time that they start to exert pressure on the fretting pads on the door aperture until their linkages have completed their full travel. It is also almost impossible to see whether the linkages are fully geometrically locked. A visual examination of the claws, therefore, serves very little purpose because it cannot detect an unlocked condition. Indeed the claw's apparently reassuring appearance could easily overshadow the importance of the other factors involved in the door's security.

2.4.4 *Summary of door indications*

To sum up, therefore, the flight deck crew's knowledge of door security was provided by the operation of the 'door unsafe' warning light. The actual security of each door was checked by visually inspecting the positions of the claw catches and the inner handle, and from the indications on the mechanical indicators. In the case of PL, it is considered that the appearance of the claws and the handle on the baggage door would have been most unlikely to have alarmed the person checking the door and that viewing conditions could have made it possible for him to misinterpret the mechanical indicators and conclude that the door was correctly locked. Although the door warning light should have remained illuminated, the possibility that the light was extinguished at departure cannot be eliminated and that, therefore, the pilots were unaware that the baggage door was not safe. Even if the light had been on, the crew were entitled to accept the aircraft provided that 'the doors were closed and locked under the Captain's supervision'. As has been pointed out, however, it was impossible to check visually whether the claw linkages were overcentred or the secondary lock plungers extended, which was the only positive way to ensure door safety. The crew, therefore, had again to rely on the visual indications and appearance of the door. It is thus easy to see how the absence of precise information on the position of the lock mechanisms, could have led the crew into accepting the door when it was in an unsafe condition.

2.4.5 *General observations on the door warning philosophy*

It was not an uncommon experience on BAe 748 aircraft for the door warning light to illuminate, particularly in flight. Most of the airborne warnings seem to have originated in the operation of the door sill micro-switch. When the cabin is pressurised the top and bottom edges of the doors are pushed slightly out of their aperture and if the striker plate is damaged or not accurately set then the micro-switch may open sufficiently to cause the light to illuminate. It has been found by the flight crews that a reduction in the cabin differential pressure will usually cause the light to extinguish. At one time several flights were made on PL with the warning light illuminated throughout until the defect was traced to a faulty micro-switch in the forward freight door. This practice was acceptable as an unserviceable warning indication was included in the operator's Minimum Equipment List. However, it is not desirable to have a warning system frequently operating particularly when it is caused by conditions which the crews associate with a safe situation. This downgrades the authority of the warning system and is likely to lead to crews disregarding a genuine emergency condition.

The single warning light served all three doors, making it more difficult to trace the cause of its illumination. This could have been one of the reasons why some of the defects recorded with the warning system remained for as long as they did before they were successfully rectified. What is more important, however, is that the light was illuminated by the operation of micro-switches within each door which had two different functions. One pair of switches indicated whether the secondary locks were engaged and the sill switch simply confirmed that the door was in its aperture. The first was a vitally important function, the second one that was less so. It is unfortunate that most of the 'false' warnings were given by the second system because this creates the sort of situation where the seriousness of a true emergency condition, that is the withdrawal of the locks, gets overlooked. It is considered that an appraisal of the electrical warning system could be made with advantage in order to achieve easier fault finding and improved information to the crew.

Company procedures permitted a flight to be undertaken with the warning light illuminated, provided that a physical check was made of the doors and they were confirmed to be all safely locked. As has been shown, however, examination of both the handle, the claws and the mechanical indicators could be highly misleading. The only certain way of guaranteeing that the door is secured is to examine the state of engagement of the secondary lock plungers. However, this cannot be done without removing the door trim and consequently the crew are forced to rely, in the final analysis, on the appearance of the mechanical indicator drums. As already stated the way that PL's were set was thoroughly misleading. It must be emphasised, however, that a progressively changing colour aspect is not a satisfactory way of providing a remote indication of the positions of plungers which must move a minimum distance downwards to ensure safe locking of the door. In the absence of the development of a completely reliable secondary lock position indicating system, it is essential that some means be established to enable the crew to view directly the engagement of the secondary lock plungers.

2.5 Pre-departure activities at Gatwick

The aircraft spent most of the day on the ground at Gatwick and the baggage door was certainly open for part of this period. It has, however, not been possible to establish when it was closed for the last time before the aircraft's departure. The consensus of the evidence indicates that this occurred prior to the loading of the mail and it is probable that the door was shut by someone who was simply making the door secure while the aircraft was parked during the day. If that is the case there is no reason why that person should have ensured that the door was correctly locked since he was not involved in, nor responsible for, dispatch of the aircraft. This could account for the door being in its unsafe condition at the time of the take-off particularly if, as seems likely, the door was closed from the outside in which circumstances it would have been impossible to overcentre the top pair of claws.

The crews pre-departure duties called for an inspection of the doors to be made before the aircraft took-off. It is, however, possible for a person looking at an already closed door to be deceived by its appearance and imagine that it is fully secured. If, for example, a crew member or other competent person had actually closed PL's door using the inner handle, there is a strong possibility that the way in which it functioned would have been noticed. After the accident revised procedures were introduced which ensured that a member of the operating crew was involved in the closing of the doors from inside the aircraft. This is a sensible precaution which is less likely to result in mistakes being made about the door's security.

2.6 First indications of unusual circumstances

The evidence indicates that the first part of the flight was uneventful with the crew carrying out their duties in a relaxed but competent manner and showing no signs of anxiety. The PA's report to the commander that the mechanical indicators on one of the rear doors were showing red was the earliest indication from the CVR evidence that something abnormal had occurred. This report was made shortly after the PA had returned to the rear of the cabin after making tea for the pilots. It is not known what drew his attention to the door but it may be that excessive noise from the seal made him look at it. Since on this particular flight he probably used one of the fixed passenger seats in the rear of the cabin in preference to the folding attendant's seat as his seated position and therefore would not have been sitting adjacent to the baggage door, this was possibly the first time that he had inspected it since departure. It is clear from his comments that the amount of red showing in the indicators caused him concern and he returned immediately to the flight deck to report his findings. He must also have examined the door handle but unfortunately his comments on its condition were too indistinct on the CVR tape to decipher.

The PA indicated that the door concerned was the 'REAR PORT PASSENGER DOOR'. Post-impact examination showed that this door was still in its aperture when the fuselage struck the ground. A thorough examination of the rear section of the fuselage revealed no evidence of in-flight structural failure of the fuselage that might have affected the security of both rear doors. It is concluded, therefore, that the PA mistakenly identified the door when making his report and that it was the baggage door to which he was referring. In the event the misunderstanding had no effect on the outcome.

When the PA made his report the aircraft was on its initial descent in preparation for the landing at Castle Donington. The commander's remarks indicate that he was seriously concerned about the security of the door and the damage it might do if it came off and hit the tailplane. The precautions he took in reducing speed and depressurising the cabin were sensible and in the light of the knowledge available to him there was nothing further he could have done.

2.7 Significance of entries in PL's technical log

PL's defects log contained many references to defects on the doors, most of which were related to the passenger and the baggage doors. The majority of these defects referred either to noisy doors or to the illumination of the door warning light. Most of the noise, which at times was sufficiently loud to worry the passengers, seems to have been caused by seal leakage and disappeared when the damaged seals were either repaired or replaced. Occasionally, however, adjustments were made to the fretting pads in order either to help reduce the noise or to ease operation of a door which had become difficult to open or close. The majority of the door warning light defects appear to have been caused by damage or loss of adjustment to the striker plate associated with the door sill micro-switch.

There was no reference in the aircraft's documentation to any adjustment having been made to the baggage door's locking mechanism. The personnel who shortly before the accident changed the lower spindle on which the external handle was mounted, stated that they did not disturb any part of the mechanism within the door. In October 1980 a serious leakage was reported in which cabin pressure was so badly affected that the cabin altitude could not be reduced below 8,000 feet while the aircraft was at FL 130. At first sight it might appear that this was the result of the incorrect adjustment which was discovered during the investigation. The absence of references to door leakage during the numerous subsequent flights could well be explained by the door being correctly closed on these occasions, since the tests showed such closure was possible. However, an analysis of the circumstances of the October 1980 report and of other reports which were made on door leakages after this, showed that the door did not react in the way that the tests demonstrated it should have if the claws were incorrectly locked. For example, seal leakage took place on two occasions at pressure differentials above 3.5 psi and according to the tests, if these leakages were caused by the mis-rigging, then the door would have opened during the descent. Additionally the secondary locks would have been disengaged causing the flight deck warning light to be illuminated throughout the flight, provided the warning system was serviceable. There was no reference to such an event in the technical log and the only reports on light illumination concerned occasions when the light came on in flight and these did not coincide with the door leakage reports. For these reasons, it is difficult to see how the leakage problems reported can be attributed to the mis-rigging found during the investigation; nor has it been possible to deduce from the technical log entries any occasion when the locking mechanism may have been adjusted.

It was therefore not possible to establish when the mechanism first became incorrectly adjusted. Indeed it is not easy to see why such an adjustment should have been made. It is possible that someone considered that the state of adjustment of the mechanism itself was the cause of either the leakages or the door stiffness. The state of wear of the fixed cam was in itself quite capable of causing stiff operation of the mechanism yet the significance of this wear would have been far from obvious to someone having no intimate knowledge of the operating principles of the door mechanism. Reference

to the manufacturer's approved maintenance manual would not have highlighted the critical importance of preserving the cam profile to ensure easy operation of the door mechanism. Again, the maintenance manual describes procedures for adjusting the door mechanism without emphasising that such adjustment is only appropriate to initially setting up the door mechanism and that any need to adjust it again is an indication of a failure or a state of unacceptable wear in the moving parts of the locking mechanism. It is interesting to note that the adjustment point found to have the unusual wire-locking is the only adjustable part of the mechanism which is accessible without removing the door from the aircraft and unriveting the inside door skin. This rather suggests that the adjustment was made as part of an attempt at fault rectification with the door still installed on the aircraft rather than during a major programme of work on the door.

In order to remove the lower spindle on which the external handle was mounted, it would have been necessary to remove the door trim which in turn would have required the removal of the indicator windows. As previously stated, these windows did not have their normal orientation at the time of the accident. When, during subsequent examination, the windows were offered up to their mountings with normal orientation, it was found that they fouled the surface of the revolving indicator drums. In the absence of any specific instructions on how to fit the windows, it might very well appear to the person replacing them that this interference between window and drum indicated that this was not the correct way to position the windows. This could account for the windows being set up in the manner in which they were found. It is interesting to note that a number of other aircraft were also found to have incorrectly installed windows, and that these included at least one aircraft belonging to a different operator.

2.8 The role of the fixed cam

The fixed tufnol cam, which guides the movement of the handle, gets gradually worn in service. The profile of each cam is different and it therefore becomes difficult to determine how much wear a cam has suffered. The effects of a worn cam are that the movements of the primary and secondary locks, which should be separate and consecutive, run into one another. The result is that when the door is being shut, the secondary plungers start to move too early and interfere with the claw linkages. More force is therefore required to move the handle and the door becomes more difficult to close. At the time of the accident there was no means of determining how much wear each cam had received, nor were there any precise instructions as to when a cam should be replaced.

Widespread cam wear led to the stiff and difficult operation of many doors throughout the operator's fleet of aircraft. This general tendency could have helped to obscure the fact that PL's door had a mechanical problem. It could also have helped to obscure the fact that the closure sequence was not completed on the last occasion the door was closed prior to the accident flight.

2.9 General door design considerations

Many early pressurised airliners had doors which opened inwards and were thus held in the closed position during pressurised flight by the cabin pressure differential, regardless of the condition and position of the locking mechanism. Experience showed, however, that emergency escape through such an exit could be rendered impossible by the need to move the door inwards against a crush of people trying to use that exit. This hazard was one of a number of factors which influenced design thinking in favour of outward opening doors and this is reflected in the British Civil Airworthiness Requirements (BCAR) current at the time that the BAe 748 was first developed. Although inward opening doors were not specifically excluded by this document, it would have been difficult to comply with the requirements unless outward opening doors were used.

The use of outward opening doors, however, imposes a requirement for very careful design of the locking mechanism to eliminate the risk of an improperly locked door opening under the effect of cabin pressure. Many aircraft types have used a system of linear shoot-bolts in the door structure engaging in cylindrical recesses in the door aperture frame. This system, although holding the door securely closed even if the shoot-bolts are not driven quite fully home, has the drawback that any distortion of the door aperture occurring in a survivable accident would render the door impossible to open. The need to guard against this risk of doors jamming was also stressed in the BCARs current at the time that the BAe 748 was designed.

The problem has been approached on some more recent aircraft by using doors of complex geometry having a small initial inward opening motion followed by an outward movement so arranged that the door comes to rest alongside the fuselage and clear of the aperture. These doors are intended to combine the in-flight security of the inward opening door with the ease of escape normally associated with outward opening doors.

The BAe 748 door design does not fall conveniently into any of these categories but is directed towards easy emergency evacuation by opening outwards and by eliminating shoot-bolts. The door's security in flight depends on the correct positioning of the geometric lock situated at each catch position. However, a number of incidents shortly after the type entered service indicated that the mechanism could not be fully relied upon in airline service conditions. Accordingly modifications were carried out which introduced the secondary locks, together with a flight deck door warning system, barometric locks and certain other features. Since the introduction of the modifications only one instance is known of a door of the passenger or crew/freight type opening in flight and experience has shown that the general concept of the door design is sound. However, the service history of the baggage door is not so satisfactory and this strongly suggests that detailed differences in the design and operating procedures between that door and the others on the aircraft are the cause of the many instances of baggage door opening which preceded the accident to G–ASPL, rather than the fundamental door design.

2.10 Incidents and the baggage door

It is strange that, since the introduction of the modifications which included the secondary locking system, almost all of the BAe 748 door opening incidents have involved baggage doors. This door, although it shares the same general method of operation as the other two doors on the aircraft, nevertheless differs in several ways from them. These differences and the manner in which the door is operated perhaps give some clue as to how the security of the baggage door can be improved. The main points are summarised below:-

(a) If one pair of claw linkages in a door fails to overcentre then there obviously will be some very complicated forces acting within the door mechanism once the cabin is pressurised. The forces exerted by that set of claws will be in a direction tending to make the door open whereas those associated with the other claws will be in a direction tending to drive the mechanism to the shut position. Since the baggage door is equipped with only four claws, it then becomes a question of the action of one pair of claws against the other and either pair may prove dominant. With the other two doors, however, a pair of unlocked claws will be acting against two pairs which are geometrically locked since each door has six claw catches. It is considered therefore that, in any situation where a pair of claws remains unlocked, there is a greater probability for a baggage door to open than there is for it to happen to either the passenger or the freight door.

(b) The viewing windows of the mechanical indicators on the baggage door are attached to the inside skin of the door while the indicator drums are pivoted from brackets attached to the outside skin. The other two doors, however, have their indicator viewing windows attached to brackets which also carry the pivots of the indicator drums. The design of the mountings of those windows makes it easier to install the windows correctly and more difficult to install them incorrectly than is the case with the indicator windows of the baggage door. The viewing window mounting design makes the relative positions of the transparency and drum more repeatable during production than does the system on the baggage door which relies upon the skill of the fitter and quality of subsequent inspection to ensure accurate positioning. It is considered therefore that in the case of the baggage door there is more scope for incorrect positioning of the windows relative to the drums allowing ambiguous indications to appear than is likely to happen with the windows of the other two doors.

(c) The inside handle on the baggage door is positioned nearer the cabin floor than that on the passenger door. The result is that it is more difficult to exert high forces when closing the baggage door, increasing the possibility of leaving the door shut but not fully locked. The position of the handle also gives the operator standing adjacent to a closed door a downward oblique view which makes it more difficult to see whether the handle is correctly positioned in the closed detent when the cam profile is worn, than is the case with the higher handle on the passenger door.

d) The baggage door is not normally used for crew or passenger entry and there is reason to believe that, before the procedures were changed, it was frequently closed by ground personnel using the external handle. This increased the possibility of only part of the locking mechanism being engaged. The baggage door is also more likely to be the first door to be closed and therefore it is far less easy to detect a short circuit in the electrical warning system adjacent to that door than a comparable fault elsewhere in the system.

It is considered that factors such as these affected the baggage door to a greater extent than the other doors and therefore increased its susceptibility to incorrect closure resulting in more frequent opening incidents.

2.11 Dissemination of aircraft incident data

It transpired after the accident that the manufacturer had records of 4 previous occasions when a passenger door had come open in flight and 35 instances where the baggage door was involved. These latter were spread fairly evenly over the years that the BAe 748 had been in service and all but three had concerned overseas operators. Although 35 may appear as a statistically small number in comparison to the number of occasions that the doors on this short-haul type of aircraft must have been used, nevertheless the number is significant when it concerns something which is likely to threaten the safety of the aircraft. Judging by the numerous occasions on which defects related to the doors have been reported, it would appear that door operations in general on the type have given considerable trouble in airline service. The questions that have to be asked, therefore, are whether the design of the door, notwithstanding its merits, was satisfactory for everyday use and also whether the accident was avoidable because the continuing reports of incidents involving door openings should have given a warning that further preventative measures were necessary.

It appears that the list of reports on opening incidents was compiled on the basis of information received, much of which was vague and incomplete. Naturally, the opening of a door at the commencement of a flight where no damage was suffered was not the sort of event which was likely to be widely notified. In fact some of the incidents only came to light because the operator of the aircraft requested another door to replace one which had been damaged or lost. There was no obligation on the manufacturer to pass this information on to the United Kingdom Airworthiness Authorities even after the introduction of the Mandatory Occurrence Reporting System (MOR) except where a defect which affected the continuing airworthiness of the product was involved. From 1976, defect meetings were established on a more regular basis than hitherto, and between that time and the PL accident 15 door opening incidents had been reported. Minutes of these meetings were sent to the CAA. However, only two incidents became known to the Safety Data and Analysis Unit (SDAU) and were recorded in the MOR information bank.

After the first opening incidents occurred the manufacturer introduced a series of modifications to all three doors which included the provision of secondary locks. These seem to have solved the problems with the passenger doors and the only known major incident reported subsequently with such doors was the result of a defect introduced into the door mechanism during maintenance. However, the baggage door incidents continued to occur. Because most of the offending doors opened during the initial climb, there seems to have been a tendency on the part of the manufacturer to attribute the cause to a failure on the part of the crew to ensure that the door was fully locked at departure time. This assessment was probably justified in many cases, particularly as there was no evidence to suspect the effectiveness of a correctly locked door mechanism in ensuring the security of the door.

Further modifications made at manufacture and advised to existing operators called for simple changes to door marking and indication arrangements to emphasise the reponsibility of the crew for checking the security of the baggage door from within. However, the number of continuing incidents showed how easy it was to appear to have shut the door and assume, incorrectly, that it was fully locked. Their numbers should have been sufficient to indicate an urgent need for investigation and rectification of their underlying causes. It should have been recognised that the people who were making these apparent mistakes were well trained aircrew who could be expected to be very conscious that their actions might affect the safety of the aircraft and therefore that there was likely to be something more significant than simple negligence. The lesson which the number of incidents should have highlighted was that the door mechanism, although it appeared both in theory and when operated in perfect conditions to be satisfactory, nevertheless, was giving rise to errors when exposed to everyday airline operations. What is most important is that it should have become apparent that the warning systems were not reliably doing their job in alerting the crews to the condition of the door locks before take-off. Comment has already been made about the ambiguities that these systems could create.

It has to be stated then, that the many occurrences should have brought about a more positive recognition that the operation of the baggage door was not satisfactory and required further consideration. However, in mitigation, it has to be said that the infrequency of the incidents, the way that they came to light and the long period over which they were spread was not conducive to giving great cause for concern. It also has to be said that the dangers which may arise from the opening of a door on any type of aircraft have probably not been given the recognition they deserve throughout all sections of the aviation industry. Finally, it has to be recognised that during the period when many of the incidents occurred, the only system for collecting and analysing reports such as these was the informal system of communication between the manufacturer and its customers.

Therefore, although it is easy to say with the benefit of hindsight that the unsatisfactory history of operations of the baggage door when exposed to airline use should have been apparent, it is easy to see why it was not. The main lesson from the circumstances of the accident is that in the present day context the MOR system was not effective in giving warning of the dangerous trend of door open incidents. In this particular case the weakness was that it failed to acquire most of the data relevant to a British manufactured aircraft type with many examples on the British register when most incidents occurred on overseas registered examples. This is most undesirable since as the certification authority of the state of manufacture, the CAA is the body to whom operators worldwide should logically look for guidance. Quite obviously significant occurrences reported to the UK manufacturer of a widely used type are the major sources of in-service data and no occurrence reporting system can be very useful if this vital information from overseas is not included in the data bank.

2.12 Post-accident actions, operational considerations

Measures taken after the accident are outlined in section 1.17.8 and appendix B. In addition to actions affecting the technical aspects of the doors, they included revised operating procedures to be followed by flight crews both in their pre-departure door checks and when airborne. It is perhaps worth mentioning the dilemma which appeared when attempts were first made to devise a procedure which crews could adopt if an unlocked door indication appeared in flight. The obvious instruction to depressurise the cabin in order to reduce the air loads on the door, had been tried by the crew of PL. It was feared that this action, far from preventing the door from opening, might actually have inadvertently precipitated the event.

Although it was not unusual on BAe 748 aircraft for the 'door unsafe' warning light to illuminate in flight, it appears that only rarely did an unsafe condition of the mechanical indicators become apparent in the air. At the time of the accident there were no instructions in either the aircraft's flight manual or Dan-Air's operations manual on the procedures to adopt should a 'door unsafe' indication appear. The commander of PL, with no guidance as to what to do, acted in a sensible manner according to the knowledge at the time in depressurising the cabin and slowing the aircraft down. The wind tunnel research carried out after the accident suggests that lowering some flap when the security of the door is suspected, may help in keeping an aircraft away from the critical areas of pitch discontinuity should a door lodge on the tailplane leading edge although the subsequent measurements of elevator hinge moments in this condition indicated that control of the aircraft would be extremely difficult over wide speed ranges which were previously thought to be little affected, flaps up or down. Flight Manual amendments prepared by British Aerospace giving drills to be used following a 'door unsafe' warning are being processed through the Civil Aviation Authority. These drills cover visual inspection of doors, pressurisation procedures, and flight procedures. The latter recommend flap selection and speed

reduction aimed at making it probable that if a door should detach it would not remain lodged on the tailplane leading edge as in light of the wind tunnel tests it is not considered possible to make any practical recommendations as to how to fly the aircraft in that condition.

2.13 Limitations on CVR capacity

Current legislation requires that a CVR has a duration of 30 minutes. For this reason, the record of crew conversations during the pre-departure checks, take-off and initial climb-out of PL had been erased by the time the aircraft crashed. Because the circumstances of this accident started with the dispatch of the aircraft with an unlocked door, a recording of the events during the earliest phases of the flight would have materially assisted in the investigation. In the case of landing accidents it may also be important to learn what was discussed in the approach and landing briefings and since these frequently take place more than 30 minutes before the accident occurs, the relevant information will no longer be retained on the CVR tape. The CVR has become a very important part of the investigator's equipment, often providing more than just speech information, and the limitation on the length of the recording is often a major handicap. It is therefore recommended that CVR equipment be required to retain more than just the previous 30 minutes of information.

3. Conclusions

(a) *Findings*

(i) Both pilots were properly licensed and well experienced; the PA had received company training in his duties.

(ii) The aircraft had a valid Certificate of Airworthiness and its documentation was in order.

(iii) The aircraft had been maintained in accordance with an approved maintenance schedule and its defects log contained no outstanding items relevant to the accident.

(iv) The baggage door opened during the initial descent into the destination airfield, separated from its hinge assembly and then struck and remained fixed to the leading edge of the right tailplane.

(v) The presence of the door on the tailplane modified the airflow in such a way that the aircraft became uncontrollable.

(vi) The aircraft became overstressed during a series of involuntary, violent pitch oscillations and suffered a complete structural failure.

(vii) The door opened as a result of the release of the four claw catches; the unusual circumstances of its opening during cabin depressurisation were the result of the top pair of claws not being geometrically locked while the bottom pair were overcentred, with the secondary locks disengaged.

(viii) The unlocked condition was present when the aircraft started its flight and was made possible by a mis-rigging in the primary lock mechanism which allowed the top and bottom pair of claw catches to lose their synchronisation.

(ix) It was not possible to determine whether the flight deck warning light was illuminated at the time of departure.

(x) The crew were unaware until a late stage in the flight of the unsafe condition of the baggage door and this was due to a combination of shortcomings in the design, construction and maintenance of the door warning systems and the appearance of the visual indications.

(xi) There was insufficient guidance in the maintenance manual to ensure that the mechanical indicator's viewing windows were correctly orientated.

(xii) It was not possible to establish when the door operating mechanism was last rigged.

(xiii) The condition of the operating mechanism made it impossible to lock the door fully using the outside handle; however, the door was capable of being fully locked by the inside handle.

(xiv) The door was probably last closed from the outside and at some appreciable time before the aircraft's departure.

(xv) All the crew members were on the flight deck when the door opened; the crew reacted properly to the 'door unsafe' condition and, within the knowledge then available, took appropriate action to minimise the risk to the aircraft.

(xvi) Existing incident reporting procedures proved to be unreliable in drawing attention to the fact that a UK manufactured aircraft type operating mainly overseas was suffering from a recurring problem of door openings.

(b) *Cause*

The accident was caused by the baggage door becoming lodged on the leading edge of the right tailplane after it had opened and detached in flight. This produced changes in the aerodynamic characteristics of the aircraft which rendered it uncontrollable resulting in over-stressing of the wings and tailplane leading to an in-flight structural failure. A contributory factor was the mis-rigged state of the door operating mechanism which allowed the top and bottom pairs of claw catches to lose synchronisation. The failure of the door warning arrangements to give adequate warning of door safety was a further contributory factor.

4. Safety Recommendations

It is recommended that:-

1 A review be conducted on the BAe 748 door indicating and warning systems to remove unreliable and ambiguous indications and appearances with particular reference to:-

(a) The desirability of making the critical elements of the locking mechanisms visible from inside the aircraft.

(b) Improving the operation of the mechanical indicators to give a positive indication only when the door is completely safe.

(c) That barometric and speed locks (if fitted) be less critically dependent on the exact position of the secondary locks for engagement to be possible.

2 The electrical warning system be reviewed to improve the reliability in flight deck warnings and to assist in identifying the location of any unsafe lock.

3 The CAA and the manufacturer review the BAe 748 approved maintenance manual to improve the guidance to operator's personnel on fault diagnosis and wear limits on the more subtle mechanical systems of the aircraft such as the door mechanism.

4 The CAA discuss with operators and manufacturers the introduction of an effective system to identify, analyse and eliminate recurring defects.

5 The MOR system be extended to require UK aircraft manufacturers to supply information on occurrences to their aircraft operating on overseas registers which come to their notice.

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