AIRCRAFT ACCIDENT REPORT 6/92

Air Accidents Investigation Branch

Department of Transport

Report on the accident to British Aerospace ATP, G-BTPE at Sumburgh Airport, Shetland Isles, on 23 December 1991

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents) Regulations 1989

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Department of Transport
Air Accidents Investigation Branch
Defence Research Agency
Farnborough
Hants GU14 6TD

4 December 1992

The Right Honourable John MacGregor
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr M M Charles, an Inspector of Air Accidents, on the circumstances of the accident to British Aerospace ATP, G-BTPE, that occurred at Sumburgh Airport, Shetland Isles on 23 December 1991.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	-	Air Accidents Investigation Branch
ATC	-	Air Traffic Control
ATIS	-	Automatic terminal information service
BA	-	British Airways
BAe	-	British Aerospace
BCAR(s)	-	British Civil Airworthiness Requirement(s)
°C	-	Centigrade (Celsius)
CAA	-	Civil Aviation Authority
CAP	-	Civil aviation publication
EAS	-	Equivalent airspeed
FDR	-	Flight Data Recorder
g	-	normal acceleration
hrs	-	hours
IAS	-	Indicated Airspeed
ICAO	-	International Civil Aviation Organisation
ILS	-	Instrument landing system
JAR	-	Joint Aviation Requirements
kg	-	kilogram(s)
km	-	kilometres
kt	-	knot(s)
lb feet/rad	-	pound feet per radian
lbf/in	-	pounds force per inch
M	-	Mach number
°M	-	Magnetic
MATS	-	Manual of Air Traffic Services
mb	-	millibar(s)
nm	-	nautical mile(s)
RAF	-	Royal Air Force
°T	-	True
UTC	-	Coordinated Universal Time
UK	-	United Kingdom
V_C	-	Design cruising speed

Air Accidents Investigation Branch

Aircraft Accident Report No: 6/92

EW/C91/12/3

Registered Owner:		British Airways
Operator:		British Airways
Aircraft:	Type:	British Aerospace ATP
	Nationality:	British
	Registration:	G-BTPE
Place of Accident:		Sumburgh Airport, Shetland Islands Latitude: 59°53'N Longitude: 001°18'W
Date and Time:		23 December 1991 at 1308 hrs All times in this report are UTC

Synopsis

The accident was notified to the Air Accidents Investigation Branch (AAIB) at 1440 hrs on 23 December 1991 by British Airways Safety Services. Preliminary enquiries were made and actions were taken to prevent disturbance of the aircraft and to preserve information within the cockpit voice and flight data recorders. The AAIB team comprised Mr M M Charles (Investigator in Charge), Miss A Evans (Flight Recorders), Mr J J Barnett (Operations) and Mr P T Claiden (Engineering).

The aircraft was engaged on a scheduled passenger flight from Sumburgh to Aberdeen; the accident occurred on take-off in unusually harsh wind conditions. At the end of the take-off ground run the aircraft began to roll to the right. The handling pilot immediately applied full left control wheel but this was insufficient to stop the roll to the right. Left rudder was then applied by the pilot to augment the left control wheel input but the aircraft continued to roll to the right and the right wing tip and aileron struck the ground to the north of the runway. The wing tip received minor damage but the outer section of the right aileron partially failed outboard of the outer hinge and bent downwards during the impact. Roll control was regained after ground impact although directional control was not re-established until several seconds afterwards. The aircraft initially adopted a non-standard departure track towards high ground but safe terrain clearance was achieved by turning further to the right and climbing. The flight crew were advised by Air Traffic Control (ATC) that the wing tip had struck the ground on take-off and, in view of the prevailing wind conditions at Sumburgh, the commander diverted

to the mainland. The diversion was flown initially towards Aberdeen and later to Royal Air Force (RAF) Kinloss where the wind conditions were more favourable for an emergency landing. En route the crew assessed the damage to the right aileron which was visible from the passenger cabin. The passengers were seated and briefed for an emergency landing which was carried out at a higher speed than for a normal landing without undue difficulty. There were no injuries during the flight.

The report identified the following causal factors:

(i) Operation of the aircraft in excessive tailwinds which damaged the right aileron whilst the aircraft was on the ground at Sumburgh.

(ii) Omission of the side and tailwind maximum recommended speeds from the ATP Flight Manual.

(iii) Failure of British Airways to heed the advice contained in section 9 of the manufacturer's Operations Manual.

Nine safety recommendations were made during the course of the investigation.

1 Factual Information

1.1 History of flight

The aircraft and crew were assigned to operate scheduled services between Manchester, Aberdeen and Sumburgh with a final sector back to Aberdeen. The sectors between Manchester and arrival at Sumburgh were largely uneventful except for failure of the nosewheel steering to engage after landing at Aberdeen until very late during the landing run. The aircraft's technical log contained entries relating to previous similar failures, the cause of which had not been positively identified. The late engagement had been classified as an acceptable deferred defect. The commander expected strong wind conditions at Sumburgh and was not prepared to operate the service with this recurrent defect. After checking the weather forecast for Sumburgh, he instructed the company's engineers at Aberdeen to investigate the fault. After the defect had been attributed to inadequate lubrication and rectified, the commander flew a short non-revenue flight to confirm restoration of normal nosewheel steering before operating the service to Sumburgh.

The sector to Sumburgh proceeded normally with the first officer handling from climb out to long finals when the commander took control for landing. Prior to landing the crew obtained a wind report from the automatic terminal information system (ATIS) of 300°M/38 kt with extremes of 51 kt and 21 kt. The landing at about 1153 hrs was normal and without any signs of control difficulty, windshear or severe turbulence. The aircraft was taxied to the main apron and shut down on a heading which placed the mean wind some 20° to right of the aircraft's nose. There the aircraft was prepared for the next sector and the crew completed pre-departure checks including an external inspection of the aircraft. Prior to starting engines the pilots listened to the ATIS frequency and recorded the following weather conditions from the 1250 hrs airfield information:

Mean Wind	Wind Variations	Cloud	Vis	QNH
290°M/47 kt	Direction 260°M to 330°M Min speed 29 kt max 65 kt	2/8 CB 1000 feet 3/8 1500 feet	10 km	987 mb

The commander opted to use runway 27 as this would keep the aircraft within the crosswind limits for take-off. From the performance manual and speed reference book he ascertained the rotation and decision speeds for a full power take-off with 15° flap; these speeds were coincident at 98 kt and, according to the Operations Manual, required no adjustment for the prevailing wind conditions. Following standard practice, the commander taxied the aircraft with the flight control locks remaining engaged until the aircraft was lined up on the runway. The taxiing route included a sustained period when the wind was blowing essentially from tail to nose. During this period the tower controller broadcast several reports of the surface wind velocity. One broadcast made about 20 seconds after the aircraft was cleared to enter and backtrack the runway reported the wind as 290°M/70 kt. After the aircraft was aligned for take-off, the control locks were released and a "full and free" check of the flight controls was carried out although neither crew member looked at the ailerons during the check. The aircraft was cleared for take-off and a surface wind check of 270°M/50 kt was passed by the tower controller. The commander held the aircraft stationary on the wheel brakes whilst increasing power and a second wind check of 280°M/65 kt was broadcast about 30 seconds prior to release of the wheelbrakes. The pilots had to rely on these transmissions for wind assessment because the nearest wind sock was about 800 metres away.

The take-off roll commenced at 1308 hrs with the first officer holding the control wheel during the early part of the ground roll whilst the commander maintained directional control with nosewheel steering; during this phase some nose-down elevator and into wind aileron were applied. At about 80 kt the commander took full control and reverted to rudder for directional control whilst maintaining the application of into wind aileron. The first officer called for rotation at or slightly above the scheduled speed of 98 kt and the commander commenced rotation. As he did so, the aircraft began to roll to the right whereupon he immediately applied full left roll control. The aircraft continued to roll to the right and, as it lifted off, the commander applied considerable left rudder. Suspecting engine failure, he instructed the first officer to select contingency power (approx 112% torque) on both engines. The aircraft continued rolling to the right and reached a peak roll attitude of approximately 38° at an airspeed of 134 kt. Some measure of roll control was regained during the next few seconds but stable flight required significant left control wheel and left rudder deflection. During the undemanded roll the aircraft turned right though some 28° resulting in it pointing towards high ground (up to 1,000 feet above mean sea level (amsl)) two miles ahead. The aircraft continued to climb whilst turning slowly to the right; directional control was not regained until the aircraft was established on a northerly heading but this track placed the aircraft downwind of the high ground where it encountered severe turbulence. However, climb performance was such that safe terrain clearance was achieved and the aircraft remained clear of cloud. Once the aircraft had achieved a safe height, the commander allowed it to accelerate and he noted that roll control authority improved with increasing airspeed. However, stable flight required about half the available left control wheel rotation plus a small amount of left rudder.

The pilots were unaware that the starboard wing tip had struck the ground during take-off but the aerodrome controller had seen the impact and he informed the crew of his observation about two minutes afterwards at an appropriate moment; the crew then declared a full emergency. In view of the wind conditions at Sumburgh, the commander elected to divert to the mainland. The transit was flown at around 200 kt at low altitude and with the flaps remaining at the take-off setting of 15°. Once safely clear of terrain, severe turbulence and cloud, the commander handed control to the first officer and went aft to reassure the passengers and to inspect the damage. He observed that the starboard aileron was out of position and was not responding to control inputs. He returned to the flight deck and, after consultation with ATC, decided to divert to RAF Kinloss because this airfield was reasonably close and had the best available combination of runway length, low crosswind component and emergency services.

En route to Kinloss, in anticipation of possible loss of control during the emergency landing, the commander gave a detailed briefing to the cabin attendants on the required emergency procedures including evacuation should it become necessary. At his behest, the cabin attendants repositioned passengers away from the plane of the propeller tips and arranged for adult passengers to sit next to unaccompanied children. They then briefed the passengers on the posture to be adopted for landing. Meanwhile the first officer handled the controls and kept the aircraft at a safe height and, where practicable, clear of cloud.

The aircraft was monitored by Highland radar and then radar vectored by Lossiemouth Approach to intercept the Kinloss runway 26 Instrument landing system (ILS) localiser beam at about 10 nm from touchdown. The landing gear was lowered about 25 nm from touchdown and the pilots decided to fly the final approach at an abnormally high speed in order to retain adequate roll control. Meanwhile, the emergency services at Kinloss were brought to full alert and a search and rescue helicopter was scrambled from RAF Lossiemouth.

The commander reviewed the "emergency landing" checklist and decided to land using 20° flap but to delay flap selection from 15° to 20° until the aircraft was about 1,000 feet above touchdown. The crew gained visual contact with the runway as they came out of cloud at 1,300 feet altitude. At 1,000 feet, as instructed by the commander, the first officer called "CABIN CREW AND ALL CREW - BRACE BRACE" on the cabin public address system and the commander selected flaps to 20° shortly afterwards. The commander then took control for the final stage of the approach which was flown at about 150 kt indicated airspeed (IAS). Stable flight required frequent corrective roll and yaw control inputs using up to three quarters of available control wheel and rudder deflection. There were no large undemanded roll excursions and the aircraft landed safely after touching down at 150 kt. The wind for landing was 290°M/15 to 20 kt and full reverse thrust was employed to decelerate the aircraft after touchdown.

The passengers and crew disembarked normally after the aircraft had been taxied clear of the runway and shut down. The pilots then disabled the flight data recorders by pulling the relevant circuit breakers.

1.2 Injuries to persons

Injuries	Crew	Passengers	Other
Fatal	-	-	-
Serious	-	-	-
Minor/none	4	26	

1.3 Damage to aircraft

The outboard end of the right aileron failed about the outermost hinge location, but remained attached by its lower skin and lower spar strap. The wing tip structure suffered general distortion outboard of the wing torsion box, the aileron operating arm was severed at its attachment to the drive rod and the rod end was distorted. In addition, minor stone damage was present under the rear fuselage in the region of the tailplane.

1.4 Other damage

Minor damage was caused to the grass surface to the right of the take-off runway.

1.5 Personnel information

1.5.1

Commander:	Male aged 44 years	
Licence:	Airline Transport Pilot's valid until 13 September 1999	
Aircraft Ratings:	Part 1: BAe ATP; HS 748; Vickers Viscount; Boeing 737; Boeing 707; single-engined Cessna light aircraft Part 2: No entries	
Instrument Rating:	Instrument Rating valid to 9 August 1992	
Medical Certificate:	Class One issued 20 June 1991 with the limitation that the holder shall wear spectacles to correct for near vision	
Flying Experience:	Total all types:	9,785 hours
	Total on type:	1,314 hours
	Total last 28 days:	51 hours
	Total last 24 hours:	2 hours
Last base check:	10 July 1991	
Last line check:	16 July 1991	
Last emergencies check:	18 March 1991	
Previous rest period:	3 days	
Duty time:	6 hours 54 minutes	

1.5.2 Co-pilot: Male aged 22 years

Licence:	Commercial Pilot's valid to 8 January 2001
Aircraft Ratings:	Part 1: BAe ATP; PA23/34/44 Part 2: No entries
Instrument Rating:	Instrument rating valid to 4 May 1992
Medical Certificate:	Class One issued 10 October 1991
Flying Experience:	Total all types: 670 hours Total on type: 470 hours Total last 28 days: 30 hours Total last 24 hours: 2 hours
Last base check:	20 August 1991
Last line check:	10 May 1991
Last emergencies check:	23 March 1991
Previous rest period:	36 hours
Duty time:	6 hours 54 minutes

1.5.3 Flight attendants:

There were two cabin attendants on the aircraft both of whom met company proficiency and medical requirements.

1.6 Aircraft information

1.6.1 Leading particulars:

Type:	British Aerospace ATP
Constructor's Number:	2012
Date of Manufacture:	8 March 1989
Certificate of Registration:	The registered owners were British Airways plc, certificate no G-BTPE/R1
Certificate of Airworthiness:	United Kingdom (UK) Transport (Passenger) category, issued by the Civil Aviation Authority and valid until 12 March 1992, No 16355/Nr 1
Certificate of Maintenance Review:	Valid to 6 March 1992
Last maintenance check:	Ramp 2 check, B check - 9 October 1991. There were no references or carried forward defects concerning the flying control systems entered in the technical log for the previous sectors.
Total Airframe Hours:	4,806.06
Number of Landings:	5,791

1.6.2 Weights

Maximum Taxi or Ramp weight:	22,999 kg
Maximum Take-off weight	22,930 kg
Maximum landing weight:	22,250 kg
Actual take-off weight:	19,446 kg
Actual landing weight:	18,676 kg

1.6.3 Centre of gravity

The centre of gravity was at 72.0 laden index take-off weight on take-off which was within the prescribed limits.

1.6.4 Aileron control system

A drawing of the aileron control system is shown at Appendix A. Aileron control is achieved by the operation of interconnected handwheels. Rotation of these handwheels operates a chain and cable control run to the outer wing quadrants. From here a lever and rod assembly transmit control handwheel movements directly to the aileron to operate it over its normal range of ±20°. There is no servo tab but a balance tab is located at the inboard end of each aileron. These tabs are operated by dual rod assemblies, connected between the tab and the wing rear spar. The tab mechanism is non-linear in operation, providing a balance gearing around the aileron neutral position, progressing to anti-balance towards the extremes of aileron deflection. A single aileron trim tab is provided immediately outboard of the balance tab on the right aileron only.

The system is designed such that emergency control of the aircraft can be established for continued safe operation in the event of a jammed or severed primary control circuit. A control cable release unit is mounted on the rear spar in the fuselage, in the right wing circuit, and enables the crew to separate the left and right ailerons from each other as well as the right circuit from the fuselage circuit. In the event of a jam in the system the left aileron may be operated directly by the left handwheel, if this section of the circuit is free, or the right aileron, through the autopilot servo motor from signals generated in the right handwheel, if it is not. This motor is located adjacent to the release unit and thus will only drive the right aileron if the circuit is complete up to its aileron operating arm. A shear pin is fitted in the right handwheel which is designed to permit separation of the handwheels at a predetermined load.

1.6.5 Control lock system

Control locks for the ailerons and elevators are 'roller in cam' mechanisms adjacent to the cable tension regulators in the respective control circuits. (The rudder is damped by a hydraulic ram integral with the rudder booster.) In the case of the aileron this is located on the wing rear spar in the centre section, to the left of the aircraft's centreline. When engaged this system is designed to immobilise the left and right wing circuits, and the fuselage circuit, which are effectively separate but which come together at this point. As each section of the aileron circuit does not have infinite stiffness, the aileron surfaces are able to deflect independently with the control lock engaged in proportion to any applied loads from, for example, ground gusts, such loads being reacted by the lock mechanism. The degree of movement is governed by the stiffness of each circuit and the level of loading (see paragraph 1.16.1). The three lock mechanisms are connected in parallel via a system of cables and rods to the control lock lever situated on the centre console in the cockpit. For the aileron lock to engage, the ailerons must be in the neutral position. At the time of this incident external control locks were not available for the aileron, a situation that has since been remedied by the issue of a temporary revision by the manufacturer, No 10/6, to the ATP Maintenance Manual. This covers the installation, and checks associated with, a revised rudder external lock and new external aileron gust locks.

1.7 Meteorological information

1.7.1 Pre-flight briefing

The pilots carried out a routine self-briefing at their Manchester base at 0620 hrs at the start of their duty period. Synoptic charts available to them showed a deep low pressure system centred on Scandinavia with a trough of low pressure extending westwards towards Iceland. Severe-gale to storm-force westerly surface winds across the Shetland Isles produced by the low pressure system were forecast. At the time there were four significant meteorological warnings (SIGMET) warnings affecting the Scottish flight information region which alerted the pilots to the likelihood of severe turbulence and mountain wave activity which would affect their schedule routes. The briefing also contained forecast weather conditions for several Scottish and English airfields which included the normal diversions for Aberdeen but did not include Sumburgh.

1.7.2 Sumburgh airfield briefing

The commander was aware that Sumburgh airport was considered by his company as a restricted aerodrome in that it had particular problems concerning terrain and weather. Although he had flown to Sumburgh many times before, this was to be his first visit for three years and so, a few days earlier, he had self-briefed on these problems using facilities and briefing sheets prepared by the company for this purpose. These sheets contained a note that "frequent strong winds reach 70 kt in winter". Company policy prohibited landing on runway 33 if the wind strength was above 40 kt, and taking-off from runway 15 if a south easterly wind exceeded 30 kt; these restrictions were due to turbulence in the lee of rugged terrain. However, apart from crosswind and tailwind considerations, there were no wind limitations affecting operations from runway 09/27. The company's aerodrome booklet, which was used for in-flight reference by the crew, contained a note that *"severe turbulence was possible on approach to, or departure from any runway."*

1.7.3 Sumburgh weather

The weather conditions for Sumburgh were obtained by the pilots at about 0845 hrs after landing at Aberdeen (the 0600 hrs forecast and the 0750 hrs actual) and again at 1033 hrs before departure for Sumburgh (the 0900 hrs forecast and the 1020 hrs actual) when the SIGMETS were repeated. The relevant weather reports leading up to the accident were:

Forecast weather:

Issue time (hrs) Valid (hrs)	Surface Wind (°T/knots)	Visibility (km)	Cloud (oktas/feet)	Weather
0600 0700 to 1600 Temporarily	 280°/30 max 43 300°/35 max 55	 over 10 4	 2ST/1000 4SC/3000 6CB/1000	 Soft hail with 10% prob of TS
0900 1000 to 1900 Intermittently	 280°/30 max45 300°/40 max 55	 over 10 4	 3CU/1500 6CB/800	 Soft hail with 10% prob of heavy TS

The forecast wind at 2000 feet in the Sumburgh area for the period 0600 to 1200 hrs was 270°/40 kt; for the period 1200 to 1800 hrs it was 330°/35 kt.

Actual weather:

Issue time (hrs) Valid (hrs)	Surface Wind (°T/knots)	Visibility (km)	Cloud (oktas/feet)	Weather
0750 Intermittently	280°/36 max 51	over 10 5	1CB/1500 5CB/1000	Recent hail
1020 Intermittently	270°/35 max 54	over 10 5	 6CB/1000	Recent snow
1120	300°/38 max 51 min 25	9	1CB/1000 5/1500	Soft hail
1248	280°/47 max 65 min 29 VRB 250°-320°	10	2CB/1000 3/1500	None

Notes:

1. Throughout these reports the QNH (the barometric air pressure at which aircraft altimeters read altitude above mean sea level) remained at 987 millibars and the temperature was +5°C until the 1248 hrs observation when it was +6°C.

2. The letters CB refer to cumulo-nimbus ; ST to stratus; SC to stratocumulus; CU to cumulus and TS to thunderstorm.

3. The surface wind given in each report is the mean wind direction and speed. Max and min refer to extremes of wind speed and VRB means the extremes of wind direction.

4. There were no verbal or written warnings of windshear for the Sumburgh area.

1.7.4 Meteorological recordings and windshear analysis

Sumburgh airfield has a single anemometer mounted on a 10 metre mast approximately 50 metres west of the control tower; this instrument drives windscales in the meteorological office and ATC. There were two recording systems installed: digital anemometer logging equipment which was unserviceable on the day of the accident, and an anemograph. The anemograph recording for daylight hours is shown at Appendix B. During the period 1300 to 1315 hrs the recorder depicted numerous gusts of over 60 kt, a maximum gust of 72 kt and several lulls to 20 kt; the mean wind velocity was 280°T/56 kt with variations in direction between 260°T and 310°T. The anemometer and windscales had been serviced and calibrated 30 days before the accident.

The anemograph recording was submitted for scientific analysis to the Aviation Applications section of the national Meteorological Office at Bracknell. The Meteorological Office report at Appendix C concludes that in addition to turbulence, the risk of windshear was widespread during the period of strong wind and convective instability and, although local topographical effects were present, they were probably not dominant. The anemograph trace revealed evidence of low level windshears of at least 4 metres per second over a distance of 600 metres at Sumburgh on the day of the accident. The classification table adopted by International Civil Aviation Organisation (ICAO) has the same parameters as those used in the Meteorological Office report and 4 metres per second over 600 metres has been classified as the borderline between having 'significant' effect on aircraft control and creating 'considerable difficulty' of control.

Windshear is defined as a change in wind direction and or wind speed in space. Low level windshear may be defined as windshear along the final approach path or along the take-off and initial climb out path. Meteorologically, windshear conditions are normally associated with one or more of the following phenomena:

Thunderstorms
Cold or Warm Fronts
Strong surface winds coupled with local topography

Sea breeze fronts
Mountain waves
Low level temperature inversions.

1.8 Aids to navigation

Not applicable

1.9 Communications

Radio communications between the aircraft and various ATC agencies including Sumburgh were normal and a transcript of recorded radiotelephony (RTF) messages was prepared.

1.10 Aerodrome and ground facilities

1.10.1 Sumburgh Airport

Sumburgh airport is situated near the southern tip of the Shetland islands. The airport elevation is 18 feet amsl and there are two asphalt runways suitable for take-offs and landings by the ATP (09/27 and 15/33). The shore line is close to the thresholds of all the runways. Runway 09/27 is the main instrument runway. To the north the terrain is rugged with outcrops to 1,000 feet amsl. Three nautical miles north west across a bay is Fitful Head, a headland rising almost vertically to 930 feet above the sea. One mile south east of the airfield there is an outcrop of rock 420 feet high which severely affects operations to runway 15/33. The dimensions of runway 27, which was used for take-off, are 1,180 metres by 46 metres and it slopes upwards by 0.082%. At each end of the runway there are concrete sea defences which limit the take-off run and emergency distances available to 1,121 metres, and the take-off distance available (in which to achieve a height of 35 feet) to 1,200 metres. There are no other land obstructions along the extended runway centreline within the airfield traffic zone.

1.10.2 Royal Air Force Kinloss

RAF Kinloss is situated on the Moray Firth near the town of Forres. It is a main operating base for maritime patrol aircraft and a military emergency diversion airfield. As such it is equipped for and well practiced at handling large aircraft. The airport elevation is 22 feet amsl and the main instrument runway 26 is 2,310 metres long and equipped with ILS. The fire and rescue service is established to the equivalent of civil category 7. The approach and radar service is provided by nearby RAF Lossiemouth which is also an operating base for search and rescue helicopters.

1.11 Flight recorders

1.11.1 Flight Data Recorder

The Flight Data Recorder (FDR) fitted was a Plessey PV1584F1 combined data acquisition and recorder unit, with a recording duration of 25 hours recorded digitally on magnetic tape. A total of 27 analogue parameters and 5 discretes was recorded. A satisfactory replay was obtained using AAIB replay facilities.

The following table gives the resolution (engineering units value equivalent to one bit) of the significant parameters and an estimate of the absolute accuracies:-

Rudder angle	0.35°	(absolute accuracy ±1°)
Aileron angle	0.35°	(absolute accuracy ±1°)
Pitch and Roll	0.35°	(absolute accuracy ±1°)
Airspeed	1.0 kt	(absolute accuracy ±2 kt)
Altitude	0.5 feet	(absolute accuracy ±20 feet)
Normal Acceleration	0.009 g	(absolute accuracy ±0.05 g)
Heading	0.35°M	(absolute accuracy ±2°)
Engine Torque	0.1%	(absolute accuracy ±1%)
Radio Altitude	6.25 feet	(absolute accuracy ±7 feet)

All the FDR parameters were calibrated by the airline after the incident, and these calibrations have been used to obtain the engineering values quoted in this report. The aileron angle was calibrated after the control system had been repaired, no rigging changes were made prior to the calibration.

Aileron angle is sensed from a synchro position transmitter located on the input side of the quadrant assembly inboard of the aileron final bell-crank. The aileron angles sensed by the FDR would therefore be those at the surface while the aileron remained connected at the operating arm, however once the failure occurred the aileron angles sensed would be those demanded by the pilot via the control cables, and not actual surface positions. The maximum recorded value of aileron deflection may not be the maximum achieved deflection because the parameter is only sampled once per second, the left and right aileron angles are also sampled at different positions in the dataframe 0.5 seconds apart. Also any elastic deformation of the linkage between the aileron and the location of the synchro position transmitter (for example in response to high aerodynamic loading of the surface against the gust locks) would not be recorded as aileron movement by the FDR.

1.11.2 Cockpit Voice Recorder

The Cockpit Voice Recorder was a Fairchild A100, which has 30 minute duration using an endless loop of tape. A satisfactory replay was obtained using the AAIB replay facility. The tape had overwritten the take-off from Sumburgh and recording began during the transit to Kinloss and continued until the aircraft landed and power was switched off.

1.11.3 Interpretation of data

Appendix D, Figure D-1 shows the initial taxi of the aircraft from the stand, and Figures D-2 and D-3 show some of the parameters recorded on the FDR for the take-off from Sumburgh.

Air Data Computer 1 outputs IAS which is supplied to both the FDR and the Primary Flight Display. This output has not been corrected for position error by the ADC therefore the values quoted for IAS from the FDR are those which should have also been displayed to the crew. As the aircraft taxied into wind, airspeed values of between 50 and 60 kt IAS are recorded which reflect the high wind speed, reported as 290°/70 kt. The airspeed system does not indicate below 30 kt IAS.

The left and right aileron angles have been plotted with UP and DOWN indicating the direction of motion of the trailing edge of each control surface. Maximum control surface deflections are: aileron and rudder ±20°, elevator 22° UP and 13.5° DOWN. As the aircraft taxied downwind with the control locks engaged, the FDR showed movements of both aileron circuits of around 3° trailing edge down, with the right aileron recording larger deflections. Fifteen seconds before turning onto the runway heading of 270° a deflection of 12° trailing edge down was recorded on the right aileron coinciding with a movement of 3° down on the left aileron. Both ailerons then continued to record movements, the right maintaining a larger down deflection than the left, until the aircraft turned into wind when the ailerons returned to the datum positions. Figure D-1 shows these movements and also the "full and free" before take-off control checks, carried out when the control locks had been released, during which the recorded values of both ailerons appear to be normal.

Figures D-2 and D-3 show the take-off from Sumburgh. With 15° of flap set the aircraft rotated at between 105 and 110 kt IAS, and lift-off occurred at 116 kt IAS (time T = 45 seconds on the Figures). The aircraft started to roll right immediately after lift-off and opposite aileron (maximum recorded angle 18° left roll demand) was applied as the aircraft lifted off. The initial rate of roll was about 7.3°/sec until the aircraft reached a bank angle of around 21° for nearly 2 seconds at around 7 feet above ground level (agl). The aircraft then continued to roll right at a slightly higher rate to a maximum of 38° right wing down at about 20 feet agl 5 seconds after lift-off. The aircraft also turned right to a heading of 300° M from the runway heading of 272° M and left rudder was applied with a maximum recorded deflection of 15°.

After take-off there is a lateral acceleration to the right of up to 0.14g (allowing for the datum offset of 0.06g), showing a movement to the right due to the roll and yaw of the aircraft. At unstick there is a single recorded lateral acceleration to the left of 0.34g; this acceleration is sampled four times a second so the acceleration to the left lasts for less than half of a second with essentially zero values either side. The data for other parameters in the subframe appears valid, and it would therefore be unlikely for this one parameter sample alone to have been corrupted. It is possible then that the large lateral acceleration to the left was caused at unstick, with a bank angle of 14° right wing down, by the right landing gear contacting the ground again causing a spike in lateral acceleration as the movement to the right was reacted by the landing gear.

Torque was increased on both engines 5 seconds after lift-off from 90% to 112%. The roll angle then decreased in response to the applied controls with wings level being achieved 11 seconds after lift-off. During this period between 10° and 18° of left roll demand were recorded. In Figure D-3 the high levels of normal acceleration recorded show the amount of turbulence experienced by the aircraft on take-off.

Flaps were not retracted during the flight to Kinloss which was carried out at flight level 45 and 200 kt IAS with a maximum speed recorded of 223 kt IAS. Approximately 6° to 7° of left roll demand was required to maintain heading. The aircraft then slowed to 170 kt IAS which required between 5° and 8° of left roll demand to maintain heading. The flaps were selected to 20° at 500 feet agl and 170 kt IAS, the final approach speed was 150 kt IAS and up to 15° left roll demand was required to maintain the approach.

Data from the previous flight was also examined, this showed that on the final approach with roll excursions of ±10°, up to approximately ±10° of roll demand was recorded, with both ailerons moving normally. During taxi downwind with control locks engaged both ailerons showed small movements of up to 2.5° trailing edge down. The mean wind speed at this time was recorded by the airport anemograph as 38 kt, but varying from 21 to 51 kt.

1.12 Examination of the aircraft

1.12.1 Ground marks and impact parameters

After the aircraft wing tip was seen to strike the ground during take-off, the airfield authorities discovered fragments of green glass from the forward navigational light, clear glass from the strobe light and flecks of grey paint amongst witness marks on the grass to the right of runway 27. These marks were characterised by two main features, see Appendix E. Firstly, there was a thin gently curving line in the grass, with minimal disturbance of the soil, starting some 685 metres from R/W 27 threshold and 21 metres to the right of the runway edge. It was some 23 metres in length and orientated from 283°M to 286°M. The second feature was a shallow furrow, changing in width from 2 cm to 15 cm over its length, which paralleled the first mark but which was located closer to the runway by 45 cm, rising to 50 cm. This furrow began 4 metres 90 cm after the start of the first mark and was some 2 metres 30 cm in length. It was apparent that this had been cut into the surface by part of the aircraft angled down at around 20° to the horizontal, but increasing towards 25° over the length of the furrow.

When these marks were examined, the gently curving longer mark was projected back, with the same curvature, towards the runway until it made a tangent with the runway heading some 7 metres in from its edge, *ie*, where the right wing tip path would have been had the aircraft taken off along the runway centreline. This suggested that the path of the wing tip had crossed over the edge of the runway almost exactly at the mid point, *ie* 590 metres from the 27 threshold. There were no signs of any contact by the right propeller with the runway surface or the grass or signs that the landing gear had touched the ground at this location.

With the exception of the minor debris mentioned above, no items were found on the airfield which were related to this aircraft.

1.12.2 Aircraft examination

The aircraft was examined at RAF Kinloss and exhibited three areas of damage which were associated with this incident.

Firstly, there was an area of skin damage on the lower fuselage aft of the pressure bulkhead in the region of the tailplane. The character of this damage suggested that small stones had been blown back with some force, presumably by propeller wash, to impinge on this area. The damage was limited mostly to dents in the fuselage and elevator skin although the fuselage had been punctured in several places. Small loose stones were present along each edge of the runway.

Secondly, significant damage had occurred to the right wing tip and outer right aileron, see Appendix F-1. Crippling failures were present on the upper surface of the wing tip and the rear spar extension, together with general distortion of the whole tip structure. There was evidence of contact with the ground by the underside of the wing tip, particularly at its trailing edge, where the structure had locally been distorted upwards. It was this contact which was consistent with having flexed the tip structure upwards, and slightly rearwards, producing the observed deformations. The glass lenses from the forward navigation and strobe lights were missing. The aileron had suffered a structural failure about its outermost hinge, see Appendix F-1, where the top surface in the region of the spar had failed and been severed by, predominantly, rearwards in-plane bending. The lower surface had been distorted, but not torn apart, such that the outer section of the aileron, including the aerodynamic balance horn, had pivoted downwards about the lower surface through approximately 90°. This horn had itself been distorted both downwards and inboard by approximately 20°, relative to the aileron, and there was evidence of earth particles, stone damage and abrasion of the paint on the horn's outboard lower quarter. The extent of this damage suggested that this section of the horn had been protruding below the wing tip at the time the tip contacted the ground. Evidence was looked for, but none found, of any abrasion on the lower outboard trailing edge of the aileron but this area was distorted slightly upwards.

The third area of damage was at the inboard end of the right aileron, specifically at the joint which connects the aileron operating arm to the drive rod, see Appendix F-2 and F-3. Here a compression/bending type of failure had occurred to both lugs of the operating arm, resulting in a disconnection of the aileron from its input drive. There was slight lateral bending present of the rod's ball-joint end fitting. In addition, there was damage to the aileron's upper surface skin in the region of the tab drive linkage consistent with it having overtravelled in a trailing edge up, right roll, sense. Before this failure of the arm had been established, a "full and free" check was carried out on the flying controls, with no abnormalities being felt. Both ailerons were seen to move during this check but it was not at all obvious that the right aileron was actually disconnected. It was apparent that the right aileron could be pushed upwards by the action of the failed joint being put into compression thereby creating an illusion, as seen from the flight deck, that the joint was intact.

A general examination of the aircraft at this time, and later by maintenance personnel from the operating company as the aircraft was being repaired, established that the aileron control system was otherwise intact and free to operate over its full range. Also, as far as could be established, the system had been rigged correctly. There was no evidence of damage to the operating arm on the left aileron. The serviceability of the elevator and rudder control systems was not in question but these were also established as having been correctly rigged and free to function, as was the controls lock system. The aileron release mechanism had not operated and the shear pin in the right handwheel was intact.

1.12.3 Subsequent detailed examination

In order to gain a better understanding of the mechanism of failure of the aileron, the outer section and the distorted wing tip structure were removed from the aircraft, along with all other damaged components, and taken to the AAIB at Farnborough. Here they were set up in their usual relative positions on a flat surface upon which was drawn, full size, part of the ground marks as measured at Sumburgh. By exploring combinations of 'aircraft' bank angle and aileron deflection it was evident that the wing tip/aileron would best fit with the ground marks as indicated in Appendix E. This demonstrated that with an aircraft heading of some 9° less than than its track, and with the aircraft's outer wing at an angle of around 20° to the ground (27° angle of bank), the gently curving thin mark had been made predominantly by the trailing edge of the wing tip whilst the shorter furrow was produced by the aileron aerodynamic balance horn, but with the aileron deflected up by some 25°. This permitted the lower surface of the aileron horn to cut into the ground at an angle of around 20°. Close examination of the directions and locations of the lines of abrasion on the paint, and impacted earth particles on the aileron and wing tip structure, supported this assessment. It also became apparent that if the horn had been deformed inwards and downwards (relative to the aileron) towards the end of the furrow, the angle at which its lower surface cut into the ground would have increased.

The failures to the aileron structure and its operating arm from G-BTPE were metallurgically examined and both judged to have been as a result of a single event overload in combined compression/bending. The material characteristics of the failed operating arm were shown to conform to the manufacturer's specification, BS L164, and it was established that both the arm and the aileron structure had been fabricated in accordance with the manufacturer's drawings. Manufacturing or material defect could therefore be dismissed as a factor in this failure.

1.13 Medical and pathological information

Not applicable

1.14 Fire

Not applicable

1.15 Survival aspects

Not applicable

1.16 Tests and research

1.16.1 Aileron control circuit stiffness measurements

In the ATP the right wing circuit is some 25% longer than the left due to the installation of the aileron release unit in this circuit and the off-centre (to the left) location of the control lock mechanism. Also, both circuits are longer than their counterparts in the HS 748 by some 5% (left) and 11% (right). Stiffness measurements of the left and right aileron circuits, with the control locks engaged, have been carried out by the manufacturer on an ATP by measurement of surface deflection versus applied hinge moment. This was done up to the proof load hinge moment of 3,960 lbf.in. The results revealed the right wing circuit to be approximately 25% less stiff than the left. At this loading the left aileron had deflected down through 8.8°, the right through 10.7°, giving effective circuit stiffnesses, respectively, of 2,225 lb.feet/rad and 1,773 lb.feet/rad. If this data is extrapolated linearly to the calculated ultimate hinge moment of 5,580 lbf.in with respect to the operating arm, then the aileron deflections expected at arm failure would be 12.2° and 15.2°, left and right respectively. These tests also revealed that approximately one third of the measured deflections were accounted for by elastic deformation of the linkage between the aileron and FDR transmitter location *ie* 20° surface deflection indicated as 14°.

In neither the HS 748 nor ATP are cable tension regulators fitted to the wing circuits. Circuit tensions are set with reference to ambient temperature and are typically, at 20°C, 50 ±3 lb and 55 ±3 lb respectively for the HS 748 and ATP. Both aircraft use 5/32" diameter steel control cable, to slightly different specifications, but cable stiffness is essentially the same. Thus the difference in circuit stiffness, both between left and right wings of the ATP, and between the ATP and HS 748, is associated primarily with differences in control cable lengths.

1.16.2 Aileron operating arm strength

The aileron operating arm used on the ATP, Pt No JD576J0067, is essentially the same as the item used on the HS 748, the main difference being the presence of a joggle on its mounting face to accommodate an external strap over the aileron spar. The arm was originally designed to meet the British Civil Airworthiness Requirements (BCAR) wind speed requirements, relating to the taxiing downwind case, of 55 kt. The picketing requirement of an 80 kt wind "horizontally from any direction" was addressed by the use of external control locks. As the ATP was designed to meet the Joint Airworthiness Requirements (JAR) the aileron operating arm was re-assessed for loads arising from the lesser JAR 25X519(a) picketing case (when compared with the BCAR 80 kt requirement) of 65 kt tail to wind.

Data taken from the Type Record for the aircraft shows that this tail to wind case was the most critical for the arm, in terms of stressing, and that the ultimate calculated hinge moment required to be reacted was 5,580 lbf.in. The corresponding figure for the JAR 25 415 (2) taxiing downwind case of 52 kt was 3,600 lbf.in, these figures relating to maximum achievable moments. (For reference, the most severe in-flight design case was identified as an accelerated roll with Vc = 225 kt EAS at 15,000 feet, M = 0.453 and with an up aileron deflection of 16.5°. This was calculated to generate an ultimate hinge moment of 4,367 lbf.in) With reference to Figure F-2, the most critical area of the operating arm is where the two lugs connect to the aileron drive rod. Here, the criterion considered was that of combined bending and compression at section A-A, see Appendix F-2, with the drive rod in compression, the bending component resulting from the drive rod axis not being parallel with that of the arm. At neutral this offset is shown as 6.5°, but at significant aileron angles was assumed to reduce to 5°. With reference to the ATP Type Record, the calculated ultimate hinge moment to be reacted through the operating arm, therefore, was associated with this offset angle.

The location of the failure which occurred on G-BTPE, and the other aircraft listed in paragraph 1.17.2, was across sections A-A and B-B (see Appendix F-2). At section A-A the reserve factor was determined to be 1.10, the lowest of all cases considered for the arm. Thus, the operating arm was shown, under static loading conditions, to be capable of meeting the JAR picketing case requirements without the use external control locks. The manufacturer estimated that, using the JAR definition of aileron hinge moment and assuming that the loads were steady, a wind speed of 83.5 kt at the aileron would be required to precipitate failure.

1.16.3 Aileron operating arm failure load

In order to substantiate the calculated load at which failure of the operating arm might be expected to occur, a test was carried out on the undamaged arm from the left aileron of G-BTPE. The arm was mounted on a rigid support and orientated such that a compressive load was applied through the correct standard drive rod, mounted vertically, in the compound direction associated with aileron in the 15° down position. This value of aileron deflection was chosen to represent the position at which the arm was estimated to fail. The offset angle that the drive rod makes with the operating arm decreases with aileron deflection, thereby reducing the lateral bending of the lugs for a given drive rod load, and thus significantly increases the load at which the arm fails. Examination of the drive rod installation drawings showed that with 15° down aileron the rod made an angle of 25° to the arm's horizontal axis and 2.5° to 3° to its fore and aft axis. The 3° value was chosen for the test in order to represent most appropriately the situation on the aircraft and was confirmed with the manufacturer prior to the test as it differed from the 5° angle (worst case) derived from the aircraft Type Record. With a very slow rate of compression the operating arm was able to resist a peak load of 2,260 lbf before becoming unstable, eventually failing in a near identical manner to the arm from the right side of the aircraft. This load equates to an ultimate hinge moment of approximately 9,300 lbf.in and compares with the calculated ultimate hinge moment at failure of 5,580 lbf.in (worst case). A check calculation was carried out by the manufacturer of the expected failure load with a 3° offset angle and this estimated a figure of 2,290 lbf, thus substantiating the predictive method.

1.17 Additional information

1.17.1 Aileron system design - picketing and ground operating requirements

The ATP was derived from the design of the HS 748 and as such the geometry of the aileron, outer wing and control circuits are essentially the same. The HS 748 was designed in the late 1950s in accordance with the BCARs; the ATP to JARs. The sections of these relating to ground gusts and picketing of aircraft are reproduced below.

BCAR's Sub Section D3 - Structures, Chapter D3-13 Ground Handling

"3 ***Ground Gusts***

3.1 Picketing. *At all weights between the Weight Empty and the Design Take-off Weight, the main picketing points and surrounding structure, control systems and surfaces shall have Proof and Ultimate Factors of safety of not less than 1.0 and 1.5 respectively under the loads arising when picketed, resulting from wind speeds of up to* ***80 kt*** *horizontally from any direction.*

3.2 Taxying Downwind. *Elevator, aileron and rudder control systems and their supporting structure shall have Proof and Ultimate Factors of safety of not less than 1.0 and 1.5 respectively under the loads arising when taxying, resulting from wind speeds of up to* ***55 kt*** *horizontally in the direction of motion of the aeroplane."*

JAR 25X519 (a) Static ground load conditions

"(a) ***Picketing.*** *At all weights between the Weight Empty and the maximum weight, stated in the appropriate Manual, the main picketing points and surrounding structure, control systems and surfaces must be designed for the limit load conditions, arising when picketed resulting from wind speeds of up to* ***65 kt*** *horizontally from any direction."*

Although not explicitly stated the picketing requirements, when applied to flying control surfaces, may be met by the use of either internal or external control locks, or both.

Another section, **JAR 25.415 (2)**, relates to ground gust conditions and requires that:

"the control system stops nearest the surfaces, the control system locks and the parts of the systems between these stops and locks and the control surface horns [operating arms] must be designed for surface limit hinge

moments H, ***due to ground gusts and taxying downwind,*** *generated according to the formula H = KcSq where --*

H	=	Hinge moment (lbf.feet)
c	=	mean chord aft of the control surface aft of the hinge line (feet)
S	=	Area of the control surface aft of the hinge line (sq.feet)
q	=	Dynamic pressure (psf) based on a design speed of not less that $14.6x\sqrt{(W/S)}+14.6$ (fps), ***except that the the design speed need not exceed 88 fps (52 kt).***
K	=	limit hinge moment factor for ground gusts derived as follows:-

Control column locked or lashed in mid-position - K = 0.75
Ailerons at full throw - K = +/- 0.5"

1.17.2 Previous incidents

Until the introduction of the ATP into service British Airways were operating a fleet of HS 748 aircraft for some years on the Highland and Islands routes and, over this period, they had no documented failures to the aileron operating arms on this aircraft type. Wind slam damage has from time to time occurred to HS 748 flying controls generally and there was one occasion recorded in the UK by another operator, in March 1986 at London Heathrow Airport, where the right operating arm on the aileron of an HS 748, G-VAJK, failed as the aircraft was being towed. The peak wind gust wind recorded on that date was 59 kt. However, since the ATP has been in operation in the UK, there have been several cases of aileron operating arm failure or damage compared with the single known event on the HS 748 over many years of operation under similar conditions. External gust locks were available for the three primary flying control surfaces of the HS 748 aircraft over this period but, until recently, external gust locks were not available for the ailerons of the ATP; the aileron system being shown by static strength calculations, using the JAR 25.415 formula and assuming steady state loading, to meet the JAR picketing requirements of a 65 kt horizontal wind. Previous incidents have been identified with ATP aircraft in which control surface damage was caused as a result of the aircraft experiencing high winds whilst parked, as follows:-

G-BTPH Manchester 25 January 1990

Due to severe wind gusts the Captain requested that aircraft be towed into wind. During this tow he observed the aileron surfaces being blown to full deflection, but with the control locks engaged. The ailerons were inspected, as per the Maintenance Manual section 04-50-24, and the right aileron surface operating arm was found buckled. Further inspection found no other damage. A full aileron/gust lock/trim system check was satisfactory.

G-OLCC Manchester 25 January 1990

Aircraft parked on Stand 50L tail into wind, with control locks selected on. Severe winds resulted in the failure of the right aileron operating arm and damage to surrounding structure. Damage was also found on the left aileron inboard hinge upper skin.

Wind gusts of up to 59 kt were recorded by the airport anemometer on the date of the two above events (Meteorological Office Data) but gust intensities were not recorded at the aircraft stands.

G-BTPF Manchester 26 February 1990

At 0700 hrs wind speed gusts of 70 kt were recorded. The aircraft was parked tail to wind on a stand, the internal gust locks were in place and no external locks were fitted. The ailerons and hinge point suffered impact damage, both aileron operating arms and the rudder lower hinge point failed.

G-OLCD Manchester 26 February 1990

The aircraft was parked tail to wind on Stand 48 with internal locks engaged and external control locks fitted to the rudder and elevator surfaces. At 0630 hrs an engineer arrived at the aircraft and noticed that the right aileron operating arm had been sheared. After locating a tug and towbar and returning to the aircraft it was found that the rudder external lock had jumped free. After a further delay, for operational reasons, it was discovered that the left aileron operating arm had failed and the rudder had been blown hard over to the right. The wind was reported at the time 260° to 290°M/40 kt mean, gusting 70 kt. The aileron operating arm from the right aileron was in the possession of the aircraft manufacturer and was made available for examination. It was apparent that this arm had also failed as a result of a compressive/bending overload, the nature of the failure being almost identical to those from G-BTPE and the arm tested during this investigation. These failed operating arms are compared in Appendix F-3.

Other incidents

The manufacturer's fully instrumented test ATP also experienced a failure to an operating arm when being tested in an artificial tail to wind situation. It was estimated by the manufacturer that local wind speeds at the aileron concerned were probably in excess of 70 kt.

1.17.3 ATP technical documentation

The ATP is certified under JAR 25, one of whose requirements (JAR 25.1581) is that an aeroplane Flight Manual must be furnished with each aeroplane. This manual has to contain the operating limitations, procedures and performance applicable to the aeroplane plus any other information that is necessary for safe operation because of design, operating or handling characteristics. For new aeroplanes, the information is furnished by the aeroplane manufacturer who supplies customers with amendments to the Flight Manual which reflect any significant changes to the aeroplane's design, limitations, performance or operating procedures. The Flight Manual, by definition in the Air Navigation Order, forms part of a UK registered aeroplane's Certificate of Airworthiness.

Under British Civil Airworthiness requirements, the type design organisation of a public transport aircraft seeking a UK Certificate of Airworthiness also has a duty to furnish the information and instructions necessary to enable the crew to acquire an understanding of the aircraft essential for its safe operation. The information and instructions may form a part of an Operations Manual prepared by the manufacturer. British Aerospace (BAe) provided British Airways with a Flight Manual and an Operations Manual for the ATP. Section 9 of the Operations Manual contained the procedures and advice for safe operation of the aircraft; it also contained a duplication of the first four sections of the Flight Manual which stipulate the operating limitations.

The Air Navigation Order requires that public transport aircraft registered in the UK carry all the information and instructions necessary for safe operation of the aircraft. It is the aircraft operating company's responsibility to provide and update this documentation but the operator need not duplicate any information or instructions available in the Flight Manual provided the Flight Manual is carried on the flight deck. The operating company's documentation is known as its "Operations Manual". In practice the manual is often divided into separate folders, each with its own sub-title. These documents are carried on the flight deck for reference by the crew. The airline's Operations Manual and any amendments to it must be submitted to the Civil Aviation Authority (CAA).

Normal practice is for an airline to base the aircraft type-specific procedural and technical content of its Operations Manual on the aircraft manufacturer's Flight and Operations Manuals. British Airways (BA) obtained dispensation from the CAA to incorporate the ATP Flight Manual within their ATP Operations Manual. Thus the Operations Manual for the ATP which was compiled and issued by BA was based on the BAe Flight and Operations Manuals but it also contained instructions and advice relating to the airline's standard operating procedures.

The main volumes were:

Flying Manual	Containing the limitations and procedures for ground and flight operation, and based largely on Section 9 of the BAe Operations Manual supplemented by extracts from the Flight Manual.
Technical Manual	Containing technical descriptions required by the aircrew for understanding the aircraft's systems and features. It was based largely on Section 8 of the BAe Operations Manual.
Performance Manual	Containing data applicable to fuel consumption, approach minima, and scheduled performance for various airfields, and based largely on the scheduled performance sections of the BAe Flight Manual.

There were other sections of the BA Operations Manual such as Flight Crew Orders which were not based upon aircraft manufacturer's documents; they were originated by the airline's management and reflected company policy.

1.17.4 British Aerospace Flight Manual wind limitations

There was no wind speed limit for ground operation of the ATP within the general limitations section of the manufacturer's Flight Manual.

1.17.5 British Aerospace Operations Manual wind limitations

When the manufacturer's Operations Manual was first issued to BA in March 1989, page one of section 9.70.1 entitled "Operations in Adverse Weather" dated Nov 10/88 did not contain any wind limitations which affected ground operations. However, during 1990, following the Manchester incidents when ailerons and rudders were damaged (see para 1.17.2), this page was amended to include the following:

"If the aircraft is operated in ground conditions where it may be subject to strong or gusty side or tail winds (in excess of 52 knots), it is possible that damage to the control surfaces or the system may occur even with the control locks engaged.

When the aircraft has been subjected to to such wind conditions, a maintenance log entry must be made to ensure that the inspections detailed in the Maintenance Manual Chapter 04-50-24, are carried out before next flight".

The relevant page dated Feb 14/90 was issued as a loose leaf amendment to version 001 (for aircraft with original flap settings) but was already included in version 003 (for aircraft with revised flap settings). Version 003 was issued complete and received by BA at about the same time. In both versions of the manufacturer's Operations Manual the new text was accompanied by vertical bars in the left margin which were intended to draw the readers' attention to the fact that this text was either new or had been amended.

The amendment was accompanied only by a letter of transmittal. On this letter, under the column entitled "reasons for change", the reason for amending section 9.70.1 was given as *"Insertion of Information relating to Operations in Strong/Gusty Wind Conditions"*. No document explaining the background to the amendment was issued.

Having completed a modification to the flap systems of all their ATPs, BA withdrew Flight Manual version 001 on 23 Oct 91 from the company's technical library.

1.17.6 British Airways Flying Manual wind limitations

The ATP Flying Manual produced by BA contained the following wind limitations in the section entitled "LIMITATIONS HANDLING":

"Maximum crosswind for take-off . . . . 30 kt
Maximum crosswind for landing . . . . 30 kt
Maximum tailwind for take-off . . . . .10 kt
Maximum tailwind for landing . . . . .10 kt
Maximum crosswind for take-off on contaminated runway . . . . 10 kt
Max tailwind permitted for take-off, contaminated runway . . . . . 0 kt"

The page was dated 31 May 90 and had been partially superseded by a flight crew notice dated 25 Apr 91 which stated:

"With immediate effect, the crosswind limit for the ATP during take-off and landing on a dry runway is revised as follows:

Take-off . . . . 36 Knots
Landing . . . . 34 Knots"

There was no mention of any other wind limits for ground operation within the Flying Manual.

1.17.7 British Airways Technical Manual wind limitations

The ATP Technical Manual produced by BA contained only one reference to wind strength during ground operations. The sentence, which was within the Ground Handling section of the Aircraft General Chapter, stated:

> *"The aircraft should not be parked and picketed into wind with winds exceeding 80 knots, or with side and tail winds exceeding 55 knots."*

1.17.8 British Airways Flying Manual - Adverse Weather Instructions

The "Adverse Weather" section of the British Airways' ATP Flying Manual stated that:

> *"Every attempt should be made to anticipate windshear and areas of known severe windshear should be avoided. All available information including pilot reports of windshear or turbulence: low level windshear alerts; and weather reports particularly regarding frontal/ squall/ thunderstorm activity; low level inversions; surface winds differing significantly from upper winds should be used to assess the likelihood of windshear.*
>
> ***If severe windshear is indicated delay take-off, or do not continue approach until conditions have improved."***

Comprehensive advice was also given regarding the detection of windshear on take-off and the actions necessary to overcome it.

A section covering turbulence after take-off also stated:

> *"If conditions of severe turbulence are forecast or reported and are liable to be encountered immediately after take-off, before flap can be retracted and the Rough Air Speed achieved, the take-off should be delayed until conditions improve.*
>
> *If severe turbulence is encountered unexpectedly, raise flap normally and slowly accelerate to the Rough Air Speed (175 kt IAS) maintain normal aircraft attitude using moderate and smooth elevator movements."*

1.18 New investigation techniques

None

2 Analysis

2.1 Introduction

The accident occurred when the aircraft rolled to the right during take-off. Both pilots stated that "ROTATE" was called at or shortly after the scheduled rotation speed of 98 kt but the FDR trace shows that rotation did not begin until between 105 and 110 kt IAS. The undemanded roll to the right started two seconds later as the aircraft reached a pitch attitude of 3° nose-up (the target pitch attitude was 6° nose-up). The commander immediately applied left roll demand which increased linearly to essentially full demand within two seconds. Despite this swift application of left roll demand, the aircraft continued to roll and the commander, who sensed rather than diagnosed an engine failure, applied about 75% left rudder deflection and instructed the first officer to select contingency engine power. The nose-down pitch change which occurred five seconds after rotation was coincident with a nose-down elevator input and the application of left rudder. Considering the commander's rapid reaction to the undemanded roll with large applications of aileron and rudder, and the magnitude of arm and leg movements required, it is not surprising that pitch control suffered momentarily. Nevertheless at no time did the radio altimeter record a descent and the commander rapidly re-applied nose-up elevator which resulted in a return to a sensible pitch attitude and a much needed gain in height. The commander's reactions were almost entirely apt and his speed of reaction was commendable; had his reactions been appreciably slower, the outcome of this accident would have been far more serious.

This analysis examines the reason for the undemanded roll to the right and considers the associated operational and technical aspects.

2.2 Impact damage

There was little doubt that the damage occasioned to the aircraft's wing and outer section of the right aileron was as a result of the the right wing tip making a grazing contact with the ground. Also, the damage to the rear fuselage was as a result of loose stones being thrown up by propeller wash from the right power plant as the aircraft departed from the runway heading at an extremely low height.

Throughout the uncontrolled excursion in roll as the aircraft took off, which covered the period from before to after wing tip contact with the ground, the FDR indicated that full left roll, or a significant proportion thereof, was being demanded by the input mechanism to each aileron. Had the right aileron been deflected significantly down as demanded, at bank angles of 27° to 32°, the outermost trailing edge of the aileron would have made contact with the ground. Although evidence was found of earth particles, stone damage and abrasion of the paint of the lower section of the aileron horn, consistent with up aileron during ground contact, there was no such evidence on the aileron trailing edge. The fact that the outer trailing edge of the aileron was distorted slightly upwards was attributed to the nose down rotation of the stiff aileron closure rib as the horn itself was distorted.

The aircraft's IAS at the time the right wing tip touched the ground was recorded as being in the region of 135 kt. The best estimate of the mean wind at this time was given as 280°M/55 kt although individual gusts had been recorded as high as 72 kt. The aircraft's ground speed, therefore, was probably in the region of 80 kt, or approximately 40 metres per second. This suggests that the ground witness mark made by the wing tip, which was some 23 metres in length, was produced in just under 0.6 second and the shorter furrow, made by the aileron aerodynamic horn, in just 0.06 seconds. The wing tip/aileron reconstruction showed that, with no horn deformation, the angle cut by the horn in the ground with the aileron deflected trailing edge upwards was likely to be the same as the angle made by the outboard wing to the ground. The measured angle made by the horn as it initially cut into the surface was around 20° indicating that, with the allowance for 7° of dihedral, the aircraft was banked to the right by some 27°. As the wing tip had touched the ground only just before the aileron horn, (0.13 sec) it follows that the aircraft was banked close to 27° to the right at the start of its tip contact with the ground. The aircraft's heading at this time was recorded at around 276°, suggesting an effective drift angle of about 7° to the right, when compared with the aircraft's track of 283°, at the start of the ground witness marks. This accords well with the drift angle derived from the geometry of the wing tip in relation to the ground witness marks, and the direction of abrasion lines on the wing tip and aileron horn of around 9°.

With the aircraft effectively side-slipping to the right and the aileron horn protruding below the wing tip a lateral, inward, force would have been generated on the outer lower quarter of the horn by its passage through the ground. The direction of this force was consistent with causing the downward and inward deformation of the horn relative to the aileron. Additionally, drag forces would have been generated at the same location, inducing a rearward bending moment of the outer section of the aileron about its outermost hinge. It was these forces that were considered responsible for the structural failure of the aileron about that hinge.

2.3 Right aileron operating arm failure

The evidence is that the failure of the right aileron operating arm was a single overload event while under compressive loading. This could not have been caused either by the trailing edge of the aileron contacting the ground initially, for which there was no evidence, or by the forced application of up aileron as the aileron horn cut into the ground, both of which would have produced a tensile loading in the aileron arm. The FDR also showed movement from the aileron synchro position transmitter, indicating left roll demand, which was not consistent with the position of the aileron from the evidence of the ground impact. The aileron arm failure must therefore have occurred before the wing tip touched the ground during take-off.

Analysis of this FDR data and the lack of any report from the crew that anything was untoward with the aircraft during its previous flight suggested that the operating arm failure occurred after the aircraft landed but before it took-off on the accident flight. Only one significant abnormality, with respect to the aileron system, was identified during this time and that was the general small random movement of both ailerons and the large downward deflection of the right aileron whilst the aircraft was taxiing downwind, with the control locks engaged, just prior to take-off. The peak recorded value of this deflection was 12.0° down from neutral. This figure compares well with the estimated downwards deflection required to precipitate an operating arm failure of 15.2°, when it is considered that the recorded value of 12° is unlikely to be the actual peak value at the surface because of the relatively low FDR aileron sampling rate of once per second. In addition the relatively low stiffness of the linkage between the aileron and the FDR synchro position transmitter will account for a loss of approximately one third of the actual deflection (see paragraph 1.16.1).

However, this theoretical failure deflection of 15.2° was derived from a worst case analysis, based on a 5° drive rod offset angle, the real (tested) case of 3° indicating that significantly higher hinge moments are required to be generated by the aileron to fail the operating arm. The equivalent surface deflection to precipitate failure, based upon a linear extrapolation of the measured circuit stiffness, would be some 25°. It is therefore reasonably certain that the operating arm failure on G-BTPE occurred at a surface deflection in excess of 15°, and possibly as high as 25°, and that this occurred as the aircraft taxied downwind towards the take-off point.

2.4 Other possible explanations for the undemanded roll

Flight tests conducted by the manufacturer with 15° flap set have shown that, under steady state conditions, with the aileron disconnected there is no tendency for the control surface to float upwards and induce a roll to the right. Other possible explanations were therefore considered for the uncommanded right roll.

Firstly, as the commander had sensed, a sudden and substantial power loss from the right powerplant could have induced a strong roll and yaw to the right but there was no evidence of power loss and this mechanism may be discounted. Secondly, a lateral imbalance in the weight distribution or flap configuration might have induced a strong roll but the fuel states in both wings after landing and the post-flight checks of the wing flaps discount any meaningful imbalance. Thirdly, a sudden variation in crosswind component could have overcome the aircraft's roll control power. The FDR trace for the take-off ground roll (see Appendix D, Figure D-2) shows movements typical of corrective directional inputs in strong, gusty wind conditions. The rudder trace shows considerable activity with excursions of up to 7° either side of a mean which becomes progressively more left reaching 5° left at rotation. The trend of increasing left rudder is indicative of a crosswind component from the right. Although it remains a possibility, there was no conclusive evidence that a sudden variation in crosswind component produced the powerful rolling moment. Whatever the cause of the initial undemanded roll to the right there is no doubt that when the right aileron contacted the ground it was positioned significantly up from the neutral as indicated by the abrasion and stone damage to the horn surface.

2.5 Pre-departure control checks

The inherent nature of the flight control gust locks denied the crew any feedback of the distress which the flight controls suffered. They correctly disengaged the locks once the aircraft was aligned for take-off and carried out "full and free" checks of all the control runs. Their decision not to look at the ailerons whilst carrying out these checks was understandable since their view of the elevators and rudder would always be obscured and a standard operating procedure to view the aileron would be difficult in darkness. Moreover, if the first officer had looked at the right aileron, he would have seen aileron movement even with the bracket failed because the linkage was still capable of transmitting a compressive load. Therefore it is unlikely that the crew would have been able to feel or see the damage to the right aileron.

2.6 Aileron control circuit stiffness

The damage that has occurred to the aileron flying controls of the ATP since its introduction to service by British Airways and Loganair, albeit when parked or operated on the ground in winds above the 'ground gust and taxiing downwind' design standard of 52 kt, contrasts with the almost total lack of equivalent damage recorded from the HS 748 fleet operated by British Airways throughout the Highlands and Islands routes over some many years. The ATP damage has occurred predominantly to the right aileron operating arm. Throughout this period the severity of the weather has not significantly changed and the aircraft are operated and handled in a similar way, although the ailerons on the HS 748 have always been capable of being fitted with external control locks. The incidence of such damage on the ATP, therefore, may be attributable to the non availability of external locks but also, as the frequency with which external locks have been used on the HS 748 is not known, to differences in the characteristics of the control systems on these two aircraft types. As the shape and size of the aileron is essentially the same the most significant difference between the two aircraft would appear to be the lower stiffness of the aileron wing circuits in the ATP, that on the right side in particular. This has been measured to be 25% less stiff than the left circuit. For a given tail-to-wind gust, therefore, the right aileron surface on the ATP will deflect more readily from neutral than the left, or those on the HS 748, and so in reality tend to generate the maximum circuit loads, and hence critical stresses in the operating arm, before the other aileron circuits considered.

There is no doubt that aileron surfaces will deflect both up and down under the influence of tailwinds, possibly in an oscillatory manner, the angular travel and hence level of damage to the arm, being dependent on wind or gust intensity. Relatively small deflections were recorded on G-BTPE, whilst taxiing downwind at Sumburgh just after landing, when peak wind gusts of 51 kt were recorded. By the time the aircraft was taxiing for take-off gusts of up to 72 kt were being recorded. That relatively large aileron deflections can occur in recorded winds below the picketing limit of 65 kt, precipitating operating arm deformation and failures, is shown by the incidents to G-BTPH and G-OLCC at Manchester Airport on 25 January 1990 when the peak gust recorded was 59 kt. The two incidents where operating arms failed on G-BTPF and G-OLCD were associated with recorded wind gusts of up to 70 kt; the manufacturer's assessment of 83.5 kt to cause failure being based on the JAR 'steady state' standard. These events support the manufacturer's Operations Manual statement that control surface damage may result from operating the aircraft in tailwinds in excess of 52 kt, but not that the aircraft can be safely picketed, without external control locks, in recorded winds up to 65 kt. To be certain of meeting this requirement without the use of external locks, it is recommended that BAe review the design of the ATP aileron control system with a view to increasing the stiffness of the right wing circuit to, at least, that of the left wing circuit, but preferably to that of the HS 748.

From the foregoing, it is appears that the situation becomes critical for the right aileron soon after recorded gust speeds increase above 52 kt with failure of the operating arm almost certainly to occur at recorded gust intensities of around 70 kt. The actual gust intensity experienced by an aircraft, however, is not necessarily the same as indicated by a single airport anemometer. Although quoted surface wind speed is essentially the wind speed 10 metres above ground level (agl), such factors as large buildings and local topography (*eg* Fitful Head at Sumburgh) are likely to produce their own localised effects, possibly resulting in higher than indicated gusts, and eroding any margin above the relevant wind speed limits for ground operations/picketing. Indeed, it is likely that this effect occurred at Manchester airport on 25 January 1990 when two ATP aircraft were damaged but where maximum recorded wind gusts (59 kt) were below the JAR picketing requirement of 65 kt. It is therefore recommended that the CAA consider a requirement to factor the parking/picketing/taxiing wind limits to take account of exposure to localised gusts of greater strength than that recorded at the anemometer.

2.7 Airworthiness requirements

The equation quoted in JAR 25.415 (2) (see paragraph 1.17.1) is the same as that in the American FAR regulations where it has been used as the fairly straightforward basis for determining tail-to-wind hinge moments on control surfaces for a considerable period of time. Recent critical evaluation of this has suggested that the factor, K, of 0.75 relates to the maximum achievable value of hinge moment and that this probably occurs somewhere between neutral and full travel. At full travel the surface is assumed to be fully or partially stalled, hence the lower value of K. With the control locks engaged, the two aileron wing circuits are essentially undamped spring mass systems, the spring element being the 'circuit stiffness' and the mass the effect of the 'rotational inertia' of the aileron about its hinge line. Thus the system will possess a natural frequency of oscillation. This equation appears to relate to a 'static' case with no terms present to specifically address any dynamic aspects of the loading such as resonance or inertial loading due to high rates of surface rotation. The failures of aileron operating arms on the ATP, those occurring on 25 January 1990 in particular, appear to be somewhat dynamic in nature. The validity of the equation is questioned in the light of this and also the results of the test of the operating arm indicating that it will fail under significantly higher hinge moments than those calculated for the assumed worst case. It is therefore recommended that the CAA reviews the validity of JAR 25.415(2) and the need for JAR 25 to require the maximum wind speeds for parking and taxiing to be given in Flight Manuals.

2.8 Technical documents

The hazard presented by strong winds to an aircraft is, to a great extent, governed by its size, mass and design philosophy. To attempt to take-off in a typical light aircraft into a gusty 65 kt wind would be extremely dangerous because the aircraft might be blown over whilst taxiing, the controls might be wrenched from the pilot's grasp and damaged, or it might become airborne in a gust with no power applied and no forward motion relative to the ground. On the other hand, a large aircraft such as the Boeing 747 would not be at risk from being blown over, its control surfaces would be stabilised by their hydraulic actuators, and it would require a groundspeed of some 100 kt before it became airborne. The ATP's size, mass and design lie between these extremes and the safety of operating in harsh wind conditions is very much a subjective decision which, ultimately, rests with the commander. However, in arriving at an appropriate decision, the commander requires, amongst many other things, access to reliable information about the capabilities and limitations of his aircraft. It is reasonable to expect all the operational limitations to be contained either in the airline's Operations Manual or in the manufacturer's Flight Manual if it is carried on the flight deck.

Following the storm damage to various ATPs in early 1990, BAe prepared and issued an amendment to "Part 9 - FLYING" of their ATP manufacturer's Operations Manual which cautioned against operating the aircraft in side or tailwinds of 52 kt or more. They did not, however, issue an amendment to the Flight Manual. In view of the incidents involving ATP control surface damage (and not withstanding the outcome of the review of JAR 25 recommended in paragraph 2.7) it is also recommended that the CAA should require appropriate parking and taxiing wind limitations to be included in the ATP Flight Manual.

The Operations Manual amendment was received by BA but its significance was under-assessed and the caution was not incorporated into the airline's ATP Flying Manual. It did, however, appear in their ATP Technical Manual but it was placed in a section which the crew were hardly likely to consult since they were not normally responsible for picketing the aircraft. Therefore, it seems probable that the BA employee(s) who reviewed the amendment failed to appreciate the significance of the word "operated" within the phrase "operated in ground conditions" and believed that the change applied only to parking and picketing wind limits.

However, BA was the operator of two of the ATPs which were damaged in the gales of 1990. The company had had the opportunity to perceive for itself a de-facto limitation on parking the ATP in strong winds and they were well placed to realise that the limitation was applicable to ground operations such as towing or taxiing. It is recommended, therefore, that British Airways should review their procedures for incorporating manufacturer's technical amendments into their Operations Manuals.

2.9 Flight crew preparation

On the day of the accident both pilots were well rested when they reported for duty and qualified to undertake the flight. They noted during their briefing that the forecast wind conditions would create difficulties at Sumburgh. The commander, by his action in having a persistent but elusive nosewheel steering defect rectified at Aberdeen, and then flying a short test flight to confirm that the defect had been corrected, demonstrated that he had given serious consideration to these difficulties. However, the company's Operations Manual contained no guidance on maximum wind strengths for operating a service and, provided the commander observed the aircraft's limitations contained in the company's ATP Fying Manual, the decision to operate to or from Sumburgh's runway 27 in strong wind conditions was entirely his. Based on the forecast, the maximum crosswind component for landing was likely to be well below the limit of 30 kt for a wet runway except when the wind was from the forecast extreme of 300°M/ 55 kt when the crosswind would be close to the limit if the runway was wet. However, this extreme was forecast to be intermittent and associated with the passage of cumulonimbus cloud and possibly a heavy thunderstorm. The commander could reasonably have decided to hold or divert if he encountered such conditions on arrival at Sumburgh which, in the prevailing winds, would be short-lived. Therefore, the commander's decision to operate the sector from Aberdeen to Sumburgh was justified and soundly based.

2.10 The take-off decision

During the intervening hour between landing at Sumburgh and departing for Aberdeen, the mean wind had increased in strength to 47 kt and the direction was by then variable between 260° and 330°M. The spread between maximum and minimum reported speeds was 36 kt and the maximum speed exceeded the mean by 18 kt. The commander would have known that these wind conditions were bound to produce vigorous turbulence, especially if the wind veered to the north west and came towards the airfield from the direction of Fitful Head. Moreover, there was the distinct possibility of excessive crosswind component, even on a dry runway, if the wind came from 330° at more than 40 kt. However, there was no guidance in the company's Operations Manual regarding when to suspend a service due to wind strength although the "adverse weather" section of the Flying Manual advised against taking-off if severe windshear or severe turbulence were likely during or immediately after take-off. There was no warning of windshear in the forecasts or actual weather reports for Sumburgh; the commander had not encountered severe turbulence during the approach to land and there were helicopters operating from the other side of the airport. There had been no recent pilot reports of severe weather and there were no automated systems at Sumburgh for detecting windshear or measuring or predicting the severity of turbulence which might be encountered on take-off. Thus severe turbulence was an ill-defined problem and turbulence a frequently encountered hazard when operating from the windy Scottish airfields which form a large part of the company's ATP route structure. As an ATP and previously an HS 748 pilot, the commander was perhaps equipped with the very experience necessary to make an informed but fine judgement about the upper limit of acceptable turbulence. Given that he had confidence in his aircraft; confidence in his judgement of the acceptability of the turbulence; no warning that windshear was present and no reason to suppose that the wind was capable of damaging the aircraft whilst taxiing, a decision to taxi to the runway threshold and make the final decision from that position was justified.

It is worth noting that other UK operators of the ATP had issued instructions to their flight crews that, for operating a service, the maximum sustained wind speed from any direction was 50 kt and that gusts in excess of this should not have occurred during the previous 10 minutes. Although this limitation was founded on an appreciation of the aircraft's experience of wind damage, it has the advantage of placing an upper limit on the degree of low level turbulence which the passengers might experience after take-off. Consideration should be given to determining sensible maximum wind limits for passenger flights. Therefore, it is recommended that the CAA instructs all UK operators to include in their Operations Manuals an upper wind limit for operating a revenue service.

2.11 Wind assessment and reporting

There can be no doubt that the salient feature of this accident was the harshness of the surface wind at Sumburgh airport. Strong and gusty winds had been a feature of both the 0600 and 0900 hrs forecasts but the mean and maximum wind strengths at the time of the accident were significantly greater than those contained in either forecast. The strength of the wind had increased markedly above the forecast level during the intervening hour between arrival and departure from the Sumburgh terminal. The mean winds on the Scottish mainland were, however, much as forecast and significantly lower in speed. Therefore, although the commander was aware that the wind conditions would be difficult at Sumburgh, he had no reason to suspect that they would be significantly worse than forecast and he was not to know just how difficult they would become until he prepared for take-off.

There was no requirement in the Manual of Air Traffic Services (MATS) for controllers to pass the surface wind to departing traffic although it is a very widely accepted practice for them to pass details of the surface wind, read from anemometer dials, together with the take-off clearance. Inclusion of an appropriate requirement was under consideration by the CAA when the accident occurred and MATS was amended on 13 March 1992 to include the requirement.

When the crew declared that they were ready for take-off, the aerodrome controller informed them that the surface wind was 270°M/55 kt. The commander had no option but to accept this measurement of the wind, which was being sensed about 1,000 metres from the threshold, because the nearest wind sock was 800 metres away. Just before he released the wheelbrakes a further wind report of 280°M/65 kt was passed which gave a crosswind component of 11 kt from the right. With the general gustiness and variations in the wind direction at the time, it is possible that the wind sensed at the anemometer was dissimilar to the wind over the runway. The absence of a wind sock close to the runway threshold denied the crew a visual interpretation of the wind in their vicinity. The provision of small wind socks close to the threshold, which are installed at other UK airports, enables departing crews to assess the wind direction relative to the runway direction immediately prior to beginning the take-off. This information is valuable in crosswinds, when the wind direction is variable and when crews pre-plan in which direction they will stop the aircraft on the runway should they have to abandon take-off with an engine fire.

In a recent publication of Civil Aviation Publication (CAP) 573 (Approval of Air Traffic Control Units) the CAA stated that it has accepted ICAO recommendations for improving surface wind indication systems and that it will, in due course, require compliance with these recommendations at all aerodromes which have ATC. As an interim measure, the CAA decided to require compliance with ICAO recommendations from all airports which support international scheduled services (these are listed in Appendix B of CAP 573). As the criterion for addressing air traffic volume and thus people at risk, this was entirely reasonable. However, this criterion takes no account of the likelihood of critical wind conditions at individual airports. It is recommended, therefore, that:

a. Sumburgh airport should be equipped with additional windsocks located close to the threshold of each runway.

b. The CAA should, with the assistance of the Meteorological Office, review the list of airfields at Appendix B of CAP 573 with a view to including UK airports which support domestic scheduled air services and which are prone to hazardous wind conditions.

2.12 Windshear

As the Meteorological Office report at Appendix C makes clear, there was a risk of moderate to strong windshear at Sumburgh but no reference to this risk was contained in any of the weather forecasts, SIGMET warnings, or weather reports. Had the commander been warned of the presence of strong windshear at Sumburgh he would probably have delayed departure until the winds abated; this was certainly the instruction contained in the BA Operations Manual (see para 1.17.8). Consequently, although windshear was not a causal factor in this accident, its undetected and unforecast occurrence is a flight safety issue which should be addressed.

The MET section of CAP 32 (The UK Aeronautical Information Publication) does not include windshear in its list of weather conditions which qualify for a SIGMET or an aerodrome warning. Similarly, the international codes for Terminal area forecasts do not include windshear. At most UK aerodromes there is no windshear forecast or detection system and warnings will only be given after ATC have been alerted by a pilot who has encountered windshear. However, the Met office provides a windshear alerting service for two major UK airports: London/Heathrow and Belfast/Aldergrove. The issue of an alert is based on one or more of three occurrences: a mean surface wind of 20 kt or more; a difference in magnitude of 40 kt between the mean surface wind and the forecast wind at 2,000 feet; and thunderstorm(s) or heavy shower(s) within 5 nm of the airfield. At Sumburgh two of these three conditions were amply met and it is possible that a forecast of windshear at Sumburgh could have been issued had Sumburgh been included in the list with Heathrow and Aldergrove.

Much of the research into windshear has been conducted in the USA where thunderstorms have produced severe downdraughts called microbursts which have caused fatal accidents involving large transport aircraft. In the UK, thunderstorms seldom approach the intensity of those commonly encountered in parts of the USA and thus it seems reasonable to assume that the microburst hazard is probably lower in the UK than in the USA. On the other hand, the risk of windshear caused by interaction between atmospheric instability, topography and Atlantic storm winds is probably higher in the UK than in the USA. Within the UK, the risk is probably greatest in Scotland due to the rugged terrain and the frequency of Atlantic storms but little practical research into the magnitude of the risk appears to have been completed. It is recommended, therefore, that the CAA should, with the assistance of the Meteorological Office:

a. Sponsor practical trials to assess the combinations of strong wind, topography and convective instability which may combine to create a significant windshear hazard.

b. Increase the number of airfields provided with a windshear alerting service to encompass those airfields most at risk to windshear.

2.13 Recovery of control

Having reached an excessive bank angle of 38° below a height of 50 feet, the commander managed to coax the aircraft back to a reasonably wings level attitude using left rudder and left roll demand but he stated that he was unable to prevent it from yawing further to the right. The FDR trace shows that more rudder deflection was available but this is no reason to criticise the commander's performance. In the few seconds after rotation the aircraft had turned some 28° to the right. By the time the turn had been contained, the aircraft was pointing at nearby Fitful Head and the commander's attention was, quite properly, directed at avoiding the rising ground directly ahead. The application of contingency power plus retraction of the landing gear improved the aircraft's rate of climb and the commander allowed the aircraft to climb at about 135 kt with a slight residual yaw to the right. Unfortunately this involuntary flight path took the aircraft immediately downwind of Fitful Head where it was subjected to very strong turbulence which made control even more difficult. The commander's decision not to retract the flaps during this stage was reasonable since he had no means of diagnosing the true cause of control difficulty (which might have been attributable to flap damage) and neither pilot was aware that a wingtip had touched the ground.

As the aircraft climbed through 2,000 feet altitude and terrain avoidance became unnecessary, the commander allowed the airspeed to increase. He noticed that roll control improved as airspeed increased and at about this time he was informed by the aerodrome controller that the aircraft had struck the ground on take-off. He was still unaware of the extent of the damage and, with the flaps remaining at 15°, he allowed the airspeed to increase to around 175 kt. At this speed, which was 5 kt below the flap limiting speed, the aircraft was controllable and the commander commenced a long left turn back towards the airfield.

2.14 Diversion

The commander's decision not to land back at Sumburgh was wise since the wind conditions were wholly inappropriate to landing with any control difficulties. He initially set course for Aberdeen and shortly after establishing RTF contact with Sumburgh Approach, the crew stated their endurance and asked for a diversion to an airfield where the wind was light. There were no civil aerodromes nearby with light wind conditions and so the crew asked ATC to check conditions at nearby military aerodromes. There can be little doubt that RAF Kinloss was the nearest suitable aerodrome with appropriate wind conditions and emergency services.

2.15 Transit

Maintaining visual flight conditions above the minimum safe altitude for as long as practicable eased the piloting task. The service and assistance given by the civil and RAF radar controllers was admirable and the crew were able to concentrate on preparing and briefing for the subsequent emergency landing.

The commander's act of visiting the passenger cabin to see for himself the damage to the right wing was proper since the first officer had no problem in retaining adequate control of the aircraft in the cruise. Having seen the damage, the commander had two logical options. He could have continued the flight with the flaps at 15° at or below 180 kt (the limiting speed) or he could have retracted the flap at about that speed and have assessed control with the flaps at 7° or fully retracted. If control had been adequate with flaps up, he could then have accelerated to a higher speed of his choice but with some risk of incurring further damage to the torn right aileron. Guidance on this decision was not contained in any of the manuals on board the aircraft, but it is unreasonable to expect every contingency to be covered therein. The decision process in this situation had to be based on the knowledge, common sense, experience, and foresight of the commander; qualities which are commonly referred to as 'airmanship'.

His decision to continue with the flaps at 15° was not unreasonable but to allow the airspeed to increase to a mean of about 210 kt with excursions to 223 kt. (43 kt above the limit) was unwise. In fact, the limiting air loads above which damage could be expected were not exceeded. The load imposed at 220 kt was

91% of the proof limit and the ATP's flaps are insensitive to vertical gust velocities and inertia effects. Nevertheless, the commander was not in possession of these facts at the time and there was no compelling need to exceed the 180 kt limit because the aircraft was controllable at that speed.

2.16 Approach and landing at Kinloss

The pilots did not execute all the items contained in the "emergency landing" checklist. Since this list was intended to cover a landing which was expected to result in major damage to the aircraft, and the commander expected to execute a safe landing, his review and selective use of each checklist item was quite proper provided that he had sound reasons for deviating from specific items. Thus, for instance, although the checklist called for 29° flap for landing and shutdown of both engines before touchdown, the commander's decision not to conform with these items was sensible especially as, in the latter case, he intended to use reverse thrust to compensate for an abnormally high landing speed.

Given the ample length of the runway at Kinloss, the ATP's braking performance and the crew's ability to control the aircraft at 170 ±10 kt with gear down and 15° flap during the initial approach, there was no need to extend the flaps to 20° for landing. It achieved only a three knot reduction in the reference airspeed from 107 to 104 kt whereas the final approach was actually flown at 150 kt. Moreover, moving the flaps was inconsistent with the earlier decisions to retain them at 15° for the entire cruise and to exceed the relevant speed limit by over 40 kt. On the other hand, landing with 20° flap presented the crew with a familiar landing configuration and avoided nuisance warnings from the ground proximity warning system.

The employment of 20° flap was not dangerous but delaying its selection until 500 feet agl on final approach was unwise. Asymmetric flap is unlikely because the aircraft is fitted with protection against this event, however, the commander could not be sure that the right flap would extend without causing additional damage or fouling the aileron. Control might well have been lost as the flap extended. Although the commander was prepared for this eventuality and ready to re-select 15° flap, at 500 feet agl it is questionable whether roll control could have been regained in the height available.

A safer alternative would have been to have established the desired landing configuration at altitude. Had the lowering of flap created difficulties, control could have been regained after an unwanted loss in altitude. After safely establishing the desired landing configuration, airspeed could have been reduced to the chosen speed for the approach. By so doing, the pilots could have established and had confidence in a minimum airspeed for the approach above which yaw and roll control remained adequate for landing.

The wisdom of conducting a landing configuration check at altitude before attempting to land a damaged aircraft was overlooked by the flight crew. It is recommended, therefore, that the CAA advise all operators of the desirability of conducting landing configuration checks (where required) at a suitable safe height, and not below the chosen approach speed, that would allow control of the aircraft to be recovered, if necessary, prior to the the final approach and landing.

2.17 Instructions to passengers

The commander's briefing to the cabin crew and their briefing to the passengers were satisfactory. The pilots then reviewed their intended actions for the final stages of the approach. The commander initially briefed the first officer to call "BRACE BRACE" after the flaps were lowered to 20° but later he amended his briefing and instructed the first officer to make the call at 1,000 feet agl. In accordance with his Captain's briefing, the first officer, whilst still at the controls, broadcast the instruction "CABIN CREW AND ALL CREW - BRACE, BRACE". According to the emergency checklist, the call at 1,000 feet should have been for cabin crew to take their seats followed by a brace call at 200 feet agl. The emergency checklist was quite specific but the commander chose to deviate from it because he wanted the co-pilot's undivided attention during the late stages of the approach.

The elapsed time between the brace call and the landing was 78 seconds. Timing of these calls is important since the first should be made early enough for the cabin crew to strap in. The second call should give the passengers enough time to adopt the brace posture but it should not be given so early as to encourage them to relax their posture in order to discover what is actually happening.

3 Conclusions

(a) Findings

(i) The crew were properly licensed, rested and medically fit to conduct the flight.

(ii) The aircraft was correctly loaded and its documentation was in order.

(iii) The aircraft was serviceable when it landed at Sumburgh.

(iv) The wind strength at Sumburgh exceeded the forecast maximum. Windshear and severe turbulence were present at about the time of take-off but windshear had not been forecast.

(v) The right aileron was damaged by a tailwind gust after the aircraft left the terminal and before it rotated on take-off. The damage was most probably inflicted whilst the aircraft backtracked the runway. The tailwind gust exceeded the maximum design case required by Joint Airworthiness Requirements.

(vi) The maximum tailwind speed for ground operations was not published by British Aerospace in the ATP Flight Manual.

(vii) British Aerospace had published advice on maximum side and tailwind speeds for ground operations as an amendment to the "Adverse Weather" chapter in section 9 FLYING of their ATP Operations Manual. British Airways failed to appreciate the significance of this advice and did not include it in their Flying Manual.

(viii) The pre-take-off checklist was properly actioned and the design of the aircraft was such that the pilots were unlikely to discover that an aileron had been damaged.

(ix) The commander's corrective actions on take-off were commendably swift and competent.

(x) The decision to divert to RAF Kinloss was correct.

(xi) Transit with the flaps at 15° at a speed above the limit for this configuration was unnecessary and unwise.

(xii) Preparations for the emergency landing were satisfactory apart from the omission of a handling check at the chosen approach speed in the intended landing configuration.

(xiii) Apart from late selection of 20° flap, the emergency landing at Kinloss was well handled.

(b) Causes

The following causal factors were identified:

(i) Operation of the aircraft in excessive tailwinds which damaged the right aileron whilst the aircraft was on the ground at Sumburgh.

(ii) Omission of the side and tailwind maximum recommended speeds from the ATP Flight Manual.

(iii) Failure of British Airways to heed the advice contained in section 9 of the manufacturer's Operations Manual.

4 Safety Recommendations

The following Safety Recommendations were made during the course of the investigation:

4.1 British Aerospace should review the design of the ATP aileron control system with a view to increasing the stiffness of the right wing circuit to, at least, that of the left wing circuit, but preferably to that of the HS 748 (Recommendation 92-100).

4.2 The CAA should consider a requirement to factor the parking/picketing/taxiing wind limits to take account of exposure to localised gusts of greater strength than that recorded at the anemometer (Recommendation 92-101).

4.3 The CAA should review the validity of JAR 25.415 (2) relating to the ability of control systems to withstand forces generated by ground gusts and consider the need for JARs to require the maximum wind speeds for parking and taxiing to be given in Flight Manuals (Recommendation 92-102).

4.4 Notwithstanding the outcome of recommendation 4.3, the CAA should require appropriate parking and taxiing wind limitations to be included in the ATP Flight Manual (Recommendation 92-103).

4.5 British Airways should review their procedures for incorporating manufacturer's technical amendments into their Operations Manuals (Recommendation 92-104).

4.6 The CAA should instruct all UK operators to include in their Operations Manuals upper wind limits for operating a revenue service (Recommendation 92-105).

4.7 Sumburgh airport should be equipped with additional windsocks located close to the threshold of each runway (Recommendation 92-106).

4.8 The CAA should, with the assistance of the Meteorological Office:

a. Sponsor practical trials to assess the combinations of strong wind, topography and convective instability which may combine to create a significant windshear hazard.

b. Increase the number of airfields provided with a windshear alerting service to encompass those airfields most at risk to windshear.

c. Review the list of airfields at Appendix B of CAP 573 with a view to including UK airports which support domestic scheduled air services and which are prone to hazardous wind conditions.

(Recommendation 92-107).

4.9 That the CAA should advise all operators of the desirability of conducting landing configuration checks (where required) at a suitable safe height, and not below the chosen approach speed, that would allow control of the aircraft to be recovered, if necessary, prior to the the final approach and landing (Recommendation 92-108).

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