AIRCRAFT ACCIDENT REPORT 2/2003

Air Accidents Investigation Branch

Department for Transport

Report on the accident to Shorts SD3-60, G-BNMT near Edinburgh Airport on 27 February 2001

This investigation was carried out in accordance with

The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996

London: TSO

This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidents.

ISBN 0 552500 9

Published 25 April 2003
Produced from camera ready copy supplied by Air Accidents Investigation Branch

Printed in the United Kingdom by The Stationery Office

136083 C4 04/03 841609 19585

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Air Accidents Investigation Branch
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March 2003

The Right Honourable Alistair Darling
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report by Mr Philip Gilmartin, an Inspector of Air Accidents, on the circumstances of the accident to Shorts SD3-60, G-BNMT, which occurred near Edinburgh Airport on 27 February 2001.

Yours sincerely

Ken Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	-	Air Accidents Investigation Branch
aal	-	above aerodrome level
AC	-	Alternating Current
AFM	-	Aircraft Flight Manual
agl	-	Above ground level
AIP	-	Aeronautical Information Publication
ALT	-	Altitude
amsl	-	above mean sea level
ANO	-	Air Navigation Order
AOC	-	Air Operator's Certificate
ATC	-	Air Traffic Control
AUW	-	All up Weight
BCAR	-	British Civil Airworthiness Requirements
°C	-	degrees Celsius
CAA	-	Civil Aviation Authority
CAP	-	Civil Aviation Publication
CVR	-	Cockpit Voice Recorder
DC	-	Direct Current
DDI	-	Documentary Data Insert
DfT	-	Department for Transport
DHC	-	De Havilland Canada
FDR	-	Flight Data Recorder
FL	-	Flight Level
FM	-	Flight Manual
g	-	gravitational acceleration
gall imp	-	Gallons Imperial
GPWS	-	Ground Proximity Warning System
HP	-	High Pressure
hPa	-	hecto Pascals (pressure)
IAS	-	Indicated Air Speed
ICAO	-	International Civil Aviation Organisation
IMC	-	Instrument Meteorological Conditions
IRVR	-	Instrumented Runway Visual Range
JAR	-	Joint Airworthiness Requirements
kg	-	kilograms
kt	-	knots
lbft	-	pounds-feet (torque)
°M	-	degrees Magnetic
MATS	-	Manual of Air Traffic services
MAYDAY	-	Distress message prefix
mb	-	millibars (pressure)
METAR	-	Meteorological Aerodrome Report
MHz	-	Megahertz
MOR	-	Mandatory Occurrence Report
MS	-	Minus (temperature)
MTOW	-	Maximum Authorised Take-off Weight
nm	-	nautical miles
OAT	-	Outside Air Temperature
PDI	-	Pre-Departure Inspection
PF	-	Pilot Flying
PNF	-	Pilot Not Flying
PS	-	Plus (temperature)
PW	-	Pratt & Whitney (Canada)
QNH	-	Corrected mean sea level pressure
rpm	-	revolutions per minute
ScATCC	-	Scottish Area and Terminal Control Centre
SID	-	Standard Instrument Departure
SNOWTAM	-	Notice to Airmen (Snow)
SPECI	-	Special Meteorological Report
SRG	-	Safety Regulation Group
SSR	-	Secondary Surveillance Radar
RT	-	Radio Telephony
°T	-	degrees True
TMA	-	Terminal Manoeuvring Area
UK	-	United Kingdom
UTC	-	Co-ordinated Universal Time
VHF	-	Very High Frequency
VMC	-	Visual Meteorological Conditions
VOR	-	VHF omni-directional radio beacon

G-BNMT on 23 February 2001
© Original photograph by permission of Mr F Seggie

G-BNMT Accident Site at High and Low Water

Air Accidents Investigation Branch

Aircraft Accident Report No: 2/2003 (EW/C2001/2/6)

Registered Owner and Operator	Loganair Ltd
Aircraft Type:	Shorts Brothers Ltd SD3-60 Variant 100
Nationality:	British
Registration:	G-BNMT
Place of Accident:	Birnie Rocks, near Granton, Firth of Forth, Scotland Latitude: 55° 59'N Longitude: 003° 22'W
Date and Time:	27 February 2001 at 1731 hrs All times in this report are UTC

Synopsis

The accident was notified to the Air Accidents Investigation Branch (AAIB) at 1744 hrs on 27 February 2001 by Air Traffic Control, Edinburgh Airport. The investigation was conducted by: Mr D King (Investigator-in-Charge), Miss G M Dean (Operations), Mr P R Coombs (Engineering) and Mr R James (Flight Recorders). An AAIB Special Bulletin (Number S1/2001), containing preliminary information about the accident, was published on 1 May 2001. During the course of the investigation, Mr P D Gilmartin was appointed to replace Mr King as Investigator-in-Charge.

A crew of two was operating the aircraft on a scheduled mail service from Edinburgh Airport to Belfast International Airport, with 1,040 kg of cargo aboard. The aircraft, a twin engined turboprop type, suffered a double engine flameout shortly after takeoff. The flight crew ditched the aircraft in shallow water in the Firth of Forth, close to the shoreline. The aircraft was severely damaged on impact with the water and the forward fuselage section became submerged. Neither crew member survived.

For some 17 hours prior to the accident, the aircraft had been parked on a north-easterly heading, facing into the prevailing strong surface winds, in near freezing conditions. In addition, overnight, there was light to moderate snowfall and drifting. The aircraft had been parked with the engine air intakes unprotected from snow ingestion. Thus, there was an opportunity for a significant amount of snow to enter the engine air intake systems. Tests showed that conditions were ideal for a large build-up of ice, snow or slush to occur in both plenum chambers, where it would not have been readily visible to the crew during a normal pre-flight inspection.

The investigation established that, following a selection by the crew of the anti-icing systems on the aircraft, specifically the selection of the intake anti-ice vanes, the subsequent movement of the vanes precipitated the near simultaneous engine flameouts. Interaction between the moving vanes and the residual ice, snow or slush contamination in both intake systems is considered to be the most likely cause of the engine failures.

The investigation identified the following causal factors:

1. The operator did not have an established practical procedure for flight crews to fit engine intake blanks ('bungs') in adverse weather conditions. This meant that the advice contained in the aircraft manufacturer's Maintenance Manual *'Freezing weather - precautions'* was not complied with. Furthermore intake blanks were not provided on the aircraft nor were any readily available at Edinburgh Airport.

2. A significant amount of snow almost certainly entered into the engine air intakes as a result of the aircraft being parked heading directly into strong surface winds during conditions of light to moderate snowfall overnight.

3. The flow characteristics of the engine intake system most probably allowed large volumes of snow, ice or slush to accumulate in areas where it would not have been readily visible to the crew during a normal pre-flight inspection.

4. At some stage, probably after engine ground running began, the deposits of snow, ice or slush almost certainly migrated from the plenum chambers down to the region of the intake anti-ice vanes. Conditions in the intakes prior to takeoff are considered to have caused re-freezing of the contaminant, allowing a significant proportion to remain in a state which precluded its ingestion into the engines during taxi, takeoff and initial climb.

5. Movement of the intake anti-icing vanes, acting in conjunction with the presence of snow, ice or slush in the intake systems, altered the engine intake air flow conditions and resulted in the near simultaneous flameout of both engines.

6. The standard operating procedure of selecting both intake anti-ice vane switches simultaneously, rather than sequentially with a time interval, eliminated a valuable means of protection against a simultaneous double engine flameout.

Four safety recommendations have been made.

1 Factual information

1.1 History of the flight

1.1.1 Previous activity

The aircraft landed at Edinburgh Airport from its previous flight at 0003 hrs on 27 February 2001. The weather conditions, recorded in the 0002 hrs SPECIAL report, were as follows:

> Surface wind 040°/22 gusting 36 kt, visibility 5,000 metres, light ice pellets, scattered cloud at 900 feet, broken cloud at 1,200 feet, temperature +1°C/ dewpoint 0°C and QNH 992 mb.

The aircraft was taxied to and parked on Stand 31, on a heading of 035°M. The inbound crew reported that there were no abnormalities observed or technical defects on the aircraft. They supervised the refuelling of the aircraft to a final load of 3,000 lbs (1,360 kg) before leaving the aircraft. Edinburgh Airport was not a main operating base for the airline and thereby flight crews were responsible for normal aircraft turnround procedures.

The aircraft was scheduled to depart Edinburgh at 0040 hrs with a different operating crew. This second crew arrived at the aircraft at about 0030 hrs. The aircraft required de-icing before departure but they were advised that there would be a delay of several hours before equipment would be available. In the interim they returned to the crew room. At 0210 hrs the airport closed as a result of the severe weather. At 0600 hrs this second crew were advised that the airport was not likely to reopen for several hours and so they returned to the aircraft to ensure it was secure before going off duty. At this time they fitted propeller straps to each engine and also put on the pitot head covers. Engine air intake bungs were not available for the crew to fit to the aircraft. The aircraft had not been de-iced.

The overnight weather conditions comprised a sustained strong north easterly wind, with a maximum recorded speed of 43 kt. Light or moderate snow fall occurred until 0952 hrs. There was no further snowfall after this time and by 1500 hrs the weather conditions were:

> Surface wind 030°/15kt, visibility 10 km, scattered cloud at 4,000 feet, broken cloud at 7,000 feet, temperature +2°C and dew point -3°C.

1.1.2 Accident flight

The pilots that were aboard the aircraft on the accident flight reported for duty at Glasgow Airport at 0810 hrs on 27 February 2001, for a planned flight to Islay departing at 0910 hrs. As a result of adverse weather conditions, that flight was cancelled and they were rescheduled to carry out the single sector flight delayed from 0040 hrs from Edinburgh to Belfast. Surface travel from Glasgow to Edinburgh was impossible due to adverse road conditions, so as soon as Edinburgh Airport re-opened at 1130 hrs, the crew were positioned to Edinburgh as passengers on another company aircraft.

On their arrival at Edinburgh the crew went out to G-BNMT. There was no record of their activities there, but at 1503 hrs they requested clearance to start engines. Start clearance was obtained and then, at 1512 hrs, the crew advised Air Traffic Control (ATC) they were shutting down due to a technical problem. During this period the right engine had been observed to start and stop several times.

The crew returned to the terminal and contacted their company at Glasgow to ask for engineering assistance. They indicated that the right engine driven generator would not come on line. A company avionics/instrument engineer was in transit through Edinburgh Airport. He was contacted by the Line Maintenance Controller at Glasgow and asked to assist the crew. He carried out trouble shooting with advice from the Maintenance Controller. This action involved transposing the connections to the Generator Control Protection Units and required the crew to start and run both engines for approximately 15 minutes. The connections were then returned to their original positions. Thereafter, the crew carried out a second engine run of similar duration, again at the engineer's request. The original fault could not be reproduced. A ground power unit was not available, so the engine starts were carried out using aircraft battery power.

The commander then requested that the engineer check the engine oil contents. He also asked him to confirm that the upper surfaces of the aircraft were free from ice and snow. The engineer noted that the oil levels were such that replenishment was not required and the only airframe contamination was a small slush deposit on the windscreen. This was cleared by the engineer. Both engines were then restarted after which the aircraft remained on stand with the engines running for about another 20 minutes.

At 1710 hrs the first officer requested taxi clearance. After a short delay the aircraft powered back off stand and taxied to depart from Runway 06. While taxiing, as part of the first flight of the day engine checks, the crew carried out an Autofeather test, during which the automatic operation of the engine anti-icing vanes to fully deploy and return was also observed, (Appendix 1, Figure 1). The commander briefed the first officer that after takeoff they would recycle the landing gear once to ensure that it was free of snow and slush.

The aircraft was cleared for a Talla (TLA) 5D Standard Instrument Departure (SID). The commander was the designated handling pilot. He carried out a normal takeoff which was followed by the landing gear being cycled up and down once, before its final retraction. A reduction to climb power was made at 1,200 feet amsl. The commander then called for the after take-off checks to be completed. When the 'Stall Warning Heaters' item was reached, he requested that the first officer put on all the anti-icing systems, (Appendix 1, Figure 2). At this time the aircraft was handed over from Edinburgh Tower to Scottish ATCC (ScATCC), which was acknowledged by the first officer. With the aircraft at 2,200 feet amsl, the first officer then selected the anti-icing systems 'ON' while the commander selected the new radio frequency. Four seconds after the selection of each anti-icing vane switch, the torque on the corresponding engine reduced rapidly to zero. The commander quickly observed that the aircraft had suffered a double engine failure and advised the first officer.

The first officer broadcast a MAYDAY call as the initial call on the ScATCC frequency as follows:

> "MAYDAY MAYDAY MAYDAY THIS IS LOGAN SIX SEVEN ZERO ALPHA WE'VE HAD A DOUBLE ENGINE FAILURE REPEAT A DOUBLE ENGINE FAILURE"

The ScATCC controller responded to the MAYDAY call passing the crew position and heading information. The first officer asked the controller to repeat the message but this transmission from the aircraft was truncated.

The commander continued to fly the aircraft, initiating a descent while allowing the airspeed to reduce to 110 kt and turning the aircraft to the right towards the coastline. The rate of descent stabilised at 2,800 feet per minute and he realised that the aircraft would have to be ditched in the water. The first officer attempted to make a further call to ScATCC advising that the aircraft was ditching, but this was not received. As the aircraft descended close to the water surface, the commander gradually increased the pitch attitude of the aircraft and correspondingly reduced the speed. The aircraft impacted the water in a 6.8° nose up attitude at an airspeed of 86 kt on a heading of 109°M. It came to rest on the sea bottom in a nose down attitude with the forward section of the fuselage submerged, 65 metres offshore, in a water depth of about six metres.

1.2 Injuries to persons

	Crew	Passengers	Others
Fatal	2	N/A	-
Serious	-	-	-
Minor	-	-	-
None	-	-	-

1.3 Damage to the aircraft

The aircraft was destroyed

1.4 Other damage

Not applicable

1.5 Personnel information

1.5.1	Commander:	Male, aged 58 years
	Licences:	Airline Transport Pilot's Licence
	Aircraft ratings:	Shorts SD3-30/60, Multi Engine Piston, Single Engine Piston
	Licensing Proficiency Check:	17 February 2000, valid to 28 February 2001
	Operator Proficiency Check:	18 August 2000, valid to 28 February 2001
	Last line check:	17 July 2000, valid to 16 July 2001
	Medical certificate:	Class 1, renewed October 2000, valid to April 2001

Flying experience:

Total all types:	13,569 hours
Total on type	972 hours
Total last 90 days	66 hours
Total last 30 days:	36 hours
Total last 24 hours:	1 hour 32 mins
Previous rest period:	12 hours 30 mins

1.5.1.1 Operating experience

The commander commenced his flying career in the Royal Air Force (RAF) operating both fixed and rotary wing types of aircraft. After leaving the RAF, he was employed for six years operating helicopters (Sikorsky S61 and Bell 214ST) principally on North Sea operations. For the next 12 years he was employed as a commercial flying instructor on fixed wing aircraft. In February 1999, he commenced an SD3-60 type conversion course with Loganair. He was employed as a Captain and in June 1999 he was appointed to a Line Training Captain position.

1.5.2	First Officer:	Male, aged 29 years
	Licence:	Commercial Pilot's Licence with Instrument Rating
	Aircraft ratings:	SD3-30/60, Multi Engine Piston, Single Engine Piston
	Licensing Proficiency Check:	8 January 2001, valid to 7 January 2002
	Operator Proficiency Check:	8 January 2001, valid to 31 July 2001
	Last line check:	29 January 2001, valid to 28 January 2002
	Medical certificate:	Class 1 renewed 7 August 2000, valid to August 2001

Flying experience:

Total all types:	438 hours
Total on type:	72 hours
Total last 90 days	72 hours
Total last 30 days:	36 hours
Total last 24 hours:	3 hours
Previous rest period:	19 hours 10 mins

1.5.2.1 Operating experience

The first officer initially completed the SD3-60 type conversion training with another operator in September 2000. He joined Loganair on 13 December 2000 and then underwent a company induction course followed by line training, before being released to normal line flying duties on 30 January 2001.

1.5.3 Company training

The commander carried out an initial course with the operator on ditching drills and use of lifejackets on 2 February 1999. He also completed a refresher course on emergency equipment and procedures in June 2000. The first officer carried out an initial course in ditching drills and the use of lifejackets on 14 December 2000. Actual opening of fuselage emergency exits is normally performed as part of initial and refresher training but opening of the overhead flight deck escape hatch is covered in theory only.

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer:	Short Brothers Limited
Type:	SD3-60 Variant 100
Constructor's No:	SH 3723
Year of Manufacture:	1987
Certificate of Airworthiness:	Valid until 15 October 2001
Engines:	2 Pratt & Whitney (Canada) PT6A-67R turboprop engines

1.6.1.1 Technical log

The final Technical Log sheet detailed the re-configuration to a freight layout, and confirmed the generator fault diagnostic attempt, with the result that no fault was found. A satisfactory check of engine oil levels was also noted.

1.6.2 Aircraft weights and centre of gravity

Maximum take-off mass	12,292 kg
Actual take-off mass:	10,140 kg
Take-off centre of gravity:	(approximately mid position in the allowable range)
Departure fuel	1,360 kg (3,000 lbs)

1.6.3 Aircraft description

1.6.3.1 General

The SD3-60 aircraft type is a high wing all metal monoplane fitted with retractable tricycle landing gear and two turboprop engines. In this cargo configuration, the interior passenger seats were removed to leave a single load area which could be accessed via the rear passenger door or the forward freight door, both located on the left side. Dedicated hold areas are located one forward and one aft of the main cabin, each has its own access door. Crew access is normally through the passenger entry door aft on the left side.

1.6.3.2 Ice protection systems

The SD3-60 aircraft type is fitted with a number of ice protection systems, each of which is operated from the flight deck anti-icing overhead panel, (Appendix 2). Anti-icing is available for the airframe, engines, propellers, windshields, pitot-static and stall warning systems. The Operations Manual required all the aircraft ice and rain protection systems to be selected ON before the aircraft entered visible moisture whenever the Outside Air Temperature (OAT) was 6°C or below. Company training indicated that this was to be achieved by the Pilot Not Flying (PNF) working from left to right across the panel operating the switches, some of which were in pairs, one for each side.

1.6.3.3 Powerplants

a) Layout

The SD3-60 type is fitted with two Pratt and Whitney PT6A-67R series turboprop engines. These have a reverse-flow arrangement, in which the compressor draws air in through a cylindrical mesh at the rear of the engine carcass and the turbine exhausts through two stacks positioned just aft of the propeller reduction gear. Each stack receives combustion gas from an annular chamber forward of, but downstream from, the low pressure turbine. Each stack turns the exhaust gas through 90 degrees, so that the outlet flow is directed aft, ie 180 degrees from the compressor and turbine gas path directions. The flows within the engine combustion system involve a 360 degree direction change between entry and exit, (Appendix 3, Figures 1a and 1b).

Each engine is supplied with air via an external, forward facing intake, positioned behind the propeller and below the engine. Air is ducted aft from the intake to a point below the aft section of each engine. Sealed bulkheads, forward and aft of each intake mesh, work in conjunction with the cowlings to form airtight plenum chambers surrounding the engine carcasses. The ducting turns the intake air through approximately 75 degrees and feeds it upwards into the bottom of the each plenum chamber.

b) Ignition

Each engine is equipped with conventional dual spark igniters, which ignite the fuel/air mixture in the combustion chamber during the starting sequence.

These are selected manually by means of a three position ('Off/Normal/Emergency') rocker switch (one per engine) located at the front of the overhead panel.

As with other turbine engines, the PT6A-67R engine only requires the use of the ignition system for engine starting. Thereafter, the engine will run with the ignition off, unless combustion becomes interrupted (for example by lack of fuel supply or disturbance of the intake airflow).

During normal starting, the pilot selects the Start switch to 'Start'. The High Pressure (HP) spools are rotated by an electric starter generator, Ignition is selected manually to 'Normal' to initiate igniter operation. Fuel is then introduced to the engine at the appropriate time manually, by actuation of the Fuel Lever. Starter and Ignition shutoff normally occurs automatically when the engine has become self sustaining above 50% 'Gas Generator' (compressor) rotation speed.

For 'windmill' relighting in flight, or for flight in adverse weather conditions (heavy precipitation, heavy icing, significant turbulence, volcanic ash etc), the Ignition system can operate continuously ('Emergency' switch position). This may allow the engine to automatically relight in the event of an engine flameout under such circumstances.

For the accident flight, the engine ignition systems were not selected to 'Emergency' for takeoff, as the Operations Manual, Part 9 Flying, indicated that it was only required to be so for takeoff and landing on contaminated (snow or slush) runways, in order to avoid the risk of engine malfunction caused by ingestion of snow or slush during the take-off run. The runway conditions at the time of departure were officially described as 'WET' (ie surface soaked but with no significant patches of standing water). However, the Operations Manual, Part 8 Technical, indicated that the 'Emergency' ignition selection for takeoff was applicable when there was a risk of ingestion of snow, slush **or water** during the take-off run. This was also reflected in a Supplement to the Aircraft Flight Manual.

Some other turboprop aircraft types, of more recent design, are equipped with 'Auto-Relight' systems, which automatically activate the igniters when a loss of torque (power) is detected, or have 'Auto-Ignition' which provides automatic operation of the igniters when certain anti-icing selections are made. The SD3-60 was certificated without such systems, in keeping with similar types at the time of its introduction into service.

c) Ice protection systems

Intake ice protection takes two forms. Firstly, the intake lips each incorporate an electrically heated mat. Further back in each intake, a selectable inertia separator ensures that solids and liquids can be ejected from the flow before they can enter the plenum chambers and block the intake meshes.

Each inertial separator consists of two vanes mechanically linked together, (Appendix 3, Figure 2). An electrical actuator is positioned in each engine cowling to drive the corresponding pair of vanes. The forward vane takes the form of a deflector, hinged at its forward edge to the upper surface of its intake duct. This deflector, when fully lowered, slopes downward approximately 10 degrees and reduces the vertical cross-sectional area of the horizontal duct by approximately 50%.

The aft vane takes the form of a bypass door, hinged along its upper edge. It is positioned part way round the curved flow path which directs the air from each horizontal duct upwards into the corresponding plenum chamber. Approximately 90% of the available forward vector of the movement of the lower edge of the aft bypass door occurs during the first 50% of its angular movement.

With the deflectors lowered, each airflow is forced to turn through an acute angle before entering its plenum chamber. Each bypass door opens forward to intercept the outer portion of this curved intake flow. The large airflow direction change ensures that the more dense material is 'centrifuged' to the outer circumference of each flow path. The position of each bypass door allows this material to pass through it and exit overboard. The bypass doors each block approximately 50% of the local duct cross-section when fully open. In this position, each door lies with its forward edge inclined upwards some 10 degrees to the horizontal.

The separator vanes are controlled by two adjacent rocker switches on the anti–icing panel, one for each engine, (Appendix 2). With the selector switches in the 'OFF' position, there would be a green 'NORMAL' indication and with the switches 'ON', and the vanes in the fully deployed position, a white

'ANTI-ICE' indication would be presented above each switch. With the vanes in transit, both indicators would be unlit.

The powerplants are each equipped with an Autofeather system, to reduce the drag of a propeller in the event of in-flight shutdown of the associated engine. Since it was established during development that less drag is produced by an inoperative powerplant if its anti-ice vanes are selected to the 'ON' position, operation of the Autofeather system also moves the vanes of the inoperative powerplant to that position. The Autofeather system is provided with a test facility for use on the ground. When the test facility is operated the propeller blades move towards the feather position and the anti-ice vanes are driven to the fully 'ON' (anti-ice) position.

1.6.3.4 Fuel system

The fuel system of the type consists of two tank groups situated above the cabin roof, occupying volumes forward and aft of the wing box and forming the aerodynamic fairing between the fuselage and the wing (Appendix 3, Figure 3).

Two cells, Nos 1 and 2, both forward of the box, normally supply the left engine. One further cell forward of the box, (No 3) together with a single cell aft of the box (No 4) normally supply the right engine.

Each tank group gravity feeds, via non return valves, a filter and a negative 'g' valve, into its own small dedicated collector tank. Each of these two collectors incorporates its own boost pump and is situated in the starboard fuselage side above the window belt. The collector tanks, each of 0.9 gall imp capacity, are designed to provide at least ten seconds of engine operation in the event of an interruption of the gravity fuel feed supply from the fuel cells. The collector tank for cells 1 and 2 is forward of that for cells 3 and 4, and fuel from each boost pump is supplied by pipework to a gallery which crosses the aircraft, connecting the left and right nacelles. The asymmetric position of the collector tanks results in different lengths of pipework being required between each collector and the corresponding connection to the main gallery.

Two low pressure valves are positioned outboard of the connections between the pipework and the gallery, enabling the fuel supply to be isolated from either nacelle. A crossfeed valve is positioned in this gallery at the aircraft centreline enabling one nacelle to be supplied from the tank group normally dedicated to the opposite engine. Each of the three valves is operated by a cable system controlled by an individual lever. The levers are positioned on the roof of the flight deck above and between the two pilots.

Each engine incorporates a fuel control unit within which is situated a HP fuel valve. These valves are cable operated and controlled by a pair of condition levers. These levers have three positions, 'FLIGHT' (fully forward), 'GROUND' (mid position) and 'OFF' (fully aft).

Selection to the 'FLIGHT' or 'GROUND' position simply alters the minimum fuel flow datum. Movement of the levers to the fully aft 'OFF' position closes the HP valves and is the normal means of shutting down the engines. A geometric detent is incorporated in the lever gate to prevent inadvertent aft movement of the levers beyond the 'GROUND' position. To reach the 'OFF' position, both levers must first be moved laterally away from one another. (Inadvertent aft movement of both levers simultaneously beyond the 'GROUND' position is thus rendered difficult to carry out without resorting to use of both hands).

Movement of the condition levers to the 'GROUND' position in the climb has no effect since fuel flow is well above the ground datum setting.

The only other system common to both tank groups is the fuel vent system which leads to a single vent outlet for the whole system, positioned below the under surface of the right wing.

1.6.3.5 Hydraulic system, flaps and landing gear

Power for the hydraulic system is provided by two pumps, one mounted on the accessory gearbox of each engine. The gearboxes are in turn driven from the HP (compressor) spools of their respective engines. The hydraulic system powers the flaps, landing gear extension and retraction, brake operation and nosewheel steering.

The flap system on the SD3-60 is cable operated through six hydraulic actuators and incorporates a small accumulator. In the event of hydraulic power from the pumps being unavailable, it may not be possible to deploy any significant amount of flap.

The landing gear on the SD3-60 is a tricycle arrangement. Each main landing gear retracts into a pod-type fairing which is supported off a stub wing structure. The nose landing gear retracts into a bay beneath the flight deck floor. The following guidance was given in the Operations Manual for occasions when snow or slush was present on the taxiways:

> *'After takeoff consideration should be given to cycling the gear to shake off accumulation of slush'*

1.6.3.6 Ditching

The aircraft was built to comply with British Civil Airworthiness Requirements (BCARs) current at the time of its certification (1982). These and subsequent airworthiness codes included requirements that ditching behaviour be evaluated. This evaluation was intended to ensure that the risk of injury is minimised and the opportunity for escape maximised in the event of the aircraft alighting on water. The preferred method of evaluation was by model testing. Such testing was to be used to establish adequate structural strength and suitable dynamic characteristics of the aircraft at water entry, so far as could be achieved within the basic configuration of the design.

Since acceptable ditching behaviour can only be achieved within narrow ranges of rate of descent, forward speed and pitch angle and is affected by aircraft configuration, the model tests were also used to establish optimum water entry conditions. The models used scale strengths of significant components, including landing gear doors, other hatches on the underside and major structural items.

Testing generally shows that aircraft must enter the water at the lowest possible forward speed, a very low rate of descent and a slight nose-up pitch angle. In the case of the SD3-60, testing was carried out using full flap extension, since this allowed a lower forward speed to be used without other detrimental effects.

By agreement between the CAA, the manufacturer and the testing agency, the tests on the SD3-60 were restricted to smooth water. It was accepted that testing in beam and head seas could be read across from results of tests carried out on the generally similar SD3-30 aircraft under such conditions.

Head seas are known to create very adverse conditions and in the case of rigid model tests of the SD3-30, vertical 'g' loading on the aircraft of 13.5 'g' was recorded in simulated scale head sea waves equivalent to 2.5 feet in height.

1.6.3.7 Emergency escape system

There are four emergency exits in the cabin of the SD3-60, plus an emergency escape hatch located in the overhead fuselage above the co-pilot's seat, (Appendix 3, Figure 4). The hatch is operated by a red handle, which needs to be turned to release a retaining catch, allowing the hatch to be opened upwards and outwards.

Crew members were familiarised with the hatch operation during conversion training and on recurrent training. It was not usual practice however for the hatch to be actually opened in training because of its location and thus the difficulty of restraining it once open.

The Operations Manual contained the following general instruction to crews with respect to ditching.

> *'It is essential that the aircraft alights on the water with all exits closed.'*

1.6.3.8 Ground Proximity Warning System

The aircraft was equipped with a Sundstrand Mark II Ground Proximity Warning System (GPWS). With this system, Mode 1 is activated when an excessive sink rate is detected. Mode 1 has two levels of caution, a "SINK RATE" alert or a "PULL UP" warning. Mode 2 is activated when the aircraft is below 1,650 feet radio altitude and an excessive closure rate to terrain is detected. This mode also has two levels of caution, a "TERRAIN" alert and a "PULL UP" warning. Modes 4A and 4B are activated when there is proximity to terrain sensed with either gear up (A), or flaps not in the landing position (B) and the corresponding aural warning "TOO LOW GEAR" or "TOO LOW FLAPS" is then produced.

1.6.3.9 Stall warning system

The stall warning system on the SD3-60 comprises stall warning detectors mounted on the leading edges of the outer wings. Activation of either detector operates stick shakers on both control columns and audible warning is provided by a horn. Stall warning is initiated at approximately 7 kt above the stalling speed.

Using the manufacturer's performance data the stall speed of the aircraft, without flap at 10,000 kg, was calculated to have been 87 kt.

1.6.3.10 Electrical system

The SD3-60 is equipped with an electrical generating system of the 'split busbar' type, which normally operates as two independent systems, each having a busbar supplied from an associated engine driven starter-generator and battery, (Appendix 3, Figure 5).

The anti-ice vane systems are powered from the main 28 Volt DC buses, to which the aircraft's batteries are also connected.

The engine intake heaters are each rated at 90 Amps and are powered from their respective DC Shedding bus. In addition, a number of other services are connected to the Shedding buses, including the strobe lights. The Shedding buses are designed to automatically disconnect in the event of a failure of the associated electrical generator. Thus, the services powered by the Shedding buses would be unavailable after such an event.

None of the aircraft avionics relating to the radar transponder are powered from the DC Shedding buses, so normal transponder operation should be available in the event of a double generator failure.

1.6.4 Operating procedures

Aircraft operating procedures for flight crew were laid out in the Operations Manual. Emergency procedures were covered in the Emergency and Abnormal checklist. These documents were derived from information contained in the Short Brothers Ltd, SD3-60 Aircraft Flight Manual (AFM), and approved by the UK Civil Aviation Authority (CAA).

1.6.4.1 Ground handling procedures

The Operations Manual Part 1 (Captain's Responsibilities After Flight) specifies that:

> *'The captain is responsible for safeguarding his aircraft if it is to be left unattended for any length of time such as during a split duty or an overnight stop. The aircraft is to be secured in such a manner that it is protected from adverse weather conditions, actual or forecast, and is to be parked or hangared in a secure place or area. Control locks and, where applicable, propeller restraint straps and pogo sticks are to be used whenever aircraft are parked. Should an aircraft be left for any length of time then engine blanks, pitot covers and chocks must be in position.'*

In particular, the Operations Manual Part 9 (Flying - Shorts SD3-60) specifies that, even for short term parking, 'propeller ties should be fitted', in order to prevent undesired rotation of the propellers on the ground.

The Operations Manual required a pre-departure inspection (PDI) to be carried out prior to every flight. The relevant items to be covered in the inspection were detailed in a checklist, (Appendix 1, Figure 3).

The engine air intakes on the aircraft are located some 2.8 metres above the ground, (Appendix 3, Figure 4). The manufacturer supplied air intake blanks (commonly called 'bungs') as original equipment, which were designed to be fitted in the engine intakes to prevent debris, dust or snow from entering the engine intake area. Although supplied originally by the manufacturer with the new aircraft, these bungs were not routinely carried on the operator's SD3-60 aircraft. The Operations Manual contained the following item as part of the parking procedure, (Appendix 1, Figure 4):

'Engine covers and bungs should be fitted if available'

The manufacturer's Maintenance Manual contained the following instruction under the title *'Freezing weather – precautions'* for aircraft to be operated within a 6 hour period:

'Close all doors and hatches and fit covers and bungs.'

The Maintenance Manual and the Operations Manual both contained a requirement for 'bungs' to be fitted prior to the aircraft being de-iced. The Operations Manual also specified that, when ground de-icing of aircraft was to be carried out, then this should be under the supervision of a company engineer.

It was the operator's standard practice to keep 'bungs' only at its main operating bases, namely Glasgow, Kirkwall and Inverness, where they were invariably fitted only by engineers to the night-stopping aircraft. The stated requirement for engineering supervision of aircraft de-icing was also not generally complied with away from the main operating bases.

No engineering personnel and no engine intake 'bungs' were provided overnight at Edinburgh to support this operation. No intake 'bungs' were therefore readily available to the crew, so they were unable to meet the stated responsibilities with regard to the safeguarding of the aircraft.

1.6.4.2 Engine operating procedures

Before the first flight of the day, a number of engine pre-flight checks were required to be carried out, one of which was an Autofeather test. This test required the crew to press and hold the Autofeather test button, with the engines at idle power. The Autofeather electronic indicators would then be checked as 'ON' and the anti-ice vanes would be observed to be running before release of the test switch. The check would then be confirmed to have been completed from the taxi checklist item:

"ENGINE CHECKS"................ "AS REQUIRED". (Appendix 1, Figure 2.)

The company standard procedure after takeoff was for a reduction to climb power to be made by the Pilot Not Flying (PNF), when requested by the Pilot Flying (PF), once the flap retraction had been completed. Power reduction would thereby normally occur at about 500 feet above aerodrome level (aal).

1.6.4.3 Engine failure and ditching procedures

There were no procedures in either the Operations Manual or the AFM for the case of a double engine failure, or for a ditching without power. In the Operations Manual there was an engine relight procedure checklist, applicable to the single engine failure case, (Appendix 1, Figures 5a and 5b). The AFM contained a recommended procedure for ditching with power which was not reproduced in the Operations Manual. This included the following guidance:

> *'Flaps should be extended fully in order to reduce forward speed at touchdown to a minimum.'*

and

> *'It is important that the aircraft is straight with wings level, at impact. If a pronounced sea is running at the time of ditching the landing should be made parallel to, and not across, the line of wave crests. At touchdown the aircraft should be in a nose up attitude, with the angle between the fuselage datum and the water being 9°.'*

1.7 Meteorological information

A meteorological aftercast reported the following information:

The synoptic situation at 1700 hrs on the 27 February 2001 showed a low pressure area to the west of Scotland with a moderate to strong unstable north easterly airstream covering much of the United Kingdom. There were numerous showers over western Scotland but no significant precipitation in the Edinburgh area.

Winds/Temperatures:

Height agl (feet)	Wind (°T/kt)	Temperature (°C)	Dewpoint (°C)	Relative humidity (%)
Surface	030/16	PS02	MS03	69
1000	040/35	PS01	MS05	64
2000	050/40	MS02	MS07	69

Actual meteorological conditions from 0002 hrs on 27 February were recorded by the automated weather station at Edinburgh Airport. There were regular half hourly observations (METARs) and a number of irregular special observations (SPECIs). The METARs for the period from 0020 hrs until the time of the accident are presented in Appendix 4, Figure 1.

The airfield observation (METAR) at 1720 hrs was recorded as follows:

> Surface wind 030°M / 16 kt, visibility 10 km, scattered cloud base 4,500 feet, broken cloud base 8,000 feet, temperature +2°C, dew point -3°C and QNH 1002 mb.

For the period covering the take-off time of the accident flight, no SNOWTAM was in force. Runway conditions were reported as "WET". It was daylight at the time of the accident, and sunset occurred at 1745 hrs.

Sea conditions were reported by the Coastguard as sea state 5 and sea swell 2. The tide was close to high water.

1.8 Aids to navigation

Not applicable

1.9 Communications

Tape recordings of the transmissions between the aircraft, Edinburgh ATC and ScATCC were available for the investigation together with radar recordings. The reference radar head was that at Lowther Hill, (N55° 22:39.23 W003° 45:09.18, elevation 2,384 feet amsl), located approximately 39 nm to the south-southwest of the aircraft's track and with a sweep period of 6 seconds. The VHF radio transmission antenna for ScATCC was located near the radar head.

1.9.1 Ground radar recording

ATC was able to monitor the position of the accident aircraft through the use of primary and secondary radar. The aircraft was first detected by radar as it climbed through 1,600 feet (referenced to a standard atmospheric pressure of 1,013.2 mb). Primary, Mode A (aircraft identification) and Mode C (encoded altitude referenced to a standard pressure setting of 1,013.2 mb) returns were evident up to the point where the aircraft suffered the double engine failure. The highest Mode C return positioned the aircraft at 2,300 feet amsl. From that point, only three further radar returns were recorded and these were primary only, with no Mode A or C component. An approximate ground track based on radar, FDR data and an estimated wind profile is shown in Appendix 5, Figure 1.

1.9.2 ATC recording

The ScATCC controller's response to the initial MAYDAY call was as follows:

> "ROGER ER LOGANAIR SIX SEVEN ZERO ALPHA ROGER YOUR MAYDAY TURN ER LEFT ON TO HEADING OF ER TWO FIVE ZERO THE AIRFIELD IS THREE MILES TO THE NORTHEAST OF YOUR PRESENT POSITION"

There was one further transmission from the aircraft but the reply from ATC was not received on board. There then followed a number of transmissions between ATC and other aircraft joining the frequency. The final transmission from the aircraft, advising of a ditching, was not received. It is considered that this breakdown in communications was as a result of the range from the receiving antenna and the nature of the intervening terrain.

1.10 Aerodrome information

At 0210 hrs, Edinburgh Airport had closed because of the snow conditions. The airport re-opened at 1130 hrs. Crew comments recorded on the CVR indicated that the taxiways were slippery and contaminated with slush when they taxiied the aircraft for departure.

1.11 Flight recorders

Two tape-based recorders were fitted to the aircraft. A half-hour duration Cockpit Voice Recorder (CVR) and a 25 hour duration Flight Data Recorder (FDR). Both recorders retained a record of the entire accident flight. Identification details of the two recorders were: FDR type Plessey (now GEC Marconi) PV1584G, model 650/1/14040/006, serial number 3105; CVR type Loral (now L-3com) A100, model 93-A100-83, serial number 58284.

The FDR had remained attached to the aircraft and was recovered from the site on the day of the accident by the emergency services. The CVR had broken free and was recovered from shallow water approximately 25 metres away from the main body of the aircraft during the following day. In both instances the recorders had remained in their respective avionics racks, but the rack mountings had become detached from the aircraft structure.

Both recorders were taken initially to a local police station before being immersed in clean water. They were then transported to the AAIB Headquarters at Farnborough for replay.

1.11.1 Flight Data Recording system

The flight data recording system comprised a single, crash-protected acquisition and recording unit connected to various transducers mounted throughout the aircraft. A flight data entry panel was provided, located on the panel in front of the right hand seat, to enable flight documentary data to be recorded when the documentary data insert (DDI) switch was depressed. Main operational power for the FDR was drawn from the 115V left AC busbar routed through two series connected switches. The first switch opened whenever the flying control locks were engaged and the second (a set of relay contacts) opened in the event of a crash being detected by an inertia switch mounted under the CVR rack. The inertia switch was designed to trigger upon detection of a deceleration in excess of 3g. The flying controls were normally unlocked as part of the checklist for entering the runway. Thus, as in the case of the accident flight, the FDR did not record events prior to this action.

In total, 16 analogue parameters and a number of discrete parameters (on or off) were recorded on the FDR. The system was calibrated on an annual basis to ensure correct operation within limits specified in the aircraft Maintenance Manual. Part of the calibration process required each of the aircraft transducers to be exercised over a range of values and the resulting recorded data values noted. The last calibration of the system had been successfully completed on the 13 October 2000. It was noted that the calibration had included the testing of the lateral acceleration transducer but subsequently that the recording system had been subject to modification action to change this parameter to longitudinal acceleration. The embodiment of this modification did not affect the investigation of the accident.

1.11.2 Cockpit Voice Recording system

The audio recording system consisted of a crash protected, four channel CVR together with a cockpit mounted controller. To pick up general cockpit area sounds, the controller had a microphone and preamplifier and was located on the panel in front of the crew. The CVR derived power from the 115V right AC busbar, with the only interlock being the inertia switch and associated crash relay described above. Thus the CVR operated whenever the aircraft was powered and the right AC busbar was energised. Under normal circumstances these conditions would be satisfied prior to engine start.

The four recording channels were allocated to the following aircraft audio sources:

Channel 1 - Not used. This channel would normally be allocated to the public address system but was not used on cargo only operations.

Channel 2 - First Officer's audio services and hot microphone (microphone always live).

Channel 3 - Commander's audio services and hot microphone.

Channel 4 - Cockpit area microphone.

1.11.3 Recording quality

Recorded information was successfully replayed from both FDR and CVR once the recording media had been removed. Both recordings were of good quality and terminated simultaneously at the moment of impact with the sea due to the activation of the inertia switch.

A small amount of data corruption had occurred at the end of the FDR recording due to contamination of the magnetic tape. This data was recovered completely by inspection of the waveforms recorded on the media.

The audio recordings of the crew were, for the most part, readily intelligible. They were however occasionally masked by the high signal level of incoming radio transmissions. It was noted that, with no dedicated audio source connected to Channel 1, the recording of very low level signals originating from electrical noise on the aircraft were discernible. It was also possible to detect sets of harmonic frequencies associated with the gas generator section of both engines on this channel. Propeller blade passing frequencies, and hence audio representations of propeller rotational speeds, were recorded on the area microphone channel and were corroborated by the values recorded on the FDR.

1.11.4 Accident flight

1.11.4.1 Pre-departure

For the reasons stated above, the sequence of events during final engine start, power back and taxi have been derived from the CVR alone and are included in the history of flight at Paragraph 1.1.2. Both engine starts and subsequent running on the ground appeared normal. Flap 15° had been selected prior to leaving the stand.

After the aircraft had powered back, it was cleared to taxi to and hold at Papa One, (Appendix 5, Figure 2). Further clearances to follow another aircraft to Lima One and then to Bravo One were received. During this initial taxi period the commander called for anti-icing 'standards' to be set for the departure. This required the selection of the pitot/static and stall warning heaters to ON.

As the crew conducted the Autofeather test (part of the engine checks required on the taxi checklist) the speed of both propellers began to decay and two faint audio signatures were recorded on Channel 1 of the CVR. These signatures rose rapidly in frequency, levelled off for a period of just under 10 seconds and then stopped. Immediately after this, the first officer commented "ANTI-ICE, BOTH ON". Then the sound of a switch selection was recorded through the area microphone and both propellers began to increase speed again. As they did so, two more audio signatures of similar characteristics and duration were recorded.

1.11.4.2 Takeoff and climb

The aircraft was cleared to line up on Runway 06 and wait. The '*Entering Runway*' checklist, (Appendix 1, Figure 2), was carried out; the flying controls were unlocked and the FDR started to record. As the strobe lights were turned on, Channel 1 of the CVR began to record low level signals at regular intervals of 1.1 seconds and frequencies consistent with the electronics associated with strobe light operation.

Following the receipt of take-off clearance, engine power was applied, stabilising at 1,700 rpm with 4,000 lbft torque on either side. As per the final take-off checklist item, the crew ensured that the igniters were selected to 'OFF'. The takeoff was uneventful and a pitch attitude for the climb was established at 5° nose up.

Following departure the gear was raised and recycled once as the first item on the '*After Takeoff*' checklist, (Appendix 1, Figure 2). As the gear was raised for the final time, the aircraft pitch attitude transiently increased to 14° before reducing to 5° again. As the aircraft climbed through 1,100 feet amsl, the flaps were retracted. Climb power was set and symmetrical engine performance had stabilised at 1,400 rpm and 3,400 lbft torque by the time that the aircraft climbed through 1,800 feet amsl. Airspeed remained constant at 150 kt and a steady climb rate of 1,000 feet per minute was achieved. At that time, the aircraft was in a gradual left turn towards the SID departure heading of 045°M.

Whilst continuing with the '*After Takeoff*' checklist, the commander confirmed that the stall warning heaters were 'ON' and then called for all the anti-icing systems to be selected to 'ON'. The checklist actions were then interrupted by ATC requesting that the crew change frequency to Scottish Control on 126.3 MHz. The first officer acknowledged the ATC instruction and the commander selected the new frequency on the radio controller, advising the first officer that he had done so. A tone associated with the selection of the new frequency was recorded on the CVR.

As the '*After Takeoff*' checklist actions were resumed, whilst climbing through 2,200 feet amsl, the sounds of four consecutive switch movements were recorded on the CVR area microphone channel. The time separation between the switch movements was determined to be 0.37 seconds (first to second), 0.40 seconds (second to third) and 0.38 seconds (third to fourth). Simultaneously with the first two of these switch movements, the start of two of the faint audio signatures detected during the earlier Autofeather test again became discernible on the CVR public address channel; one signature being associated with each switch movement. At the same time as the third and fourth switch movements, an electrical noise spike was recorded on the same CVR channel, again one spike for each movement.

1.11.4.3 Engine power loss

Three point nine five (3.95) seconds after the first audio signature started, the CVR showed the gas generator speed of one engine starting to drop rapidly. That of the other engine began to drop 0.4 seconds later (3.95 seconds after the second switch movement). From the CVR alone it was not possible to determine which engine had started to fail first, but the FDR recording showed that the left engine torque began to reduce towards zero slightly before that of the right.

From the CVR, the gas generator speeds on both engines reduced to approximately 50% within two seconds. At that point, a number of noise spikes were recorded on CVR Channel 1 followed, less than half a second later, by the sound of the public address system 'Hi/Lo' alert tone. This tone is usually activated when either of Crew Call, Passenger Call, No Smoking or Fasten Seat Belts are selected. It was also observed that the 1.1 second period waveforms associated with the operation of the strobe lights were not evident during the remainder of the CVR recording.

1.11.4.4 Crew diagnosis of the failures and aircraft descent

No torque was being developed on either engine and airspeed started to reduce. A nose down elevator input was recorded on the FDR within one second of the failure of the first engine and pitch attitude started to decrease. The aircraft achieved a maximum altitude of approximately 2,300 feet amsl (about 2,600 feet, referenced to a standard atmospheric pressure of 1,013.2 mb). Neither propeller feathered as a result of the simultaneous double engine failure and both continued to windmill, slowly reducing speed over the remainder of the recording to 1,060 rpm.

Eleven seconds after the loss of engine power, the area microphone recorded the sound of a switch selection being made; there was no associated noise spike recorded on the public address channel of the CVR. One second later, the sound of another switch selection was recorded and the public address channel recorded the concurrent start of two of the faint audio signatures observed during the Autofeather test. (Subsequent analysis, combined with detailed wreckage examination, concluded that this was the selection of the anti-ice vanes to the 'OFF' position, see Sections 1.11.5 and 1.12.1).

The commander asked the first officer what he had done. The first officer replied "NOTHING" and stated that both generator warning lamps had illuminated. Within 15 seconds of the engine run downs, the commander stated that they had had a double engine failure and started a right turn with 18° of bank angle. The first officer made a 'MAYDAY' call to ATC stating the aircraft's callsign and the nature of the problem. Pitch attitude and airspeed had stabilised at 6° nose down and 116 kt respectively and the aircraft was descending through 1,850 feet amsl at the start of the radio transmission. Towards the end of the transmission, the pitch attitude of the aircraft was further reduced to 8.3° nose down. Airspeed increased to 123 kt but descent rate, previously stabilised at approximately 2,800 feet per minute, began to increase.

As ATC began to acknowledge the 'MAYDAY' call, a GPWS Mode 1 'SINK RATE' alert was activated. The aircraft was descending through 1,400 feet amsl, with a descent rate of approximately 3,200 feet per minute, as the alert started and the commander began to raise the nose of the aircraft towards 4° nose down. Airspeed and descent rate began to reduce and stabilised at 115 kt and 2,800 feet per minute respectively. The GPWS alert continued.

ATC requested that the aircraft turn left onto a heading of 250° and informed the crew that the airfield was 3 miles to the northeast of their present position. The first officer asked ATC to repeat the message stating "SAY AGAIN, LOGANAIR SIX SEVEN ZERO ALPHA". From correlation of the recording made by ATC with that on the CVR it was determined that the last few words of the transmission from the aircraft had been truncated to "SIX SEVEN ZERO ALPH...". No further communications were received by ATC from the aircraft. However, no interruptions were observed in the radio traffic received by the aircraft. Transmission cut off occurred as the aircraft descended through 750 feet amsl.

Whilst the first officer was speaking to ATC, the commander began to roll the aircraft towards wings level onto a final heading of approximately 110°M.

As ATC began to reiterate the previous instructions and the aircraft descended, the GPWS Mode 1 alert changed to a warning of "TERRAIN" followed by a continuous warning of "Whoop, Whoop, PULL UP".

During the last twenty seconds of the flight, pitch attitude was gradually increased to 3° nose up and then, over the last 5 seconds, more quickly increased to a final, stable value of 6.8° nose up. Airspeed began to reduce, as did descent rate. The first officer made one further radio transmission to advise ATC that the aircraft was ditching, but this was not received.

During the more rapid pitch increase over the final five seconds, the sound of the stall warning was recorded on the CVR and airspeed values reducing through 103 kt were recorded. One further GPWS warning of "TERRAIN….. TERRAIN" was heard before the recording ceased. The FDR recorded final aircraft attitude and airspeed values of 6.8° nose up, 3.6° left wing down and 86 kt. Total flight time had been just under three minutes. No evidence of flap movement from the 0° position was recorded in the FDR data, neither did the crew refer to flap setting on the CVR recording. An annotated graphical plot of pertinent parameters is shown in Appendix 6.

1.11.5 CVR Spectral Analysis

Much of the corroboratory evidence for documenting anti-ice vane movement in the above narrative was derived from spectral analysis of the CVR. Each aircraft engine intake was equipped with a linear, electromechanical actuator that controlled the position of that engine intake's pair of anti-ice vanes. The actuator itself comprised a 28 volt DC electric motor, a pair of microswitches to detect extremities of travel, and a rotary to linear gearbox assembly. The actuator motor had a 14 segment electrical commutator and a single pair of brushes. As the powered motor rotated, electrical noise would have been generated on the power supply wires each time that a commutator segment passed under a brush and the next coil on the motor armature was energised. With the motor rotating at sufficient speed, the fundamental frequency of the electrical noise (or a harmonic of it) was within the recording bandwidth of the CVR.

The ratio of the rotary to linear gearbox was such that the motor was required to rotate approximately 5,600 times to allow full travel of the actuator arm. The frequencies of the audio signatures recorded on the CVR were consistent with a

14 segment commutator motor rotating at the speed required to achieve full actuator arm travel in 10 seconds.

Tests were conducted on an isolated actuator of identical build. After allowing for the fact that, whilst not being mechanically coupled to an anti-ice vane assembly, the actuator motor was able to run at a slightly higher speed, the audio signature of the noise waveforms observed were consistent with those previously described. A time versus frequency spectrogram of the test actuator results is shown in Appendix 7.

Time versus frequency spectrograms for the period of time around the engine failures are shown in Appendix 8, Figures 1 and 2.

It was not possible to determine whether the CVR picked up these low level waveforms from radiated or conducted interference. It is considered likely that it was conducted, the route being through the DC bus/earth return supplying the aircraft's audio system.

1.12 Wreckage and impact information

1.12.1 Wreckage examination

When the AAIB personnel arrived at the scene, the tide had receded and the aircraft was lying in a recess on a sandy beach, only partly submerged in seawater (See Frontispiece). The flight deck was largely destroyed structurally and the aircraft was firmly embedded in the sand with the engine nacelles and the landing gear sponsons almost totally buried. The tail unit had separated and floated away to a point some 100 metres to the east of the main wreckage.

The aircraft was lying such that the fuselage axis was at approximately 45 degrees to the horizontal (nose down) with the wing leading edges both resting on or within a few inches of the sand. Considerable quantities of small debris items were scattered across the beach. It was judged, however, that the aircraft had been structurally complete at impact.

Once the tide rose, the aircraft became almost covered and as neap tides were approached, it remained progressively less exposed and hence less accessible at subsequent low tide conditions.

The aircraft was ultimately salvaged, with some difficulty, but limited additional damage. It was dismantled before being returned to the AAIB Headquarters at Farnborough, where a more detailed examination was carried out. During the salvage it was noted that both engine anti-icing vane systems were set to the 'OFF' position.

1.12.2 Detailed examination

1.12.2.1 Powerplant

The engines and the nacelles were subjected to careful examination. The former were then removed and shipped to the premises of the manufacturers at Longueuil, Montreal, Canada where they were strip examined under the supervision of an AAIB Inspector.

No evidence was found of any pre-impact defect within either engine or powerplant. The evidence was consistent with that to be expected if the engines and nacelles had entered the water whilst no power was being generated. Although the cylindrical mesh screens on the engine intakes were somewhat distorted, in a manner suggestive of operation with some degree of blocking present, this evidence was considered inconclusive since;

a) Some ice build up could have occurred on previous flights leading to distortion resulting from the pressure difference across the mesh and;

b) The aircraft entered the sea at speed and a rapid flow of water into the intakes could have caused this distortion

No evidence could be found of any technical defect which could account for the loss of engine power and no single crew action could be conceived which could explain the near simultaneous double power loss.

1.12.2.2 Crew seats

The two crew seats and harnesses were examined. The seats were found to have remained attached to the flight-deck floor. Whilst neither harness had failed, separation of the upper section of the fight deck structure from the lower section had occurred, coupled with general disruption of that area. Since it is not clear how much of the latter occurred at impact, it is unclear from the wreckage examination whether significant intrusion of the occupied volume occurred at that time.

1.13 Medical and pathological information

There was no evidence of any pre-existing medical condition in either pilot that could have contributed to the cause of the accident. Post mortem examination established that drowning was the cause of death for both pilots.

1.14 Fire

None

1.15 Survival aspects

1.15.1 Search and rescue

The emergency services reached the accident area at 1740 hrs but then had some difficulty in reaching the aircraft from the shore. At 1806 hrs a lifeboat was alongside the main part of the wreckage and a rescue helicopter was overhead. Divers were on the scene at 1943 hrs and in the water by the wreckage at 2011 hrs. Internal access to the wreckage was gained through the flight deck overhead escape hatch, which was found to be still in place, and also through the rear of the fuselage.

1.15.2 Water temperatures

The sea water temperature in the area was between 6°C and 8°C. Survival time in these temperatures would normally be less than one hour, but could also be adversely affected by the shock of a sudden immersion. The ability to hold ones breath can be severely curtailed by this, perhaps to just a few seconds, thus reducing the chances of successful escape from a submerged aircraft.

1.15.3 Crew overhead escape hatch

In January 2000 there was a ditching accident following a double engine flameout on the same type of aircraft. The investigation found that the crew had unfastened the overhead escape hatch just before the aircraft impacted the water. Both crew members had then escaped from the aircraft by this means before the aircraft became submerged.

1.16 Tests and research

1.16.1 Background

It was ascertained that the aircraft was parked facing into wind from the time of its arrival at Edinburgh until it taxied off the ramp before the accident flight.

During the first part of this period it snowed for approximately eight hours and wind speeds were high, with strong gusts. The temperature remained between freezing and +1°C. Consultation with specialists on ice/snow characteristics confirmed that, at temperatures close to freezing, snowflakes become wet and readily coalesce with adjacent snowflakes. With a strong wind, surface turbulence encourages mixing and collisions between flakes. This favours joining of individual flakes to create larger flakes. A percentage of large area, low thickness flakes would result, which would have had a low terminal velocity. They would thus have readily flowed upwards in any local upward airflow.

1.16.2 Flow conditions in the air intakes and gas paths

The reverse-flow air intake arrangement and complex internal flow path within engines of this type lead to considerable doubt as to the likely air velocities through non-operating power units subjected to external wind flow, whilst an aircraft is parked.

An experiment was therefore carried out on another SD3-60, during which the wind generated air flow rate through the engine core was evaluated. Special test equipment was manufactured for this purpose. This took the form of a conical duct with a flexible connection to a flanged junction piece, designed to be bolted to the engine exhaust casing, in place of one of the exhaust stacks. An electric fan, incorporating a synchronous motor, was attached to a flanged connection at the other end of the conical duct.

When operating, the fan drew air in at the lip of the forward facing external nacelle air-intake. It then drew it through the intake system, plenum chambers and the total engine gas path, to the exhaust outlet of the engine. A series of pressure tappings in the wall of the conical test duct were connected via flexible pipes to a digital pressure test set. The outlet of the remaining exhaust stack was blocked off.

The fan was set to run at such a speed that measurements could be made under conditions of pressure difference between the aircraft air intake lip and the engine exhaust, as calculated for an external wind velocity of approximately

30 kt along the aircraft axis. These experiments showed that with the aircraft facing winds of approximately this speed, the airflow velocity through the airframe intake path was significant.

1.16.3 Air-flow simulation

One of the engine cowlings from the crashed aircraft was re-assembled with replica internal bulkheads manufactured from transparent plexiglass to simulate the presence of the forward and aft boundaries of the plenum chamber, whilst a cylindrical timber trunking was used to simulate the engine carcass. The intake mesh from an engine was fitted over an open section of the timber trunking, positioned at the same longitudinal station as it occupied in the engine installation.

An extractor fan was installed at the forward end of the timber trunking. An adjustable shut-off valve was manufactured and installed forward of the fan to control the flow rate through the whole intake system, (Appendix 9). With the extractor fan running, the valve was adjusted to produce an internal flow velocity similar to that experienced in a 30 kt external wind as derived in the test described above. A selection of fragments of different densities of material were thrown into the intake flow path forward of the cowling lips. These materials were judged to have had higher terminal velocities than that estimated for the larger snowflakes. As mentioned previously the terminal velocity of a percentage of the snowflakes would have been very low.

The behaviour of the fragments within the plenum chambers was observed through the transparent bulkheads. It was noted that they readily rose up from the region of the bypass door to pass over the top of the timber trunking. Much of the material came to rest on the top of the intake mesh. Other fragments came to rest against the front of the bypass door. It was concluded that snowflakes with the lower terminal velocities as outlined above would even more readily rise into the tops of the plenum chambers. The test was repeated for a number of wind speeds and it was found that considerable lifting of simulated flakes high into the plenum chamber occurred even at much lower air speeds.

1.16.4 Compressor surge margins

Calculations on airflow behaviour were carried out using compressor performance data supplied by the engine manufacturers. The data related to the engine delivering climb power in the ambient conditions that existed at 2,000 feet in the Edinburgh area at the time of the accident. These indicated that flow breakdown could be expected if the intake area was reduced by approximately 78% of the cross-section.

1.17 Organisational and management information

1.17.1 Operator

The airline held an Air Operator's Certificate (AOC), issued by the UK Civil Aviation Authority in accordance with the specifications of Civil Aviation Publication (CAP) 360. The company operated four SD3-60 aircraft at the time of the accident, which formed part of a mixed aircraft fleet. The other aircraft types comprising the fleet were DHC-6s (equipped with PT6A-27 turboprop engines) and Saab 340s (equipped with General Electric CT7-9B turboprop engines). The aircraft were variously employed on scheduled passenger and freight services on domestic and international routes.

The company held JAR 145 approval for line maintenance of the SD3-60 aircraft type, issued by the UK CAA. It held corresponding approvals for both line and base maintenance of the remaining types on its fleet.

1.18 Additional information

1.18.1 Witness evidence

The avionics engineer who observed the engine runs on the aircraft prior to the accident flight confirmed that the aircraft airframe was free of ice and snow accumulations. He had cleared a slush deposit off the windscreen, but agreed with the commander that no other external icing was visible on the aircraft.

One witness came forward who was watching the aircraft as it climbed on the departure routing. He saw two simultaneous puffs of black smoke come from the aircraft and then it began to descend before disappearing from his view. Other witnesses, located on the shore close to the crash site, saw the aircraft descending under control towards the sea. They then saw the aircraft hit the water and the forward section disappear from view.

1.18.2 Similar occurrences of icing induced engine power loss

During the course of the investigation, a report was received that there had been a previous occurrence, on an SD3-60 aircraft operated by a different company in the UK, of a double engine power anomaly as a result of accumulated ice or snow arising from pre-flight conditions. The power interruption occurred while the aircraft was on its take-off run. The event had not been reported at the time through the established mandatory reporting system and had occurred approximately eight years before the loss of G-BNMT. Both crew members and the station engineer concerned were located and spoken to, but the intervening period had resulted in considerable differences of recollection of the precise circumstances.

The AAIB reported in the Bulletin 1/2002 on an incident which occurred on 20 March 2001 in which a DHC-8 aircraft experienced an undetected build up of slush in the engine intake and plenum areas. The aircraft was fitted with PW127 engines, a type with an intake system very different in concept from that on the PT6A-67, but which has similarly located and configured intakes in the engine nacelles. This accumulation had occurred while the aircraft was parked facing into wind in falling snow and resulted in both engines flaming out during the subsequent taxi for takeoff. The Bulletin also cited previous occurrences on the type.

1.18.3 Terrain along the shoreline

The shoreline close by the aircraft's position at the time of the loss of power did not have much open ground suitable for an attempted forced landing. Ahead of where the aircraft impacted the sea, above the sea wall, there was an open area of grass of approximately 500 metres length. Much of the beach is not exposed at high tide conditions and the shoreline is protected in places by a concrete sea wall. The shore is generally free from buildings but there are a number of trees and rising terrain making much of the locality inhospitable for a forced landing.

2 Analysis

2.1 Operation of the aircraft

2.1.1 Crew qualifications, experience and training

Both pilots were properly qualified and experienced in their respective roles to operate this flight. They each had an adequate rest period prior to reporting for duty at 0810 hrs at Glasgow Airport. The maximum allowable flying duty period for the crew was 14 hours. At the time of the accident they had completed 9 hours 20 minutes of duty.

The commander had undergone the operator's standard recurrent training programme, which included refresher training in ditching and lifejacket drills. The first officer had completed the company's standard introductory course which included training in both these aspects. There was no record of either pilot having physically operated the overhead emergency escape hatch, as this was not normally conducted on safety or conversion training.

The commander would have been experienced in practising forced landings without power in light single engine aircraft, as a result of his considerable instructional experience. This experience in judging a forced landing was probably of value to him on this occasion.

2.1.2 Operating procedures

2.1.2.1 Pre-flight

The aircraft was initially managed as though it were being prepared for an immediate flight, but as a result of delays and the eventual closure of the airport it was parked for much longer than intended. It is clear also that the weather conditions were very severe, of a nature not routinely experienced in the United Kingdom. Many other aircraft at Edinburgh on the morning of 27 February 2001 had suffered snow/slush accretions. Some examples of engine intake accumulations on larger turbofan engines, photographed during that morning, are shown in Appendix 5, Figure 3.

The inbound crew completed their turnround responsibilities (with the exception of the fitment of the propeller straps) and left the aircraft in the belief that it would be departing immediately. The second crew, who were to take over the aircraft, never did so as a result of the prevailing weather conditions, although they carried out some actions at about 0600 hrs to secure the aircraft before going off duty.

The weather when the accident crew took over the aircraft had improved and they were not necessarily aware of the conditions to which it had been exposed.

There were differences between the procedures laid out in the manuals of the manufacturer and the operator with regard to the fitting of intake bungs. In order to accord with the manufacturer's Maintenance Manual, bungs should have been fitted during the severe weather conditions prevailing. The Operations Manual did not reflect any immediate requirement, but did require 'bungs' to be fitted if the aircraft was to be parked *'for any length of time'*, which was generally interpreted as being during a 'split duty' or an overnight stop.

Both the manufacturer's and the operator's manuals did require that bungs be fitted to the aircraft prior to ground de-icing operations, which was the expectation on this occasion, (Appendix 1, Figure 6). The lack of provision of suitable 'bungs' by the operator meant that the flight crew could not meet the specified responsibilities for safeguarding the aircraft.

When the second crew arrived at the aircraft, it would be expected that they would fit the bungs in preparation for de-icing, but neither bungs nor steps were provided by the operator in order to allow this to be carried out. It could not be determined whether, if bungs and steps had been available, the second crew would have fitted them as soon as they knew the aircraft needed de-icing.

It seems likely that aircraft in the fleet were routinely de-iced in contravention of the requirements laid down in the Operations Manual. When crews were operating away from a main base, there was no apparent provision made by the operator for the crews to be able to fit 'bungs', nor were they provided with the required engineering supervision for the ground de-icing operation.

This absence of bungs, or the means to fit them, suggests that the potential for this type of engine intake contamination prior to flight, and the potential effects thereof, had not been recognised. Although such events appear to be rare, there was anecdotal evidence (not widely known throughout the industry) of a double power loss during the take-off run on another SD3-60 aircraft, and several recorded events on the DHC-8 aircraft, which also has similarly located and configured intakes in the engine nacelles. Unfortunately, at the time of the accident, information about the possibility of such an event was not widely known.

More effective promulgation of information about these events would have led to a greater degree of awareness of the potential consequences of snow/slush contamination in the intake area.

It is probable that, by the time the accident crew arrived, any accumulation of snow or slush on the airframe had been blown away or melted. In the absence of any other information, it is assumed that the crew carried out normal pre-flight procedures and checks. The commander, who had the responsibility for ensuring that the aircraft was fit for flight, did not consider that the aircraft required de-icing. The engine intakes are located at a height at which steps would have been required to see into them. Steps were not available at the aircraft and a visual inspection inside the intakes was not specifically part of the pre-flight procedure. If the intakes had been closely examined, with the aid of steps or staging, before the first engine start took place, then it is possible that some deposits of snow may have been visible within the intake cowl area. However, it is unlikely that the snow/slush contamination problem in the plenum chambers would have been detected. The volumes within the plenum chambers, shown by the tests to have been most vulnerable to snow/slush build-up, are not visible without use of mirrors or removal of engine cowlings. AAIB Bulletin 1/2002 details a similar problem area for the DHC-8 aircraft.

The reason for the failure of the generator to come on line at the initial start attempts was not determined. The troubleshooting procedure involved the ground running of both of the engines before the eventual departure of the aircraft. This was not the usual pre-flight procedure for the crew and meant that some of the engine pre-flight checks were conducted out of the normal sequence. In spite of this, all the checks were confirmed as completed before takeoff. The pre-flight problems with the generator are not considered to have played any part in the accident.

Powerback from stand was an unusual but accepted procedure in the SD3-60 fleet, which would require the use of greater than idle power. It is known that the crew operated the anti-icing vanes at least once prior to flight. Thus, neither the operation of the anti-icing vanes at idle power, or of the engine at greater than idle power, during taxi or takeoff, prevented the subsequent engine flameouts.

For the accident flight, the engine ignition systems were not selected to 'Emergency' for takeoff, as the Operations Manual, Part 9 Flying, indicated that it was only required to be so for takeoff and landing on contaminated (snow or slush) runways, in order to avoid the risk of engine malfunction caused by ingestion of snow or slush during the take-off run. The runway conditions at the time of departure were officially described as 'WET' (ie surface soaked but with no significant patches of standing water). However, the Operations Manual, Part 8 Technical, indicated that the 'Emergency' ignition selection for takeoff was applicable when there was a risk of ingestion of snow, slush **or**

water during the take-off run. This was also reflected in a Supplement to the Aircraft Flight Manual. The reason for this anomaly in its documentation was not explained by the operator. However, as the engine failures did not occur during the take-off ground roll, it is highly unlikely ingestion of water from the runway surface was the cause of this event.

2.1.2.2 After takeoff

The crew carried out a precautionary cycling of the landing gear after takeoff in accordance with instructions given in the Operations Manual. This resulted in a delayed selection of climb power, normally done at 500 feet aal, which then took place at 1,100 feet aal. The *'After Takeoff'* checklist was then carried out. The reading of the 'stall warning heaters' item, appears to have been the cue for the commander to request selection of the anti-icing systems, in anticipation of the aircraft encountering in-flight icing conditions during the climb. Thus the delay caused by the landing gear retraction probably caused the engines to fail at a greater altitude than otherwise might have occurred.

2.1.2.3 Selection of anti-icing systems

The crew had no reason to expect any in-flight engine icing problem as they were operating in clear weather at that stage of the climb. The commander anticipated the aircraft going into cloud and correctly asked the first officer, in good time, to select the anti-icing systems 'ON' (Appendix 2). The first officer put the icing systems on in the manner he had been instructed in training, by working from left to right across the overhead panel and selecting each pair of switches in turn. This method allowed only a moment between the operation of each one of a pair of switches.

The time from switch activation to the almost instantaneous total loss of engine power was four seconds. The time for the anti-icing vanes to fully deploy is approximately ten seconds. Therefore, a greater delay between the operation of each one of a pair of switches would probably have resulted in a corresponding delay between the engines flaming out. This may have allowed time for one engine to run down before the activation of the second switch, thereby offering an opportunity to avert the second flameout.

Additionally, if the Ignition systems had been selected 'ON' for takeoff, as would have been the case for a departure from a snow/slush covered runway, then, provided that they remained on, the interruption of engine power may have been limited to a short transient loss only.

The Ignition system may well have facilitated a rapid relight of an engine suffering transient intake flow disturbance, caused by the movement of any snow/slush accumulations on actuation of the anti-ice vanes. Use of the Ignition system in advance of anti-ice vane selection, in such a precautionary manner, did not form part of the standard operating procedures in the company fleet of SD3-60 aircraft.

2.1.2.4 Double engine flameout

The commander, who quickly observed that the aircraft had suffered a double engine failure, was probably alerted by the sound of the decreasing gas generator speeds. Also, red warning captions for the left and right generators would have been displayed on the Central Warning Panel. The time from the first indication of a problem to the aircraft impacting the water was 62 seconds.

Following the engine flameouts, the crew did not have a recognised procedure by which they could have attempted an engine relight. The existing engine failure procedure was lengthy and was not suited to the rapid relight that would have been required. A more rapid relight procedure, or an auto re-ignition system, would be desirable.

Either a time-delayed sequencing of the anti-ice switch selections, or prior selection of the Ignition system, may have prevented the double engine power loss and may thus have prevented the loss of this aircraft, provided that the intake air supply disruption due to snow/slush movement was merely transient.

2.1.2.5 Ditching

For the last 30 seconds of the flight there were continuous GPWS audio warnings in the flight deck. At five seconds before impact, the stall warning system activated. These warnings would have been distracting for the crew; no communication between them took place during this period.

As the aircraft descended, it would have become clear to the commander that they could not reach the shore. The initial turn of the aircraft was to the right, towards the coastline, but not directly. This kept the aircraft heading somewhat into wind and towards an open area of grass. A turn towards the nearest point of land, which was probably out of the line of sight of the commander, would have put the aircraft into an undesirable position, heading out of wind towards steeply rising terrain (Appendix 5, Figure 1).

It was probably not possible for the crew to have deployed any wing flaps following the engine flameouts because of a lack of hydraulic pressure, nor was there any evidence that they attempted to do so. They were thus committed to attempting a landing without flap and therefore had to accept a higher touchdown speed and a higher final rate of descent.

There was no procedure in the Operations Manual which was applicable in the circumstances in which they found themselves, so they attempted a ditching at the slowest possible speed and attained a similar attitude to that recommended for the 'power available' case. The commander probably achieved the best possible speed and attitude combination for the situation but the impact forces were such that there was considerable disruption of the aircraft structure.

It is likely that the only escape route available to the crew would have been through the overhead hatch. This would probably have been very difficult to open with the flight deck submerged. The training that the crew had received in ditching procedures and the use of lifejackets would not have been of any practical use to them in the circumstances of this accident. It was never anticipated that they might have to escape from a submerged aircraft. It is worth noting that had the hatch been opened prior to hitting the surface this escape route may have been more available, but such an action would have been contrary to the published ditching procedures.

2.2 Air Traffic Control

The 'MAYDAY' call was the ScATCC controller's first contact from the aircraft, the crew having only just transferred from Edinburgh Tower control. On receipt of the call, he correctly acknowledged it and attempted to give assistance as described in the Manual of Air Traffic Services. In fact, although he gave the crew the correct heading for a return to the airfield, he passed incorrect positional information. It is not likely that this had any influence upon the subsequent actions of the crew who had been in Visual Meteorological Conditions since takeoff and would have had good situational awareness. Also, there was no evidence of any attempt by the crew to follow the heading change instructions that they were passed.

2.3 Recorded flight information

2.3.1 Analysis of electrical noise from CVR recording

The anti-ice vane systems were powered from the main DC buses, to which the aircraft's batteries were also connected (Appendix 3, Figure 5). To the right of, and adjacent to, the anti-ice vane switches were two rocker switches which controlled the engine intake heaters (Appendix 2). Each engine intake heater was rated at 90 amps and was powered from its respective DC Shedding bus. It is likely that the activation of each heater element and the associated current surge would have caused a momentary electrical disturbance on the DC bus system. In the same manner that the relatively quiet public address channel of the CVR picked up the electrical noise from the anti-ice vane actuator motor, it is considered likely that the two noise spikes, recorded as the anti icing systems were selected to ON, were induced by the activation of the intake heaters.

From this analysis, and that previously described, the probable sequence of anti-ice system rocker switch selection was left anti-ice vane, right anti-ice vane, left intake heater and then right intake heater.

Following the double engine flameout and loss of the associated generators, the left and right DC Shedding buses would have gone offline. Analysis of the CVR indicates that two switch selections were made in the twelve seconds after the event. It was not possible to distinguish in either case whether one switch selection had been made or whether two (or more) simultaneous selections had been made. It was noted that there was no associated electrical noise spike with the first but that anti-ice vane movement started with the second. If both intake heaters were selected to OFF by the first switch operation, no noise spike would have resulted as the power to the system would have already been shed. However, with DC power still available on the main bus, a simultaneous selection of left and right anti-ice vanes to OFF would have resulted in the two low level audio signatures observed.

In addition to the intake heaters, a number of other services were connected to the Shedding buses including the strobe lights. As in the case of the intake heaters, the strobe lights would have been depowered once their associated Shedding bus had been disconnected. This is the likely reason that there was no evidence of electrical noise due to strobe light operation during the aircraft's descent.

Time versus frequency spectrograms for the period around the engine failures are shown in Appendix 8, Figures 1 and 2.

2.3.2 Interruption of secondary radar

None of the aircraft avionics relating to secondary radar were powered from the DC Shedding buses and so would have been operational following the double engine failure. However, there were no secondary radar returns transmitted from that moment on. The cockpit mounted display controller for the radar transponder was found, following the accident, to be still selected to ALT. This selection should have enabled the transmission of both Mode A (ident) and Mode C (encoded altitude) returns.

From information received from the manufacturer, the application of power would result in the display controller being fully operational within less than two seconds. The transponder itself required between three to five seconds to achieve full power capability. The manufacturer also stated that the majority of transponder units of this type were capable of achieving this within a typical period of three seconds. Following the engine failures and the decay in output voltage from the generators, bus switching would have occurred and the Shedding buses disconnected. A number of electrical transients were recorded on the CVR at that time and, within half a second, the 'Hi/Lo' crew call tone was activated. There is no obvious reason why the crew had activated this tone. However, anecdotal evidence suggests that on many aircraft types it is not unusual for this tone to be activated during DC power bus switching and this might be taken as an indication of the presence of momentary power interruptions or under-voltages.

The sweep period of the ground based surveillance radar in use was six seconds and, with three secondary returns missing, the period of transponder system inoperability should have been between 12 to 18 seconds. This period is far longer than the time required by the transponder to recover from a power interruption, but nevertheless may account for the loss of the first secondary return. The aircraft had been battery started prior to flight and the capacity of those batteries would have been adversely affected by the low ambient temperatures. Thus it is possible that the voltage present on the main DC buses after the generators went off line was significantly lower than that normally expected. This may have led to an increased start up time requirement for some avionic systems. There is no evidence to support or refute this theory but it could explain the loss of the two subsequent secondary returns.

From the FDR data, it could be deduced that primary radar coverage ended as the aircraft descended through approximately the same flight level as when coverage commenced, at 1,600 feet (referenced to a standard pressure setting of 1,013.2 mb).

2.3.3 Interruption of radio communications

Transmissions from the accident aircraft were curtailed as the aircraft descended through 750 feet amsl. It is possible that the aircraft's VHF transmitter was operating at reduced power for the reasons stated above. However, as the direct line of sight to the receiving antenna on Lowther Hill became blocked by intervening high ground, this is likely to have led to the blanking of the signal. It is likely that the higher power transmissions from ATC could still be received by the aircraft, whilst those of relatively lower power originating from the aircraft could not.

2.4 Consideration of the engine flameouts

2.4.1 Conditions when the aircraft was parked

To obtain a better picture of the overnight conditions a graphical plot was constructed from the recorded weather data, (Appendix 4, Figure 2).

From the tests carried out, it is clear that snow almost certainly entered the plenum chambers while the aircraft was parked facing into the adverse weather conditions and would have readily risen onto the top and sides of the engines. Since snow was falling and considerable wind was blowing when the aircraft initially shut down, shortly after 0003 hrs, snow would have come into contact with the hot engine casings. It would obviously have melted, but as the engines cooled and the wind and snowfall continued, snow would gradually have begun to accumulate and freeze onto the casings. Fresh snow could be expected to have continued to deposit on the frozen snow. The engine support struts and a number of wiring looms in the plenum chambers would add to the surfaces on which snow could lodge.

With the wind and snow conditions recorded during the night preceding the accident, snow could be expected to have rapidly built up. By the following morning, when snowfall ceased, it probably occupied a significant proportion of the available volume within the plenum chambers.

2.4.2 Fuel System

A number of possible scenarios for the engine failure were considered. The possibility of snow having blocked the common fuel vent, which supplied the two tank groups, was reviewed. Since the ambient temperature for much of the afternoon preceding the accident was +2°C, and the diameter of the pipe-work was small, it was felt that snow in this area would not have produced or retained a hard 'plug' which could have been capable of preserving a significant pressure difference between the tank air space and ambient pressure. The location of the fuel vent under the right wing would also not have been conducive to significant contamination or blocking.

It is also clear that the orientation of the fuel tanks, collectors and boost pumps (ie a tank group supplying one engine being positioned well forward of the group supplying the other engine) would result in some difference in the fuel pressure that was being supplied to left and right engines respectively, with the aircraft at climb attitudes. It would thus be unreasonable to expect that a vent blockage could result in near simultaneous loss of supply pressure to both engines. This would need to be the case if both engines flamed out in the way the FDR indicates that they did on G-BNMT (ie within less than half a second of one another).

It was noted that the layout of the fuel system made it difficult to postulate a single inadvertent crew action which was capable of causing near simultaneous flameout of both engines.

2.4.3 Mechanical failure

Another way that could be visualised of causing the two engines to cease producing power would be to have suffered internal mechanical failure in both units.

This was considered to be statistically highly unlikely. It was also ruled out by the absence of any evidence of mechanical failure being noted during the engine strip examinations. It is also virtually impossible to have had a subtle undetected failure occur in both engines at the same moment.

2.4.4 Engine icing effects

The fact that both engines lost power virtually simultaneously, and coincidentally with the anti-icing vanes being in motion, gave a strong indication that movement of the vanes was implicated in the power losses. The fact that a small time-stagger occurred in the initial selection of the vane switches, and a similar stagger occurred in the timing of the power losses, further reinforced this view.

Since vane movement modifies the airflow path, it is reasonable to assume that, with contamination present in the area of the vanes, a larger change in flow conditions on vane selection would occur than would be the case in an uncontaminated situation.

The experiments demonstrated that the conditions during the night would have led to substantial quantities of snow building up in the plenum chambers above and around the engine carcasses. The wind continued, albeit at lower velocity, through the day and its direction remained close to the aircraft axis. Although the temperature rose slowly to +2°C, it is unlikely that this had much effect on the large heat sink resulting from the large volume of snow which would have accumulated in the plenum chambers during the preceding eight hours of heavy snowfall.

Once the engines were run, however, they would have warmed rapidly, melting the material in contact with them and causing a mixture of unknown proportions of snow, slush and water to fall to the bottom of each plenum chamber, coming to rest in the region of each bypass door.

Subsequent engine running, drawing intake air at a maximum ambient temperature of +2°C over a wet, slushy mass, would have resulted in a rapid cooling effect which would have readily re-frozen at least some of the slushy material.

The engines were started and stopped a number of times between the arrival of the crew at the aircraft and its departure from the stand. During this period, a minimum wind speed of 16 kt, with occasional gusts to higher figures, continued to blow towards the front of the aircraft at an angle close to its axis. This would have resulted in a continuous low velocity flow of air at +2°C passing through each intake system, when the engines were not operating.

At first sight, the snow/slush lying against or adjacent to the bypass doors would be expected to melt during the periods of idleness of the hot engines. In practice, however, the continuous feed of cold air produced by the wind and the temperature drop created by its flow over the melting ice/slush would have ensured that the warm engine had little or no chance to further melt the slushy or possibly re-frozen material.

The flow would, however, have rapidly cooled the engine carcass both externally and internally. Operation of the intake vanes occurred at least once during the diagnostic ground running as well as during the pre-start checks, (Appendix 1, Figure 7). This would have caused the bypass doors to push the slushy material forward. It is most likely, however, that once the vanes were returned to their normal position, the airflow induced by the engines caused the material gradually to slide back towards the position of the closed bypass doors.

It is therefore reasonable to conclude that when the aircraft left the stand, considerable quantities of ice/snow/slush remained in the two intake systems, close to, or against, the bypass doors. Normal procedures call for testing of the Autofeather systems before takeoff and the CVR indicated that this had been carried out. During such tests, movement of the vanes towards the anti-ice position would also occur, again moving the ice/slush material forward. Once again, however, it is reasonable to expect that it would have slid back, against the closed bypass doors, under the influence of the airflow, before takeoff began.

Takeoff took place with the vanes in the 'normal' position. The FDR/CVR data shows that after reduction of power to the climb setting, the vanes were operated and the motors drove them towards the anti-ice position. After an elapsed time equivalent to half that required for full vane travel, each engine torque dropped rapidly to zero. Clearly, as mentioned earlier, operation of the vanes was the factor which lead to the flameouts. Since this is not normally the consequence of such a selection, it would seem reasonable to deduce that the effective airflow path geometry was changed, on this occasion, to a greater degree than normal.

The re-frozen melt material which was postulated as lying against, or close to, the front face of the bypass doors when the aircraft left the stand, would be moved forward again by the opening of those doors in each intake. With each vane of the system effectively reducing the local cross-section by 50%, when fully deployed, sufficient melt material to reduce the remaining local unobstructed cross-section by just over a further 25% would result in engine surge at this compressor condition.

As, however, the recorded time of movement, derived from the CVR, represented only half deployment, a very large amount of contaminant would appear to be required to lead to compressor surge.

Examination of the intake geometry indicates that approximately 90% of the available forward vector of the movement of the lower edge of the bypass door occurs during the first 50% of its angular movement. A reasonable sized, semi frozen, mass of contaminant, being pushed forward by the door, would move in such a direction that the remaining free space between it and the rear edge of the partly depressed forward vane would readily create more than a 75% reduction in available local cross-section. Although a similar, or higher, degree of blockage would have occurred during ground operation, the much lower compressor demand under the engine idle condition would not have lead to flow breakdown.

Notwithstanding the fact that the re-frozen melt material in front of each bypass door would have occupied a fraction of the volume of the original snow, the volumes available to accommodate that snow in the plenum chambers are large. This is particularly so in relation to the volume of material required in the region of the bypass door to account for the above phenomenon.

Although some of the melt material may have been ingested by the engines during the ground running, the wet state of the snow released from the plenum chambers as a result of engine heating would have resulted in the bulk of it falling as a series of 'snow-balls'. These would not have been readily picked up by the airflow. Thereafter, temperature and airflow conditions would have tended to produce a frozen 'skin' on the melt material further reducing any tendency for ingestion.

With a view to these circumstances the manufacturer issued an All Operator Message in October 2001 advising of the potential hazards associated with ice or snow accumulation within the engine intake and plenum area, (Appendix 10).

2.5 Survivability

The ditching characteristics and limitations of conventional aircraft in general and those of the SD3-60 in particular have been outlined earlier. It is clear that the required water entry conditions of low speed, low descent rate and defined pitch angle range can only be met whilst engine power remains available and with full flap selected. Some degree of advanced warning of an imperative need to ditch is therefore necessary, to enable the aircraft to be landed in accordance with the conditions established during the model testing.

The first indication that the crew had of a problem was the actual loss of power. Thereafter, without being able to restore power in the available short time span, they were unable to achieve the appropriate combination of parameters, ie the optimum tested configuration, needed to ensure successful water entry. In addition, model testing is carried out assuming a defined, reasonably smooth, sea state. This was not present on the occasion of the accident. Indeed a rough, confused sea was reported. Under such conditions, the structural strength of any aircraft is unlikely to be sufficient to enable it to alight without severe damage and occupants can be expected to experience high deceleration forces during water entry.

It was therefore not possible for the aircraft to ditch in the sea without inflicting the high degree of damage to the fuselage structure, as occurred in this impact. The evacuation procedures in the Operations Manual were based on the ditching test data, in which there was an assumption that the aircraft would adopt a tail low attitude and float on the water after ditching. Thus, they did not take account of any loss of the structural integrity of the aircraft.

In a previous ditching event, a crew successfully escaped from the aircraft, after having released the overhead hatch prior to impact. It could not be determined whether such an action would have been beneficial in this case, and such action would have been contrary to published advice.

The sea state and the water temperature were such that crew survival in the water for a prolonged period would have been unlikely.

3 Conclusions

(a) Findings

1 The aircraft landed at Edinburgh at 0003 hrs on 27 February 2001 and was serviceable at the completion of its flight. Its subsequent planned departure was cancelled due to bad weather conditions at Edinburgh.

2 The aircraft was parked facing into strong/moderate surface winds for about 17 hours before departure on the accident flight.

3 There was snow falling for between nine and ten hours during the period that the aircraft was parked.

4 There were some significant and relevant differences between advice contained in the manufacturer's Maintenance Manuals and that presented in the Operations Manual. The Operations Manual did not adequately reflect the manufacturer's advice to protect the engine intakes when the aircraft was parked in adverse weather conditions.

5 Air intake blanks ('bungs') were not available on the aircraft, nor were any readily available at Edinburgh Airport, so the flight crews were unable to fulfil the ground handling responsibilities specified in the Operations Manual, Part 9 Flying. No protection of the aircraft's engine intakes was therefore afforded during conditions of light to moderate falling snow and strong surface head winds. A significant amount of snow almost certainly entered the engine intakes during this time.

6 Large volumes of this snow would have accumulated in the two engine intake plenum chambers, a location not externally visible to the crew during a normal pre-flight inspection.

7 The flight crew were not necessarily aware of the severity of the conditions that the parked aircraft had been exposed to overnight, as they did not arrive at the aircraft until the afternoon of the accident, by which time the weather had improved considerably.

8 The crew members were properly licensed, adequately rested and medically fit to conduct the flight. The flight crew operated the aircraft within the limits laid down by the operator's Flight Time Limitations scheme.

9 Both engines were operated and shut down again on a number of occasions before the aircraft left its parking position.

10 The crew carried out all normal operating procedures in accordance with their company Operations Manual, both before and during the flight.

11 The engine anti-icing vanes were operated through their full range, with the engines at idle power, on at least one occasion prior to departure.

12 At some stage, probably after engine ground running began, the deposits of snow, ice or slush almost certainly migrated from the plenum chambers down to the region of the intake anti-ice vanes. Conditions in the intakes prior to takeoff are considered to have caused re-freezing of the contaminant, allowing a significant proportion to remain in a state which precluded its ingestion into the engines during taxi, takeoff and initial climb.

13 The engine Ignition systems were not selected on prior to departure, which was in accordance with the normal operating procedures for a 'wet' runway as specified in the Operations Manual, Part 9 Flying.

14 Both engines flamed out coincident with the operation of the engine intake anti-icing vanes during the climb.

15 The engine flameouts were considered to have been caused by blockage or disturbance of the intake air flows, caused by the movement of accumulations of snow, ice or slush which were disturbed by, and acted in conjunction with, the actuation of the intake anti-ice vanes.

16 No procedure was available for the crew to attempt a rapid re-light of an engine following the double engine flameout.

17 No procedure was available for ditching the aircraft other than with one or both engines operating.

18 No realistic procedure could be envisaged for successfully ditching the aircraft after the loss of both engines, as the optimum touchdown parameters, which had been derived from model testing, could not be attained without the use of at least one operative engine and the flaps at the landing setting. The flap system was rendered inoperative in this instance. In addition, the sea state was rough, which was not conducive to a successful ditching.

19 The commander achieved a combination of speed and aircraft attitude touchdown parameters that were probably the optimum under these adverse circumstances.

20 Crew escape may have been precluded by the nature of the impact, or by difficulty in operation of the flight deck Emergency Escape Hatch under water.

21 The sea state and water temperature were such that, had the crew been able to escape from the aircraft, survival in the water for more than a few minutes would have been unlikely.

22 At least one previous similar occurrence of a double power anomaly on a Shorts SD3-60 aircraft was discovered but, because it had not been reported through the Mandatory Occurrence Reporting scheme, no further lessons had been promulgated after that event.

23 Either a time-delayed sequencing of the anti-ice switch selections, or prior selection of the engine Ignition system, may have prevented the double engine power loss. Either course of action may thus have prevented the loss of this aircraft.

b) Causal factors

The investigation identified the following causal factors:

1 The operator did not have an established practical procedure for flight crews to fit engine intake blanks ('bungs') in adverse weather conditions. This meant that the advice contained in the aircraft manufacturer's Maintenance Manual *'Freezing weather - precautions'* was not complied with. Furthermore intake blanks were not provided on the aircraft nor were any readily available at Edinburgh Airport.

2 A significant amount of snow almost certainly entered into the engine air intakes as a result of the aircraft being parked heading directly into strong surface winds during conditions of light to moderate snowfall overnight.

3 The flow characteristics of the engine intake system most probably allowed large volumes of snow, ice or slush to accumulate in areas where it would not have been readily visible to the crew during a normal pre-flight inspection.

4 At some stage, probably after engine ground running began, the deposits of snow, ice or slush almost certainly migrated from the plenum chambers down to the region of the intake anti-ice vanes. Conditions in the intakes prior to takeoff are considered to have caused re-freezing of the contaminant, allowing a significant proportion to remain in a state which precluded its ingestion into the engines during taxi, takeoff and initial climb.

5 Movement of the intake anti-icing vanes, acting in conjunction with the presence of snow, ice or slush in the intake systems, altered the engine intake air flow conditions and resulted in the near simultaneous flameout of both engines.

6 The standard operating procedure of selecting both intake anti-ice vane switches simultaneously, rather than sequentially with a time interval, eliminated a valuable means of protection against a simultaneous double engine flameout.

4 Safety recommendations

The following safety recommendation was made on 6 March 2001 during the course of this investigation:

4.1 Recommendation 2001-39

It is recommended that the CAA requires the manufacturer to advise all operators of the possibility of snow accumulation in the engine air intakes, when parked, subsequently resulting in engine failures. Further to advise that such a failure may be precipitated by a change of intake conditions resulting from the activation of the anti-ice vanes.

Further safety action

Following a review of operational practices the CAA published a flight operations department communication on 20 October 2001 (FODCOM 17/2001) (Appendix 11). This document required all UK operators to review their Operations Manuals and ensure that they include the following procedures:

> *'1. Who is responsible for the de/anti-icing of the aircraft;*
>
> *2. Specific procedures for removal of contaminants from engine intakes, other intakes and undercarriage;*
>
> *3. Fitting/removal of blanks to engine intakes, and other intakes;*
>
> *4. Type specific de/anti-icing procedures;*
>
> *5. Operational guidance on the precautions to be taken when aircraft are moved from a heated hanger to sub-zero conditions; and*
>
> *6. Instructions relating to the removal of snow and ice from engine and other intakes should be developed.'*

4.2 Further safety recommendations are made as follows:

Recommendation 2002-39

It is recommended that the CAA publish information to educate flight crews as to the potential hazards associated with ice, snow or slush accretion in areas of the engine intakes which are not externally visible and highlight the necessity to conduct appropriate detailed inspections when such conditions are suspected. Such information should then be promulgated widely through the industry.

Recommendation 2002-40

It is recommended that Bombardier Aerospace (Short Brothers Ltd) review the following, with regard to the potential for a double engine failure:

a) The Emergency Checklist, with a view to establishing a procedure for a rapid engine relight.

b) The provision of an Auto-ignition system, or suitable crew procedures to ensure that the Ignition systems are activated prior to the operation of intake anti-icing systems.

Recommendation 2002-41

It is recommended that the CAA ensures that its safety oversight programme of AOC Holders includes processes to check that operators have made suitable arrangements to provide flight crews with all necessary equipment to carry out all procedures specified in the relevant Operations Manuals.

P.D. Gilmartin

Inspector of Air Accidents
Air Accidents Investigation Branch
Department for Transport
March 2003