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Engine-intake Icing Sets Stage for Ditching of Shorts 360 During Cargo Flight

Snow likely entered unprotected engine air intakes when the twin-turboprop airplane was parked overnight facing into strong surface winds. Intake-airflow disruption resulting from the crew's selection of the intake anti-icing vanes during departure caused nearly simultaneous flameouts of both engines.

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FSF Editorial Staff

About 1731 local time on Feb. 27, 2001, both engines on a Short Brothers SD3-60 (Shorts 360) flamed out during departure from Edinburgh (Scotland) Airport for a cargo flight. The flight crew was not able to restart the engines and ditched the aircraft in shallow water in the Firth of Forth. The aircraft was destroyed on impact with the water, and both pilots were killed.

The U.K. Air Accidents Investigation Branch (AAIB) said, in its final report on the accident, that the following were causal factors:

- "The operator did not have an established practical procedure for flight crews to fit engine intake blanks [plugs] in adverse weather conditions. This meant that the advice contained in the aircraft manufacturer's maintenance manual [in a section titled] *Freezing weather — precautions* was not complied with. Furthermore, intake [plugs] were not provided on the aircraft, nor were any readily available at Edinburgh Airport;

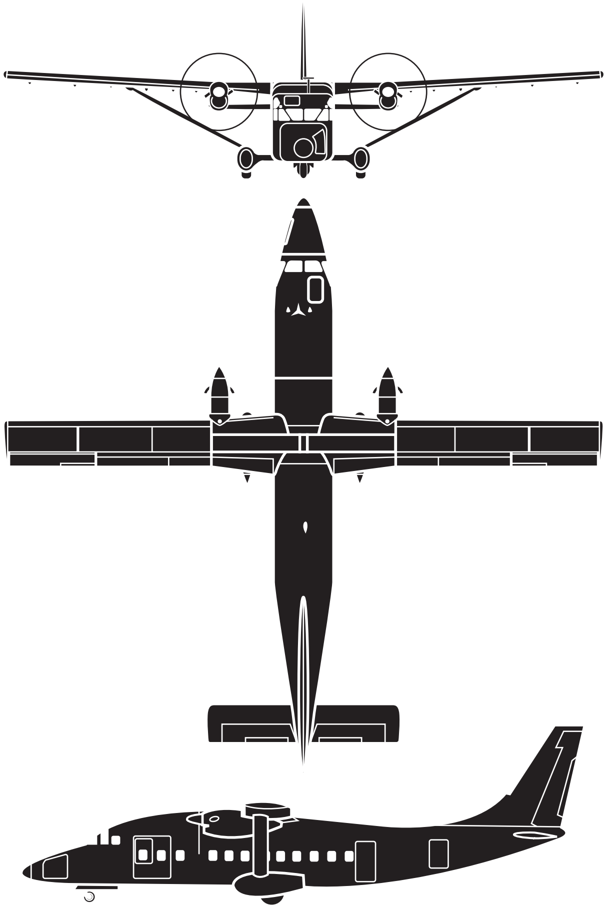
- "A significant amount of snow almost certainly entered the engine air intakes as a result of the aircraft being parked heading directly into strong surface winds during conditions of light [snowfall] to moderate snowfall overnight;

- "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 preflight inspection;

- "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 refreezing 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;

- "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 airflow conditions and resulted in the near-simultaneous flameout of both engines; [and,]

- "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."



Short Brothers SD3-60

The Short Brothers SD3-60 (Shorts 360) is an unpressurized twin-turboprop short-range commuter/regional transport derived from the SD3-30 (Shorts 330), which first flew in 1973. The 330's twin vertical fins were replaced with a swept single vertical tail, the fuselage was lengthened 0.9 meter (3.0 feet) to accommodate six more passengers, and more powerful engines were installed. The 360 first flew in 1981, and deliveries began in 1982.

The airplane is equipped either with 990-kilowatt (kW; 1,327 shaft-horsepower [shp]) Pratt & Whitney Canada PT6A-65R engines or 1,062-kW (1,424-shp) PT6A-65AR engines driving Hartzell five-blade propellers, or with 1,062-kW PT6A-67R engines driving Hartzell six-blade propellers. Maximum usable fuel capacity is 2,182 liters (577 gallons).

The 360 accommodates two pilots, a flight attendant and up to 36 passengers. A cargo version was produced with strengthened floor panels. Maximum takeoff weight is 12,292 kilograms (27,100 pounds). Maximum landing weight is 11,839 kilograms (26,100 pounds).

Takeoff distance at maximum takeoff weight and standard atmospheric conditions is 1,280 meters (4,200 feet). At maximum takeoff weight and maximum power, maximum cruising speed is 218 knots. Range at 10,000 feet with maximum fuel and no fuel reserves is 1,667 kilometers (900 nautical miles).♦

Source: *Jane's All the World's Aircraft*

The aircraft, operated by Loganair, had been landed and parked soon after midnight on the day of the accident. At the time, the surface wind was from 040 degrees at 22 knots, gusting to 36 knots, light ice pellets were falling, and surface temperature was one degree Celsius (C; 34 degrees Fahrenheit [F]).

"The inbound crew reported that there were no abnormalities observed or technical defects on the aircraft," the report said. "They supervised the refueling of the aircraft to a final load of 3,000 pounds (1,360 kilograms) before leaving the aircraft. Edinburgh Airport was not a main operating base for the airline; [therefore,] flight crews were responsible for normal aircraft turnaround procedures."

At the time of the accident, Loganair conducted scheduled passenger flights and cargo flights in four Shorts 360s and in an unspecified number of de Havilland Twin Otters and Saab 340s.

Another flight crew was scheduled to depart in the accident aircraft at 0040 for a cargo flight to Belfast, Ireland; however, they were told to expect a delay of several hours before equipment would be available to deice the aircraft. At 0210, the airport was closed because of severe weather.

"At 0600, 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," the report said. "At this time, they fitted propeller straps to each engine and also put on the pitot-head covers. Engine-air-intake [plugs] were not available for the crew to fit to the aircraft. The aircraft had not been deiced."

The report said that weather conditions that night were "very severe, of a nature not routinely experienced in the United Kingdom." Sustained, strong surface winds from the northeast and light-to-moderate snowfall prevailed until 0952.

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

By 1500, weather conditions had improved to surface winds from 030 degrees at 15 knots, visibility 10 kilometers (six statute miles), scattered clouds at 4,000 feet and a broken ceiling at 7,000 feet. Surface temperature was two degrees C (36 degrees F).

The report said that the accident flight crew had an adequate rest period before reporting for duty at Glasgow Airport at 0810.

The commander [captain], 58, held an airline transport pilot license and a Shorts SD3-30/60 type rating. He had 13,569 flight hours, including 972 flight hours in Shorts 360s. He began his career flying fixed-wing aircraft and rotary-wing aircraft in the Royal Air Force. He then flew helicopters in the North Sea for six years and instructed in fixed-wing aircraft for 12 years. He was employed by Loganair in February 1999. The airline appointed him as a line training captain in June 1999.

The first officer, 29, held a commercial pilot license, an instrument rating and an SD3-30/60 type rating. He had 438 flight hours, including 72 flight hours in Shorts 360s. He completed Shorts 360 training with another operator in September 2000 and was employed by Loganair in December 2000. The first officer began line-flying duties on Jan. 30, 2001.

Both pilots received initial training that included ditching procedures and the use of life vests. The report said that initial training and recurrent training conducted by Loganair included opening the aircraft's four emergency exits. Operation of another emergency exit — a hatch above the first officer's seat — was discussed but was not demonstrated during training.

"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," the report said. "Crewmembers were familiarized 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 crew was scheduled to depart from Glasgow at 0910 to conduct a flight to Islay.

"As a result of adverse weather conditions, that flight was canceled, and they were rescheduled to carry out the single-sector flight delayed from 0040 from Edinburgh to Belfast," the report said. "Surface travel from Glasgow to Edinburgh was impossible due to adverse road conditions; so, as soon as Edinburgh Airport reopened at 1130, the crew were positioned to Edinburgh as passengers on another company aircraft."

When the crew arrived at Edinburgh, they went out to the aircraft.

"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."

The report said that nothing is known of the crew's activities at the aircraft.

"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," the report said. "In the absence of any other information, it is assumed that the crew carried out normal preflight procedures and checks."

The crew would have needed a stepladder to visually inspect the engine intakes.

"Steps were not available at the aircraft, and a visual inspection inside the intakes was not specifically part of the preflight procedure," the report said. "If the intakes had been closely examined … 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 … without use of mirrors or removal of engine cowlings."

"Steps were not available at the aircraft, and a visual inspection inside the intakes was not specifically part of the preflight procedure," the report said.

At 1503, the crew requested clearance from Edinburgh Tower to start engines. Several times during the next nine minutes, the right engine was observed to stop and then start. The crew then told the controller that they were shutting down the engines because of a technical problem.

The crew told maintenance personnel at Loganair's base in Glasgow that the right engine-driven generator failed to come on line. The line-maintenance controller at Glasgow asked an avionics/instrument engineer [maintenance technician] who was in transit at Edinburgh to assist the crew.

"He carried out troubleshooting with advice from the maintenance controller," the report said. "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, [and] the crew carried out a second engine run of similar duration, again at the engineer's request. The original fault could not be reproduced."

Investigators did not determine why the generator did not come on line during the crew's initial attempts to start the engines.

"The preflight problems with the generator are not considered to have played any part in the accident," the report said.

The commander asked the engineer to check the engine oil levels and to confirm that no ice or snow adhered to the aircraft. The engineer found the oil levels sufficient and only a small deposit of slush on the windshield, which he cleaned.

The crew started the engines and ran them for about 20 minutes. At 1710, the first officer requested taxi clearance from Edinburgh Tower.

When investigators arrived at the accident site, the tide had receded and the airplane was only partly submerged in seawater.
(Photo: U.K. Air Accidents Investigation Branch)

"After a short delay, the aircraft [was] powered back off stand and taxied to depart from Runway 06," the report said. "While taxiing, as part of the first-flight-of-the-day engine checks, the crew carried out [a propeller] autofeather test, during which the automatic operation of the engine anti-icing vanes to fully deploy and return was also observed."

The aircraft weighed 10,140 kilograms (22,355 pounds) on takeoff; maximum certified takeoff weight is 12,292 kilograms (27,099 pounds).

The crew did not select the engine-ignition systems before takeoff on the wet runway. [Most turbine engines have igniters that normally are activated automatically by the starting circuit to help start the engines. The igniters produce heat (e.g., a flame or sparks) that ignites the fuel-air mixture during starting. After the engines are started, combustion is self-sustaining and the igniters are deactivated. In addition to their use in engine starting, igniters typically are selected manually or activated automatically before/during flight in certain conditions, such as heavy precipitation, icing or turbulence to help prevent engine flameout. In some aircraft, igniters are required to be used during takeoff and landing.[1]]

The report said that Part 9 (*Flying*) of the company's operations manual required selection of the ignition systems before takeoff on a runway contaminated with snow or slush; Part 8 (*Technical*) of the operations manual and a supplement to the airplane flight manual (AFM) said that ignition systems should be selected for takeoff when there is a risk of ingesting snow, slush or water into the engines.

"The reason for this anomaly in its documentation was not explained by the operator," the report said. "However, as the engine failures did not occur during the takeoff ground roll, it is highly unlikely [that] ingestion of water from the runway surface was the cause of this event."

After retracting the landing gear on takeoff, the crew recycled the gear to ensure that it was free of snow and slush. Climb power was set while flying the airplane through about 1,200 feet. The commander began a turn to 045 degrees, in compliance with the departure procedure, and called for the "After Takeoff" checklist.

"When the 'stall-warning heaters' item was reached, he requested that the first officer put on all the anti-icing systems," the report said.

The company's operations manual required ice-protection systems for the airframe, engines, propellers, windshield, pitot-static system and stall-warning system to be engaged before the aircraft enters visible moisture at an outside air temperature at or below six degrees C (43 degrees F).

At this time, the Edinburgh Tower controller told the flight crew to establish radio contact with Scottish Air Traffic Control Center (ATCC). The first officer acknowledged the instruction, and the commander selected the radio frequency for Scottish ATCC while the first officer selected the anti-icing systems. The aircraft was at 2,200 feet.

Among the systems selected by the first officer were the inertial separators, which comprise two electrically-driven vanes in the air intake areas in each of the reverse-flow Pratt & Whitney PT6A engines. When the system is selected, one vane is lowered into the air inlet. The vane reduces the intake area, increases the speed of the airflow and causes the airflow to enter the plenum at the rear of the engine at a more acute angle. The inertia of solid particles and liquid particles causes them to take a straighter path through the intake, and most of the particles exit the intake through a bypass outlet that is uncovered by movement of the other vane.

Four seconds after the first officer selected the engine anti-ice vanes, the engines flamed out. The report said that indications of the flameouts would have included the sound of decreasing engine/propeller speed, decreasing torque indications and red generator-failure warning lights. The flight crew did not have a procedure for rapid relighting of the engines.

"The existing engine-failure procedure was lengthy and was not suited to the rapid relight that would have been required," the report said.

Neither the operations manual nor the AFM contained procedures for handling a dual engine failure or for conducting a ditching without power.

The aircraft was at about 2,300 feet when the commander told the first officer that the engines had failed, decreased the aircraft's pitch attitude, reduced airspeed to 110 knots and began a right turn towards the coastline.

"The rate of descent stabilized at 2,800 feet per minute, and he realized that the aircraft would have to be ditched in the water," the report said.

Neither the operations manual nor the AFM contained procedures for handling a dual engine failure or for conducting a ditching without power.

"In the operations manual, there was an engine-relight procedure checklist applicable to the single-engine-failure case," the report said. "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 nine degrees.'"

The report said that there was no indication that the crew attempted to extend the flaps.

"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," the report said. "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."

When the commander advised the first officer that the engines had failed, the first officer told Scottish ATCC, "Mayday, mayday, mayday. This is Logan six seven zero alpha. We've had a double engine failure. Repeat, a double engine failure."

The controller said, "Roger, Loganair six seven zero alpha. Roger your mayday. Turn left onto heading of two five zero. The airfield is three miles to the northeast of your present position."

The first officer told the controller to repeat the message. The report indicated that the controller replied but that the first officer did not receive the radio transmission.

About this time, the aircraft was descending through 1,850 feet. The pitch attitude decreased to about eight degrees nose-down and descent rate began to increase.

"The aircraft was descending through 1,400 feet, with a descent rate of approximately 3,200 feet per minute, as [a ground-proximity warning system (GPWS) 'sink rate'] alert started and the commander began to raise the nose of the aircraft towards four degrees nose-down," the report said. "Airspeed and descent rate began to reduce and stabilized at 115 knots and 2,800 feet per minute, respectively. The GPWS alert continued."

The report said that the continuous GPWS warnings during the last 30 seconds of the flight and activation of the stall-warning system five seconds before impact likely distracted the crew.

"No communication between [the pilots] took place during this period," the report said.

The aircraft was descending through about 750 feet when the commander stopped the right turn on a heading of 110 degrees.

The first officer radioed that the aircraft was being ditched, but the controller did not receive the transmission.

"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 report said.

The time from engine flameout to water contact was 62 seconds. Sea conditions were described as rough.

"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," the report said. "It was therefore not possible for the aircraft to ditch in the sea without inflicting a high degree of damage to the fuselage structure, as occurred in this impact."

The aircraft struck the water at 86 knots and in a 6.8-degree nose-up attitude.

"It came to rest on the sea bottom in a nose-down attitude with the forward section of the fuselage submerged, 65 meters [213 feet] offshore, in a water depth of about six meters [20 feet]," the report said.

Both pilots drowned.

"The seawater temperature in the area was between six degrees C and eight degrees C [43 degrees F and 46 degrees F]," the report said. "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 one's breath can be severely curtailed by this, perhaps to just a few seconds, thus reducing the chances of successful escape from a submerged aircraft."

The hatch above the first officer's seat likely was the only escape route available to the crew.

"This would probably have been very difficult to open with the flight deck submerged," the report said. "The training that the crew had received in ditching procedures and the use of [life vests] 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 procedure."

The ditching procedure published in the operations manual said, "It is essential that the aircraft alights on the water with all exits closed."

"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."

The report said, "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."

During the investigation, AAIB received a report that a double engine failure resulting from an accumulation of ice or snow before flight had occurred eight years earlier during a Shorts 360 takeoff roll.

The report said that on March 20, 2001, a buildup of slush was found in the engine intakes of a de Havilland Dash 8 that had been parked facing into the wind in blowing snow. AAIB had included information about the Dash 8 incident "and previous occurrences on the type" in Bulletin 1/2002.

"Unfortunately, at the time of the [Loganair Shorts 360] accident, information about the possibility of such an event was not widely known," the report said. "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."

The report said that if the crew had selected the engine-ignition systems (igniters) for takeoff and if the ignition systems had remained engaged during departure, a brief transient loss of power might have occurred. Selection of the engine-ignition systems before selection of the anti-ice vanes also might have resulted in a rapid relight of the accident aircraft's engines.

"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," the report said. "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."

The report said that rather than selecting both engine-ignition systems almost at the same time, a delay of more than about 10 seconds between the selection of the ignition systems for each engine might have allowed the crew to observe the flameout of one engine and prevent the other engine from flaming out.

"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' [systems], which provide automatic operation of the igniters when certain anti-icing selections are made," the report said. "The SD3-60 was certificated without such systems."

In response to a recommendation made by AAIB during the investigation, the U.K. Civil Aviation Authority (CAA) on Oct. 20, 2001, issued *Flight Operations Department Communication 17/2001*.

The report said, "This document required all U.K. operators to review their operations manuals and ensure that they include the following [information]:

- "Who is responsible for the de[icing]/anti-icing of the aircraft;
- "Specific procedures for removal of contaminants from engine intakes, other intakes and undercarriages;
- "Fitting/removal of [plugs] to engine intakes and other intakes;
- "Type-specific de[icing]/anti-icing procedures;
- "Operational guidance on the precautions to be taken when aircraft are moved from a heated hangar to sub-zero conditions; and,
- "Instructions relating to the removal of snow and ice from engine [intakes] and other intakes."

On March 4, 2002, the manufacturer issued *All Operator Message SD002/02*. The message included the following information:

> Through the experience of one operator, it has been discovered that failure to install engine intake covers … when [the aircraft is] parked can allow ice/snow buildup in the engine air intake immediately ahead of the aft vane of the inertial separator and up into the upper plenum area. Heat generated during preflight engine running could cause any buildup of ice/snow in the upper plenum areas to melt and fall, creating an accumulation in the lower nacelle where, given the appropriate conditions of near[-zero] or sub-zero temperatures, it may refreeze.
>
> Simultaneous deployment of the inertial separator vanes onto this accumulated ice/snow could potentially cause a complete and simultaneous double engine-power loss.

The message required use of either a ladder or a raised platform to conduct "tactile inspections" of engine intakes before flight and removal of any snow or ice. The message also required that if no snow/ice is found, the inertial separator must be selected at least twice after the engines are started, to melt or loosen any snow/ice accumulations in the plenums.

Based on the findings of the investigation, the AAIB issued the following recommendations:

- "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:
  - "The emergency checklist, with a view to establishing a procedure for a rapid engine relight; [and,]
  - "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; [and,]
- "Recommendation 2002-41 — It is recommended that the CAA ensure that its safety oversight program of AOC [air operator's certificate] 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."♦

[FSF editorial note: This article, except where specifically noted, is based on the U.K. Air Accidents Investigation Branch report no. 2/2003 (EW/C2001/2/6): *Shorts SD3-60, G-BNMT, near Edinburgh Airport on 27 February 2001*. The 91-page report contains illustrations and appendixes.]

Note

1. FSF Editorial Staff. "Engine Flameouts in Sabreliner and MU-2 Linked to Nonuse of Continuous Ignition." *Accident Prevention* Volume 59 (August 2002).

Further Reading From FSF Publications

Global Aviation Information Network. "Operator's Flight Safety Handbook." *Flight Safety Digest* Volume 21 (May–June 2002).

Roelen, A.L.C.; Pikaar, A.J.; Ovaa, W. "An Analysis of the Safety Performance of Air Cargo Operators." *Flight Safety Digest* Volume 20 (July 2001).

FSF Editorial Staff. "Double Engine Failure Leads to Ditching of Cessna 402C." *Accident Prevention* Volume 56 (August 1999).

FSF Editorial Staff. "Ice Ingestion Causes Both Engines to Flame Out During Air-taxi Turboprop's Final Approach." *Accident Prevention* Volume 56 (February 1999).

Flight Safety Foundation. "Protection Against Icing: A Comprehensive Overview." *Flight Safety Digest* Volume 16 (June–September 1997).

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