Investigation of Fatal Double Engine Flame-out to Shorts SD 360 Turboprop

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Author Biography:

Peter Coombs joined the UK AAIB in 1972 and has performed over 200 field investigations to civil and military fixed and rotary winged aircraft and a comparable number of other technical investigations. As a Student Apprentice with the British Aircraft Corporation from 1966 he gained experience of manufacture, development and testing of aircraft and missiles, including BAC 1-11, VC10 and Bristol Britannia airliners, before becoming a design engineer on the Concorde SST. Awarded a Master of Science Degree in Aircraft Design at the College of Aeronautics, Cranfield in 1971, he flies single and multi engined aircraft and is an active flying instructor.

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A New Approach to Powerplant Investigation and an Unusual Cause Determined

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ACCIDENT BACKGROUND

In the early evening of 27 February 2001 a Shorts SD 360 Twin turbo-prop aircraft took off from Edinburgh, Scotland. Although normally serving as a passenger airliner, on this occasion it was carrying only two flight crew and a cargo of mail. Just over a minute after take-off, a distress call was received stating that both engines had failed. The machine descended rapidly and ditched in shallow but exposed and extremely choppy waters of a local sea inlet, the Firth of Fourth. It sustained considerable damage at the water impact and soon became partly submerged. Neither crew member survived.

Investigation of the accident required salvage of the aircraft from the very exposed waters, where it was lying between low and high tide positions, followed by detailed examination of its systems and power-plants, development of a robust theory as to the cause of the obscure double power loss and the preparation and implementation of experiments to support the theory.

The wreck site was such that the aircraft could only be accessed on one occasion on foot (Figure 1) before the changing tidal cycle dictated that at the lowest tides the aircraft still remained partly submerged (Figure 2). This situation was to continue until approximately a week had passed. The recovery task was further hampered by the extent to which the aircraft became buried in the sand with succeeding tides (Figure 3).

Eventually, however, the wreckage was salvaged (Figure 4) and detailed examination began. In the meantime both DFDR and CVR were recovered, de-contaminated and replayed successfully.

My past experience of multiple power loss has led me to expect that one engine may lose power for a variety of reasons, whilst a second engine generally does so after a time interval, usually following crew actions intended to secure the first engine but incorrectly applied. The only other double power losses I can recall investigating have been: -

(1) An occasion on which both engines were selected to nearly empty main tanks on departure, following accidental fuel uplift into auxiliary tanks, unobserved by the crew.

(2) An occasion when an Eastern Block certificated aircraft, equipped with an automatic engine safety/shut down system, suffered an electrical fault which energised fuel shut-off valves on both engines, driving them to the closed position shortly after take-off.

Fuel exhaustion, severe engine intake icing and volcanic ash contamination are of course also well known multiple power loss causes.

The simple two-tank fuel system layout of the SD 360 did not favour the possibility of a system handling error. The possibility of a repetition of the second failure scenario described above was effectively precluded by the purely mechanical operation of both HP and LP fuel valves and the ergonomic difficulty of operating both left and right hand controls of either simultaneously. The large fuel uplift apparently carried out at Edinburgh, together with fuel remaining on arrival, virtually precluded the possibility of complete fuel exhaustion so soon after departure and the aircraft was not flying in icing conditions at the time of the power loss. Finally, as I am sure you know, there are no volcanoes within 5000 miles upwind of Edinburgh.

It was therefore with great surprise that I learnt from our recorder specialists that both engine torque values dropped from climb power to zero precipitately and within milliseconds of one another. This occurred at about 1800 feet, within 8 seconds of the Captain requesting the First Officer to select the anti-ice systems and almost exactly 5 seconds after the sound of two switch selections which were immediately followed by the electrical sound of two motors operating.

RELEVANT FEATURES OF THE AIRCRAFT

The aircraft type is powered by two PT 6A series reverse-flow turbo-prop engines. Each engine is orientated with its compressor at the rear. There are a number of reversals of air and combustion gas flow directions within each power plant, (a total of 720 degrees direction change of flow axis between the external intake and the aft facing exhausts). As shown in Figure 5, air is supplied to the engines via a forward facing intake behind and below each propeller, whilst exhaust gases leave via a pair of curved pipes at the front of each engine, arranged to direct the gases backwards. The air, having entered each external intake, passes below the whole length of the relevant engine, before turning through a right angle and travelling vertically upwards into air tight plenum chambers. From these, it is drawn into each engine compressor through a cylindrical mesh guard. (Figure 5). An external view of a nacelle on the salvaged wreck, showing the intake and one exhaust stack, is shown at Figure 6.

In icing conditions, the crew may select so called anti icing vanes to the ON position (Figure 5). Under these circumstances, a ramp (or forward vane) is lowered from the top surface of each air intake path, reducing the available cross-section for the airflow and causing it to both accelerate and change direction through a bigger angle than would be the case without the vanes deployed. This centrifuges solids and liquids to the outer radius of the curved airflow path. At the same time, a bypass door (or aft vane) opens in each airflow, causing that part of the flow cross section containing the solids and liquids to be ejected overboard rather than to enter the plenum chambers to risk forming a frozen obstruction on the mesh guard covering the inlet to the relevant engine.

INITIAL TESTS

Tests carried out on an example of the linear actuator type which drives the inertia separators (Figure 5) confirmed that the frequency of the electrical ‘noise’ produced was identical to that of the acoustic noise present on the CVR initiating 5 seconds before engine torque was recorded as lost by the DFDR. It therefore became clear that staggered operation of the selector switches of each inertia separator took place 5 seconds before a similarly staggered sudden loss of all power on both engines occurred. There was thus little doubt that deployment of each inertia separator had lead to the consequent power loss of the corresponding engine. This left the question of how this entirely normal system operation could have had such a dramatic and abnormal effect on both engines.

RELEVANT WEATHER

Early in the investigation it became clear that the aircraft had arrived at Edinburgh at midnight, approximately 17 hours before the accident and had been refueled with the intention of departing within 2 hours. Snow began to fall as the aircraft arrived, however, and became so severe that de-icing services and runway snow clearance activities became overwhelmed. No movements took place through the remainder of that night and snow continued to fall until 08-00 next morning. Services only recovered early in the afternoon. Through the night, moderate snow (the meteorological term) was accompanied by wind gusting up to 40 Knots from a NNE direction, the aircraft also being parked on a heading of approximately NNE. The temperature was between zero and +1°C. As the day began the wind moderated but continued to gust up to 17 knots on the same heading whilst the temperature slowly rose to 2 °C by mid-day.

SEQUENCE OF EVENTS PRIOR TO DEPARTURE

A new crew arrived in the early afternoon and observed that the aircraft was now free of visible contamination apart from an area of the windscreen. Following a pre-flight check the aircraft was started but it was found that a generator would not come on line. The aircraft was shut down and assistance summoned.

A ground engineer carried out trouble shooting and a simple rectification. This required both engines to be briefly run by the crew whilst electrical loads were applied. These included operation of all anti icing systems i.e. windscreens, propellers, air intakes and inertia separators, before the engines were again shut down. Once the problem was rectified, normal pre-departure actions took place and the engines were re-started. During taxiing, the normal checks were carried out. These included a check of auto-feather. When a propeller is feathered on this type, the corresponding inertia separator is automatically powered to the anti-ice position to further reduce drag.

THE ACCIDENT FLIGHT

With inertia separators now re-set to the normal position, take-off and initial climb took place followed by torque and RPM reduction to climb settings. Only shortly after further re-selection of the inertia separators to the anti-ice position, in preparation for entering a sub-zero cloud layer, did the fatal double power loss occur.

INVESTIGATION PROCESS

Since the most unusual event during the period of idleness at Edinburgh was the weather of the night, I decided to find out what effect the snowfall had on the air intake systems. A special rig was therefore built, consisting of a controllable extractor fan, mounted on a tapered transition tube incorporating pressure tapping points. The tube was bolted in the place of one exhaust stack of an engine in a borrowed SD 360 aircraft. The other exhaust on that engine was sealed off. The pressure tapings were connected to a digital pitot-static test set.

A downstream pressure drop was created by the fan, having similar magnitude to the pressure difference between the intake face and exit pipe pressures (Figure 5) calculated for the known average headwind speed recorded during the night’s snow storm. The speed of the airflow created in the extractor tube was measured by means of the digital test set and the corresponding speed in the intake system calculated. Despite the complex flow path through the total power-plant and the effect of at least 7 stages of fixed and a similar number of stages of rotating blades in each engine, the velocity through the system was found to be a high percentage of the local wind speed.

An engine intake system and engine cowling panels, salvaged from the wrecked aircraft, were then assembled into a mock-up of a nacelle incorporating a dummy engine, complete with the intake mesh. Sealed plenum chamber bulkheads were manufactured from Plexiglas and fitted in representative positions within the cowlings. An electric extractor fan was mounted within the dummy engine and an adjustable shut-off valve was fitted at the forward end. Figure 7 shows the front of the arrangement before the adjustable shut-off valve was fitted. The fan was run and the valve adjusted to create airflow velocities in the mock intake system of similar values to those measured and calculated earlier in the intake of the borrowed aircraft.

Simulated snow flakes, comprising finely cut fragments of expanded polystyrene, were released near the external intake and their progress through the trunking and into the plenum chamber was observed via the Plexiglas rear bulkhead. It was found that the flakes readily rose up to and over the top of the dummy engine.

It was therefore clear that during the night, the wind, despite the complex flow path involved, created a powerful air-flow into the external forward facing intakes, through the intake trunking, upwards via the plenum chambers, through the engine inlet mesh filters and through the engines. This airflow had sufficient speed to lift snowflakes up into the area of the plenum chambers, passing around and over the engines. Numerous pipes, tubes wiring looms and skin stiffeners within the plenum chambers would have ensured that snow was readily deposited on these obstructions and the chamber volumes easily filled with snow. Figure 8 shows a plenum chamber interior volume with the upper cowling removed. The condition of many parked aircraft noted in the morning after the snowfall ceased attested to the large volume of snow which must have passed into the intake and thus remained in the plenum chambers.

EFFECT OF AMBIENT CONDITIONS

Although the ambient temperature rose above freezing during the following morning, the large heat sink of the snow filled plenum chambers, allied with the latent heat of melting of ice and the small margin of ambient temperature above freezing level would have severely limited the volume of trapped snow which melted. In contrast, the outside surfaces of the aircraft heated more rapidly, due to exposure to sunlight and ultimately required no de-icing. Examination, by a crew, of the high mounted aircraft intakes from the ground or indeed from a closer position would not, for geometric reasons, enable the interior of the plenum chambers to be seen.

EFFECT OF SUBSEQUENT ENGINE OPERATION

Engine starting would rapidly raise the temperature of the engine carcasses, causing the deposited snow to turn to slush and fall from the plenum chambers into the region of the inertia separators. Although some melt material may have been ingested, the bulk of the tightly packed slushy substance would have arrived at and remained in the area of the vanes. Since air was being drawn through a narrowing cross-section created by the wet slush deposit, and the deployed inertia separators, a condition analogous with the throat of a carburetor would occur, in which a temperature drop would be created. A drop of only approximately 2 degrees C would lead to gradual re-freezing and solidification of the surface of the slush. Operation of the inertia separators would cause the bypass doors to move the solidifying ice volume forward. Once the separators were returned to the normal position, however, the solidified masses would be free to slide backwards towards the bypass doors, under the influence of the airflow. After engine shut down, the wind would continue to drive air at just above freezing temperature over the re-frozen slush, limiting the effect of the hot engines on the ice and rapidly cooling the engines by both internal and external flow.

The engines were soon re-started, creating a renewed cooling effect, presumably returning the slush to a fully frozen state. Again, inertia separators were operated automatically during auto-feather checks, presumably driving re-frozen slush forward. Once the separators were returned to the off position the ice was again free to slide back towards the bypass doors.

As was stated earlier, there is compelling evidence that the anti-ice vanes were selected ON seconds before the fatal power loss. This action normally causes a 50% area reduction or blocking of the free flow of air to the engines at the position of each first vane and a similar 50% blocking at the more down downstream position of the bypass door (Figure 5). Data supplied by the engine manufacturer showed that an 87% reduction of cross-sectional area of the intake duct, under the torque, RPM and ambient air conditions recorded and derived at the time of the power loss, would cause engine surge and flame-out. A similar degree of blocking occurring at the low power settings and hence much lower mass-flow rates present during operation of the intake vanes on the ground, however, would not have this effect.

Thus a mechanism can be visualised in which weather conditions introduced large volumes of snow into the intake systems where it remained undetected and in a largely solid state. Operation of engines and vanes took place in a sequence which resulted in a large volume of re-frozen slush finally lodging in the region of the inertia separators where it added to the blocking effect created by deployment of the latter. With the final volume of slush reducing each inlet duct cross-section by approximately 40%, the effect of its presence and that of the deployment of the vanes would have been sufficient to cause both engines to surge and flame out. The DFDR shows that the HP spools of both engines decelerated almost immediately to below their self-sustaining speed. This effect, coupled with the absence of continuous or auto ignition, ensured that flame-out was total and the engines did not re-light.

SUMMARY

Although many other possible causes have been suggested for this power loss, none was found to be as likely as the process described above, given the known conditions and sequence of events. As with most accidents involving icing, the direct evidence was lost and in this case the contamination conditions within the intake systems could not be physically confirmed. Nonetheless, a process of reasonable deduction, based on all the available evidence and the test results, leads us to conclude that the sequence described above was the cause of the power loss.

Figure 1: General view of main section of wreckage at low tide, on morning after the accident

Figure 2: View of partly submerged wreckage at subsequent low tide

Figure 3: View of almost submerged wreckage at high tide

Figure 4: Salvage ships in position during lifting 6 days after accident

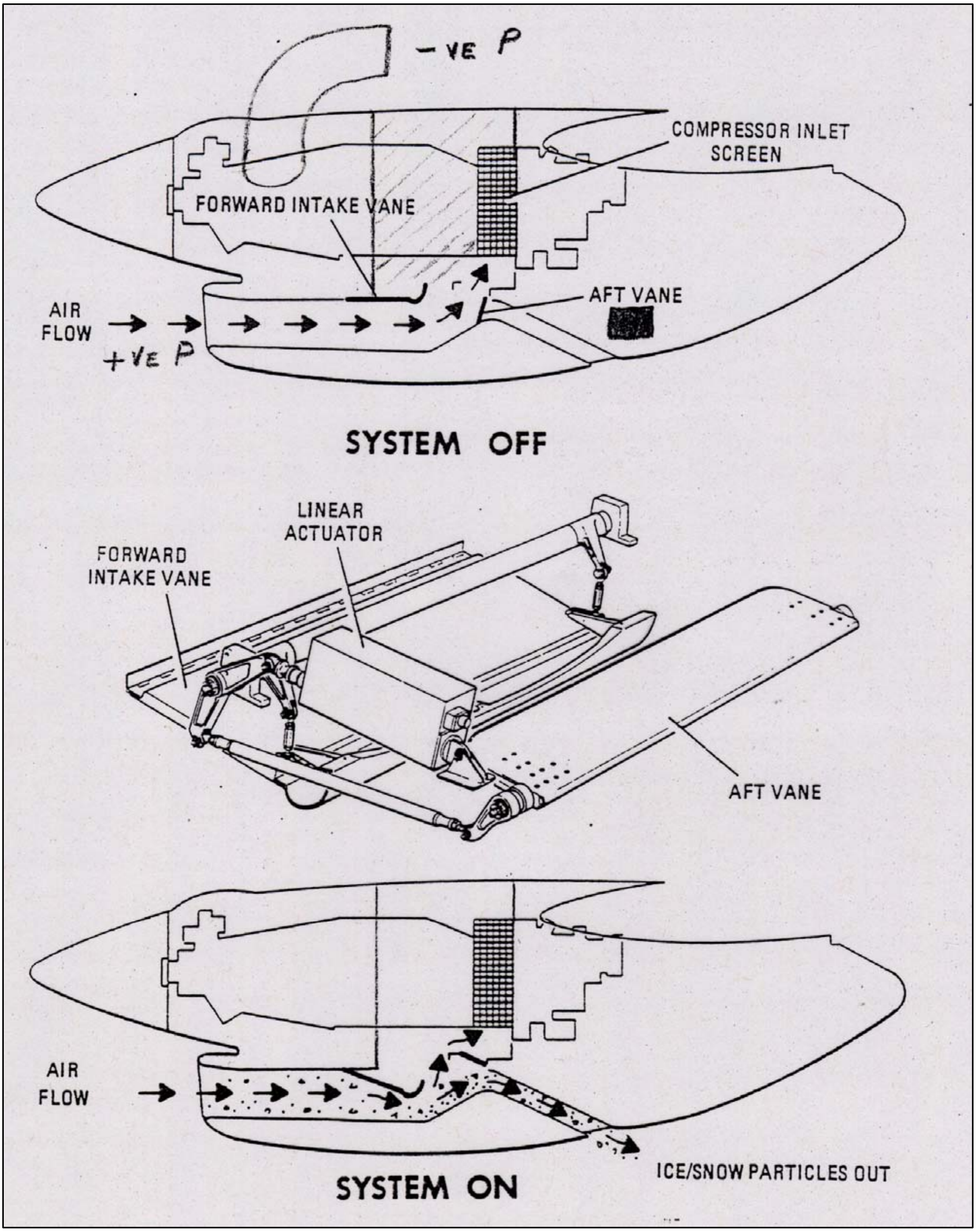

Figure 5: Schematics of Nacelle with Inertia Separator Vanes in Normal (or OFF) Position, above and Deployed (or ON) position below. Plenum Chamber Volume is Shaded in Upper Section., Vane drive Mechanism is Shown in Middle Diagram

Figure 6: Left engine nacelle with external intake and one exhaust stack visible after wreckage recovery

Figure 7: Assembled Nacelle Mock-Up, utilising panels salvaged from wrecked aircraft, incorporating cylinder forming dummy engine. Extractor fan can be seen. Adjustable valve has yet to be fitted to threaded shaft in front of fan. Transparent Plexiglass bulkheads are fitted in place of metal bulkheads at front and rear of plenum chamber (not visible).

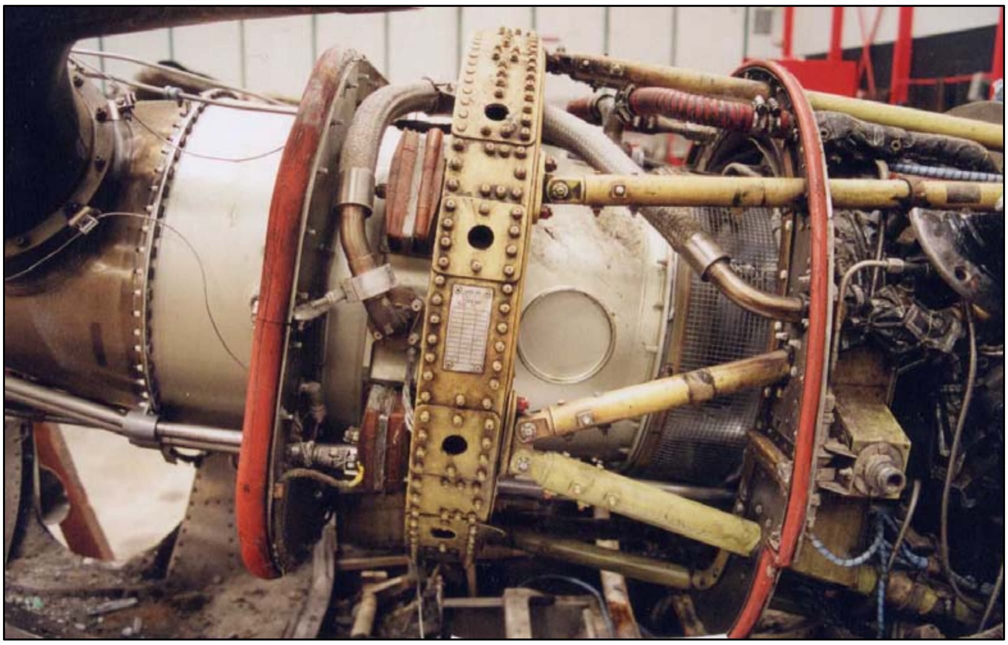

Figure 8: View of Interior of Plenum Chamber with Cowlings Removed. Enclosed Volume is Between Orange Coloured Seals. Exhaust stack Visible at Top Left.