Piper PA60-602P, N64719

AAIB Bulletin No: 2/2002	**Ref: EW/C2000/11/06**	**Category: 1.3**
Aircraft Type and Registration:	Piper PA60-602P, N64719	
No & Type of Engines:	2 Lycoming IO-540 350 HP piston engines	
Year of Manufacture:	1982	
Date & Time (UTC):	30 November 2000 at 1635 hrs	
Location:	Fortingall, Perthshire, Scotland	
Type of Flight:	Private (Ferry)	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew 1 fatal	Passengers N/A
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	FAA Private Pilots Certificate with Instrument and multi-engine ratings plus Austrian Validation certificate	
Commander's Age:	70 years	
Commander's Flying Experience:	Total in Logbook 1,860 hours	
	Last 90 days More than 38 hours	
	Last 28 days - Unknown	
Information Source:	AAIB Field Investigation	

Aircraft Description

The aircraft was an Aerostar Model PA602P built in 1982 and converted to a Model 700 Superstar in 1990 by Machen in the USA. The engines were six cylinder, direct drive, horizontally opposed types, each with twin turbo-chargers, intercoolers and a dual magneto ignition system. Each engine drove a Hartzell three-bladed, hydraulically operated, constant-speed, full-feathering propeller. The leading edges of the wings and empennage were de-iced by inflatable boots; the propellers were de-iced by electrically heated mats bonded to each blade. On this aircraft the windscreen was electrically de-iced.

Fuel system

A total of 130 US gallons of fuel could be carried in the wings, outboard of the engine pylons. Within the fuselage there was another tank holding 43.5 US gallons with a multiple sump assembly beneath it. There was also an auxiliary fuel tank mounted above the main fuselage tank. With the fuel selector 'ON', the wing tanks fed their respective engines and the fuselage tanks fed both.

Each engine had an engine driven fuel pump (EDP) which supplied fuel under pressure to the fuel injection regulator, which measured air flow and metered the correct proportion of fuel to a flow divider. Fuel was then fed to each cylinder via the flow divider. The EDP was a positive displacement, rotary vane pump mounted on the engine accessory case and driven by a splined shaft.

One electric boost pump was installed in each engine fuel supply line to provide fuel pressure for starting and some flight conditions. Once the engines have started, the boost pumps should be left running during the taxi and power checks. The boost pumps should then be switched 'OFF' before take-off so that failure of an EDP to maintain fuel pressure becomes apparent before the aircraft is airborne. The boost pumps should be switched 'ON' again for any climb above 10,000 feet.

Induction air system

Twin turbochargers on each engine used exhaust gas to raise the pressure of the induction air. Automatic waste gates could maintain the take-off manifold pressure to approximately 20,000 feet. The engine induction air system had screens mounted forward of the primary air inlets to prevent ice impingement. If the alternate air supply was manually selected, the fronts of the inlets were blocked off by flaps and air was instead drawn from around the engine accessories at the rear of the engine. Selection of alternate air was controlled from selectors via cables. There were also automatic spring-loaded alternate air flaps located below the induction air filters between the turbochargers and the injector regulators. These flaps should open when the output air pressure from the turbochargers is less than ambient air pressure.

Aircraft history

The aircraft had been retained on the US Register whilst in private ownership within Austria. During the autumn of 2000 it was sold to an American aircraft dealer by an Austrian aircraft dealer who arranged to have the aircraft ferried to New York via Newcastle, Keflavik, Narsarsuak and Goose Bay.

The aircraft was maintained under FAR Part 91 that requires an annual inspection which was last performed on 20 April 2000. A total of nine discrepancies were noted by the inspector but these did not affect the aircraft's airworthiness. The discrepancies included: a suspect engine starter vibrator; a leaking landing gear hydraulic actuator; a time expired ELT battery; loose rivets; an overdue airworthiness directive concerning the combustion heater, which was then deactivated; and an overdue hydrostatic test on the oxygen bottle which was then discharged. At that time the aircraft had flown 2652.5 hours since the 700 Superstar Conversion in 1990 but less than 150 hours since 1996. Both engines had been overhauled between 1994 and 1995; between then and 20 April 2000 the left engine had run for 328.4 hours and the right engine for 463.4 hours. These details were obtained from the inspector because all the aircraft log books and maintenance records were on board and were lost in the post impact fire.

After the annual inspection the aircraft flew for less than five hours before it was flown to the manufacturer's agents in Straubing on 30 June where it was offered for sale. In early October a prospective buyer instructed the Austrian dealer to obtain a pre-purchase inspection. The dealer recommended that the manufacturer's agents should carry out the inspection which they did on 13 October and preparation for export. There were a total of 28 observations in the agent's report regarding the condition of the aircraft but, apart from loose rivets, there was no mention of the nine discrepancies noted in the annual inspection report of the previous April. Notably, however, the report commented that the alternate air flap on the right engine did not close completely and the nose landing gears were stuck because a shear pin had broken. No rectification was carried out by the agents at Straubing.

The aircraft left Straubing on 16 November 2000 and was flown to a maintenance facility in Linz where work was carried out on the following four items: the broken shear pin was replaced on the nose landing gear doors; a new battery was fitted; the R/H starter vibrator was renewed; and the hose to the left-hand engine inter-cooler and oil filter, which had been leaking, was replaced. A subsequent engine ground run was performed. The work order was dated 24 November 2000.

Pilot History

The pilot was an Austrian national who had learned to fly in his fifties. He had carried out several transatlantic ferry flights including seven eastbound and six westbound crossings between September 1992 and September 2000. The last entry in his personal flying logbook was dated 11 September 2000 for a flight in a Beech Bonanza. However, the pilot's friends said that although he flew frequently, he did not log all his flying, particularly flying in aircraft that he did not consider to be high performance types. The relevant totals in the logbook were 1,700 hours pilot-in-command and 1,226 hours instrument flying. His most recent biennial flight review was conducted in a Piper Seneca on 8 November 1999.

The aircraft types in his logbook included aircraft comparable to the Aerostar such as the Beech Baron and the pressurised version of the Piper Aztec. He had also flown as pilot-in-command in high-performance aircraft such as the SOCATA TBM700 turbo-prop and the Cessna Citation Jet. There was no record in the logbook of previous flights in an Aerostar or Superstar. In the days preceding the accident flight, he had removed the Flight Manual and operating handbook from the aircraft and had been studying them at home. The manuals were, apparently, returned to the aircraft for the ferry flight but they were not found within the wreckage; they were probably consumed by fire.

The pilot had once lived in Canada and spoke English well. His FAA Medical Certificate 3rd Class was obtained in the USA and dated 29 April 2000. The certificate was endorsed with a requirement to wear spectacles for near vision and several pairs of corrective spectacles were found in his flight bag. According to the post-mortem report, he was in good health on the day of the accident and a friend, who was with him the night before the accident flight, said that he was not suffering from a head cold. His planned itinerary for the day was to fly from Voslau, a small domestic airfield south of Vienna, to Linz and from there to Keflavik via a refuelling stop at Newcastle. The flight plans presumed a total airborne time of about nine hours.

Events preceding the accident flight

The pilot left his friend's home near Vienna at about 0630 hrs UTC to fly the Superstar from Voslau to to Linz on a VFR flight plan. At Linz he telephoned his friend to say he had arrived safely despite problematic weather and he agreed to telephone again when he reached Newcastle. The aircraft was refuelled before departing at 10:33 hrs on a 790 nm IFR flight plan to Newcastle. The cruising speed was given as 220 KIAS at FL 160 (approximately 16,000 feet altitude) and the time of flight was estimated at four hours. The aircraft landed at Newcastle at 14:30 hrs and was directed to the general aviation apron on the south side of the airport where it was met and marshalled by one of the handling agent's staff. Shortly afterwards the refuelling bowser arrived. The pilot showed the bowser operator the location of the refuelling points and briefed him on the correct order to fill the tanks.

Between 1435 hrs and 1515 hrs all the tanks were filled to capacity with a total of 584 litres of 100LL AVGAS; the fuel capacity of this aircraft was 800 litres. Whilst refuelling was in progress, the pilot visited the handling agent's offices. At the reception desk he asked for weather information which was handed to him, together with relevant NOTAMs and a copy of his flight plan which had been filed in Austria. The pilot flicked through this information pack without appearing to study any one particular document. He seemed to glance at the pages and spent less than one minute looking at all the information. He then left the desk and returned to the aircraft with the information pack. About 10 minutes later he came back to the reception area where he purchased two US quarts of engine oil that he subsequently transferred to the aircraft's left engine. He returned to the building a third time and paid his fuel and handling charges. During this visit he was invited to have a cup of coffee before he departed. The pilot accepted the offer but said that he ought to be leaving soon. He sat down to drink the coffee and flicked through a magazine for about 10 minutes without speaking to anyone. The staff present thought he looked tired and one asked him if he was 'OK'. The pilot replied that he was and shortly afterwards he went to the aircraft. His was the only aircraft on the apron that afternoon and about 10 minutes later the staff heard the engines start and the aircraft departed the apron area with the engines sounding normal. The pilot did not mention any aircraft defects or problems to the agent's staff and they were unaware of any problems with the aircraft. Its laden weight was within the permitted limits and the centre of gravity position was close to the aft limit.

History of the accident flight

Start-up, taxi and take-off were apparently normal with an IFR clearance for a noise abatement right turn-out on track towards the Talla VOR beacon. Soon afterwards the pilot was given clearance to join controlled airspace on track towards Talla at FL 140 and to expect the flight planned level of FL 200 when cleared by Scottish Radar.

As the aircraft was climbing through FL 120 the Talla sector controller first cleared the pilot to climb to FL140 and then almost immediately re-cleared him to climb to FL 200. The pilot replied "ER NEGATIVE I WOULD LIKE TO MAINTAIN ONE FOUR ZERO FOR THE TIME BEING" and the controller granted his request. At 16:21 hrs the pilot transmitted "SCOTTISH NOVEMBER SIX FOUR SEVEN ONE NINE ER REQUESTING HIGHER TO GET OUT OF SOME ICING". Initially the controller offered FL 160 but the pilot replied "IF POSSIBLE TWO ZERO ZERO". Immediately he was given clearance to climb to FL 205, the correct quadrantal cruising altitude.

Recorded radar data showed that for the next six minutes, the aircraft's rate of climb and airspeed were erratic. The pilot made one brief transmission of "SCOTTISH" at about 16:30 hrs but nothing more was said by him or the controller for another 20 seconds. Then the controller said "NOVEMBER SIX FOUR SEVEN ONE NINE ER I SEE YOU'RE IN THE TURN DO YOU HAVE A PROBLEM". There was no reply and so the controller repeated his message, eventually receiving the reply "YES I HAVE ER AN EMERGENCY". The controller asked the pilot to

"SQUAWK SEVEN SEVEN ZERO ZERO" but the pilot replied "HANG ON". By this time the aircraft was descending rapidly in a gentle right turn. The controller twice asked the pilot for the nature of his problem but the pilot asked the controller to 'HANG ON FOR A MOMENT". The controller could see the aircraft was near high ground and losing altitude rapidly. He twice passed messages to this effect to the pilot but he did not receive an immediate reply. At 16:33 hrs the pilot transmitted "CAN YOU GET ME ER SOMEWHERE WHERE I CAN LAND I CAN'T MAINTAIN ALTITUDE AT ALL". Immediately the controller instructed the pilot to take up an easterly heading and gave him the aircraft's position relative to the airport at Perth. The controller then asked the pilot for his flight conditions (twice) to which the pilot eventually replied "I'M COMING OUT OF ER THE CLOUDS NOW" followed by "JUST BREAKING OUT". The controller then said "ROGER DO YOU HAVE ANY POWER AT ALL OR HAVE YOU LOST THE ENGINE". The pilot replied "I GOT POWER AGAIN BUT I HAVE NO CONTROL". That was his last recorded RTF transmission made at 16:34:40 hrs. The final radar return placed the aircraft at an altitude of 3,150 feet overhead Drummond Hill which is on the north bank of Loch Tay, near the village of Fortingall, and rises to 1,500 feet amsl.

Witness reports

Several witnesses in the vicinity of the crash site reported hearing the aircraft and a few saw its lights. The first call to the emergency services was from an eye-witness and timed at 16:39 hrs so the crash probably occurred at about 16:38 hrs. Consequently, the aircraft could have been flying at low altitude in the Fortingall area for up to five minutes. This is consistent with the testimony of several witnesses who heard but did not see an aircraft 'circling' in their vicinity. Most of these witnesses reported hearing 'healthy' engine noises although three reported hearing abnormalities consistent with cyclic changes in rpm.

The aircraft was first seen by a witness on the north side of Drummond Hill on a westerly heading at a height of around 500 feet before it disappeared behind or into a bank of mist. It was also seen heading north at very low height between Fearnan and Drummond Hill by a witness in Fearnan. The witness lost sight of the aircraft behind trees for a few seconds before he saw it falling rapidly. The aircraft burst into flames when it hit the ground.

The owner of the farm house nearest the crash site was in his car about 500 metres north-east of his home when he saw the aircraft coming from the direction of Drummond Hill. He saw it execute a sharp turn before diving and striking the ground. He reported hearing a loud throaty roar from the aircraft's engine just before the crash but he considered this noise was abnormal for an aeroplane, as if the engine had a problem.

Meteorology

An aftercast from the Bracknell Meteorological Office showed a strong south south-south westerly flow in the area between Newcastle and Loch Tay. Rainfall radar pictures showed a disorganised band of rain spreading through the area, probably falling from altocumulus cloud with a base between 8,000 and 10,000 feet. The freezing level was also at about 8,000 feet. The meteorologist stated in his report that "*There was little or no embedded instability*" and "*The temperature profile suggested that freezing rain was unlikely*" although moderate icing was forecast. The 1800 hrs UTC chart of significant European weather, which had been included in the pilot's information pack, forecast moderate icing from below Fl 100 up to FL 200 over central Scotland.

An auxiliary weather observer about three miles south of the accident site stated that the main cloudbase was between 1,500 and 1,800 feet amsl with detached banks of mist at lower altitudes. The visibility was approximately 8 miles although visibility was limited because it was nearly dark. Light to moderate rain had been falling since about 14:30 hrs. The wind was from the south-south west at about 10 kt but the wind strength was probably much greater at altitude. The surface air temperature was 8°C.

Flight data

The aircraft was not fitted with any flight recorders but radio telephony (RTF) recordings of the entire flight and recorded radar data for most of the flight were provided by National Air Traffic Services from tape recordings at Newcastle Airport and the Scottish Air Traffic Control Centre (SCATCC). Radar data obtained from the Lowther Hill and Glasgow Airport antennae were also recorded at SCATCC. Because of range and terrain factors, the Glasgow data did not relate to the start or end of the flight so these data were used to augment the Lowther Hill data.

The two radar recordings did not use the same clock and there were significant time differences between discrete events during the climb and descent phases of the flight. The difference was 48 seconds with events on the Lowther Hill radar appearing to be slow relative to the same events on the Glasgow radar. There were also significant time differences between the RTF clock times and the radar clock times. These differences were approximated from imprecise events such as clearances to turn and climb that would have prompted alterations in the radar derived flight path, and from changes in the transponder code. The Lowther Hill clock seemed to be slow relative to the Newcastle RTF clock by about 45 seconds. The difference between the Lowther Hill and Scottish Centre RTF clocks was more difficult to determine but the radar data clock seemed to be about 45 seconds slow relative to the RTF clock.

The radar data were used to determine elapsed time, track and groundspeed. From these parameters and from meteorological data supplied by the Met Office at Bracknell, heading, true airspeed, equivalent airspeed and vertical speed were calculated. Given the speeds involved, for the purpose of this investigation, equivalent airspeed (EAS) was a close approximation of indicated airspeed (IAS).

On-site examination

The aircraft had initially struck the edge of a forest of pine trees (up to 10-12 metres in height), while descending on a 45° flightpath on a heading of approximately 080°, in a direction away from the tops of the hills above the accident site. The initial impact had disrupted the wings and tailplane. Sections of the left wing, with evidence of impact with the trees and post-impact fire, were found under the trees within the forest, in addition to the left-hand wing tip, left aileron, an outboard portion of the left stabiliser and the left elevator. The right stabiliser also showed evidence of impact with the trees; both the stabiliser and the right-hand elevator were found under the trees. The impact with the trees had released fuel from the wings that had ignited and scorched the trees, but no sustained fire had occurred.

The aircraft had then impacted the ground just clear of the trees in a nominally level, erect attitude and with a low forward speed. Sections from the right wing were found around this impact area. The aircraft had then slid down an incline before coming to rest approximately 60 metres from the initial impact at the base of the trees and slewed to the right on a heading of 100°. The remains of the right wing, with the right engine, had almost detached from the fuselage. The right engine was not significantly damaged by the post impact fire. The left engine had rolled into an inverted attitude on top of the rear fuselage and was severely fire damaged. Fuel from the centre fuselage tank had continued to feed the fire in the main wreckage. The underside of the cockpit had been disrupted in the impact and some instruments (Horizontal Situation Indicator and turn/slip indicator) had been ejected during the ground slide. The cockpit and fuselage area was severely damaged by the ground fire.

Flying controls

The aircraft had dual primary flight controls operated by means of push-pull rods, torque tubes and bell cranks. It was not possible to determine any control malfunction or restriction prior to impact since the elevator and aileron systems were severely disrupted during the initial impact with the trees. The rudder surface was found deflected to the left by approximately 10°. The electrically operated rudder trim tab was found in an approximately neutral position. The hydraulically operated fowler type flaps were up at impact and the landing gear was retracted.

Propellers

The condition of the propeller blades at impact showed some rearwards bending. The left propeller blades exhibited some leading edge damage which was not apparent on the right. Later examination of both propeller hubs at an overhaul facility found that both showed a similar pattern of internal damage indicating that all the blades had been in a fine pitch setting at impact. The right hand propeller governor was tested satisfactorily; the left hand unit was too badly fire damaged to test but it was disassembled and no mechanical failures were apparent. From the damage it was concluded that the left engine was at higher power that the right engine at impact and that neither propeller was feathered.

Engines examination

Left Engine

Strip inspection showed that the left engine had been mechanically sound before the accident. The engine tachometer had stuck at a cruise power setting (2,000 rpm). This supported evidence from the propellers which indicated that the left engine was developing more power than the right at impact.

The left boost pump was damaged in the post impact fire and could not be tested but the pump switch was selected to the 'ON' position. The turbocharger system waste gate actuator was found partially extended (8 mm out of a possible maximum movement of 25 mm) and the left-hand turbocharger waste gate was open. This was consistent with a low power, or low altitude condition.

Right Engine

Strip inspection of the right engine showed that it had been mechanically sound before the accident and could still be turned. The engine tachometer was indicating a low power setting (750 rpm). This supported evidence from the propeller of low power at impact. Both magnetos were tested satisfactorily and the engine spark plugs appeared normal. The fuel injector was tested and operated satisfactorily. The throttle position, as found, was near to the closed position, although this could have moved during the impact because the plastic sleeve on the Idle Cut-off (ICO) stop was bruised and had been struck by the throttle.

The turbo-charging system waste gate actuator was found retracted with the right hand turbocharger waste gate open; this was consistent with a low power, normally aspirated condition. However, since the actuator was spring loaded to this position, it could also have been consistent with engine shutdown. The left-hand turbocharger waste gate was free to move and therefore gave no indication of its position at impact. There was a pre-existing hole in the right-hand turbocharger waste gate which appeared to have been caused by corrosion. This would have had some effect on the performance of the turbocharging system at altitude.

Manual selection of alternate air was controlled from selectors via cables that appeared fully functional. The position of the alternate-air inlet-flap was consistent with alternate air having been selected on the right engine. However, subsequent information regarding the pre-flight condition of the aircraft suggested that this flap did not close completely as it should. The effect of this would have been to allow some alternate air to enter the induction system at all times.

The right boost pump was tested and still functioned but its switch was damaged. As found, the switch position did not give a reliable indication of the selection at impact. The engine driven pump (EDP) was tested and fuel was found to be leaking from the air side of the pump at low rpm. At cruise or maximum power, the pump maintained fuel pressure (if primed by the electric boost pump) with no leakage. However, at low rpm, the EDP could not maintain pressure and fuel leaked out through the connection port, which had a small orifice and was open to atmosphere.

The right engine EDP

Disassembly of the EDP revealed a tear in the diaphragm between the fuel and air sides of the pump. The diaphragm consisted of two layers of butyl rubber with reinforcing fibres. Examination of the tear by a materials specialist revealed that:

> *'Both layers of the diaphragm had failed almost co-incidentally, centred on a sharp change in profile. Adjacent to the failure these regions exhibited evidence of degradation in the form of cracking and cavity formation apparently associated with a mineral filler material at the surfaces of the sheets.*
>
> *Examination using scanning electron microscopy (SEM) demonstrated the cracking at the filler particles and the corrosion deposit on the outer layer from the spring assembly. The split surfaces were generally free from deposits but out of the entire rupture lengths of approximately 15 mm the central 7 - 9 mm exhibited a dark stain on the two inner surfaces adjacent to the splits. Within this zone, the reinforcing fibres exposed by the splits appeared less prominent and their ends were mechanically damaged, particularly in the central 4 mm. Beyond this region, the rupture deviated from the profile change in the diaphragm and the fibre ends were relatively undamaged.'*

The materials specialist concluded that the tear appeared :

> *'To have occurred progressively over a significant period of use. Mechanical degradation in the form of de-cohesion of the mineral particles in the surface regions was the initiating factor, caused by the continual flexing of the diaphragm. It is likely that these cracks propagated through the layers, although the fibre reinforcement would have failed later, again progressively. Thus, initial leakage would have been very small with slow growth up to the extent that the split still*

followed the profile of the layers. At this point, a major increase in the size of the rupture appears to have occurred, probably resulting from failure of the last of the fibres within the initial region.'

As part of the fuel system, the EDP should have been inspected annually but in practice, the EDP would be an 'on-condition' item since a diaphragm failure would only be detected during engine operation. The EDP would not be removed or disassembled as part of the annual check.

Failure of the EDP

The failure of the right EDP diaphragm had occurred progressively over a significant period of time. Probably a small leakage would not have caused sufficient loss in fuel pressure for the right engine to stop and so would not have been apparent to the pilot (and could have been present for a long period of time). It is therefore probable that the major increase in the size of the rupture occurred during this flight.

At the time of the initial problem, the aircraft was in the climb and above 10,000ft; therefore, the fuel boost pump switches should have been at 'ON'. This would have ensured fuel pressure to the fuel injection system for the right engine despite any failure of the engine driven pump. The left switch was found selected 'ON', and although there was no reliable indication of the selection on the right switch, it would have been entirely logical for the pilot to have selected it 'ON' at the same time as the left. If he had turned the pumps on at the correct time and left them 'ON', subsequent failure of the engine driven fuel pump on the right hand engine should have had no effect. If, however, he had not selected the boost pumps 'ON' as he started to climb from Fl 140, the right engine may have suffered fuel starvation at the higher power setting required for the climb. The pilot may then have experienced asymmetric power/control problems.

Flight path analysis

From the time the aircraft was first detected by Lowther Hill's secondary radar until it climbed through FL80 at 15:55 hrs, the aircraft climbed at a steady rate of 850 fpm and the airspeed was close to 120 KIAS. As it passed through FL 80, the rate of climb reduced to about 750 fpm although the airspeed remained much the same. At 15:59 hrs, as the aircraft climbed through FL 106 the radar data showed a significant and sustained reduction in rate of climb from 750 fpm to 525 fpm and a slight reduction in indicated airspeed from 120 to 115 KIAS.

The aircraft reached FL 140 at 16:04 hrs and then accelerated in level flight to an indicated airspeed of about 180 KIAS. This cruise speed was consistent with a 75-percent power rating. The radar data showed the pilot maintaining a straight track towards Talla and a strong tailwind component was contributing to a groundspeed of about 245 kt. These conditions were maintained until about 16:16 hrs when a trend of decreasing airspeed became evident. The rate of decrease was slow and at a steady rate of 4 kt/min.

During its climb from FL 140 the aircraft's vertical speed was never greater than 500 fpm upwards with short periods of level flight and two brief periods of descent at a rate of about 500 fpm. In those six minutes, the aircraft climbed to a peak of FL 161 and the airspeed reduced from 140 KIAS to about 120 KIAS. At 16:27:40 hrs the aircraft's rate of descent began to increase markedly and it started a turn to the right. The vertical speed was almost 6,000 feet per minute downwards and the onset coincided with the start of the right turn. The airspeed at this time was about 120 KIAS; the normal clean stall speed is 88 KIAS. At the final radar return the aircraft was flying level or almost level at about 90 KIAS having lost more than 12,000 feet altitude in the preceding 4 minutes. There were no indications within the radar data that the aircraft had been spinning and its bank angle had probably not exceeded 45°. The flight path was fully consistent with a stall and subsequent control difficulties. The most obvious contributory cause for losing control well above the normal stalling speed was ice accretion and this would have been consistent with the pilot's expressed intention of climbing to escape icing conditions.

The vertical speed during the descent was erratic but the overall trend was a reduction in rate of descent to about 1,000 fpm or less by the time of the last radar return. The airspeed trend during the same period was less erratic and showed a consistent, linear reduction. Therefore, the pilot's declaration of "I HAVE NO CONTROL" reflected a persistent rather than a transient condition, and there may have been a partial restoration of engine power during the descent.

A diagram showing the aircraft's flight path over the ground together with altitudes amsl is shown at Figure 1 *(JPG 494kb)*. The position data were derived from the Lowther Hill radar because the Glasgow radar lost contact with the aircraft below FL 90. Not all RTF messages are shown but where they are shown, the difference between the RTF and radar clock times has been corrected by adding a nominal 48 seconds to all the radar data times.

Flight anomalies

There were four anomalies during the flight. Firstly, the pilot's wish to remain at Fl 140 instead of immediately climbing to the flight planned level of FL 200. Secondly, the aircraft was capable of coping with forecast light to moderate icing conditions yet it appears to have failed to do that. Thirdly, the pilot was unable to regain control after stalling. Many icing encounters have resulted in a stall but if sufficient height is available, control is often recovered after losing a few thousand feet (eg see AAIB Report 4/92). Finally, the aircraft seems to have climbed and descended at unusual combinations of airspeed and vertical speed, both before and after control was lost.

The pilot should have been able to climb to his planned cruising level of FL 200 using constant climb power so there was no obvious explanation for his expressed wish to remain at FL 140. One reason might have been related to the significant and sustained reduction in rate of climb and airspeed as the aircraft climbed through FL 106. If he had not switched on the electric boost pumps, and the EDP diaphragm had ruptured at that stage, he would have lost power from the right engine. Faced with a long and dark ocean sector, he was unlikely to have continued the flight. Consequently, his desire to cruise at FL140 was probably related to a weather issue or perhaps to a heating or pressurisation problem. Alternatively, he may have been concerned by some minor fault which, lacking familiarity on type, he might have thought was related to an error on his part. Moreover, it is possible that he was distracted by a trivial issue and did not notice a change in the ice accretion rate.

Ice accretion

Icing could have affected the aircraft in several ways. Firstly, there could have been a general build-up over the airframe leading to a reduction in aerodynamic efficiency and an increase in weight. Secondly, an accumulation of ice aft of the leading edge de-icing boots would have aggravated the aircraft's aft centre of gravity position and degraded pitch control. Thirdly, icing could have jammed some of the flight controls or caused them to overbalance (a tendency to move to full deflection which has to be resisted by the pilot). Fourthly, icing could have choked or clogged the air intakes of the engine turbo-chargers and finally, a combination of two or more of these factors could have occurred. A warning in Aerostar Airworthiness directive 98-04-23 states:

> *"Severe icing may result from environmental conditions outside of those for which the airplane is certificated. Flight in freezing rain, freezing drizzle or mixed icing conditions (supercooled liquid water and ice crystals) may result in ice build-up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. This ice may not be shed using the ice protection systems, and may seriously degrade the performance and controllability of the airplane."*

Icing Conditions

The Bracknell meteorologist considered that the possibility of rapid ice accretion was low. The steady reduction of airspeed over five minutes was consistent with a prolonged rather than a rapid ice encounter. The pilots of another aircraft at FL150 heading south in the same area stated that they encountered light to moderate icing. The Superstar pilot may not have noticed a slow ice build-up because he was tired, the autopilot was engaged (masking any trim changes), the daylight was fading, he might have been in thick cloud and he might have been engrossed in troubleshooting another problem. If he had used them correctly, the de-icing boots should have coped with light to moderate icing but it was not possible to determine from the aircraft remains the overall condition, serviceability and selection of the de-icing boots.

Variable airspeed and vertical speed

The pilot should have been able to climb to his planned cruising level using constant climb power so once climb power was set, he was unlikely to have throttled back during the climb. Between 4,000 feet and 8,000 feet the rate of climb was steady at about 800 fpm and the airspeed was also steady at 120 KIAS, which is approximately the best rate of climb speed. As the aircraft climbed through 8,000 ft, there was a small but definite reduction in the rate of climb to about 700 ft/min. With the freezing level at about 8,000 feet, this could be consistent with switching on the anti-icing systems or cabin pressurisation. The airspeed then reduced slightly to between 110 and 115 KIAS for a constant rate of climb up to 13,000 feet. The steadiness of the track flown and vertical speeds during the climb suggest that the autopilot was engaged in vertical speed mode at a constant power setting.

Within the last 500 feet of the climb to FL140 there was a marked increase in airspeed of about 20 KIAS although the rate of climb remained constant. This anomaly was confirmed by data from both radars. Unless the pilot decided to increase power for the forthcoming cruise, which seems very unlikely, the only logical explanation is a change in the wind conditions. As the acceleration began, the aircraft was about 5 nm south-east of Hawick and heading north-west. In that area it was between 5 and 10 nm north of the line of Cheviot Hills that run west to east, approximately along the latitude 55° 17' N, and rise to nearly 2,000 feet amsl. With a 35 kt wind from the south at 2,000 feet and a 40 kt wind at 14,000 feet from 200°T, the probability of orographic lift in this area was significant. With the autopilot set to provide a rate of climb, extra energy from orographic lift would have been converted to airspeed.

In his report, the meteorologist stated :

"There was a high probability of super-cooled water droplets in the altocumulus cloud up to and around 12,000 feet. It is known that if clouds are associated with active fronts and particularly if there is an orographic effect due to the proximity of mountains, the chance of severe icing is much increased.

The aircraft remained at FL 140 for over 11 minutes where the calculated outside air temperature was minus 12°C. Between Hawick and Dunfermline, its average speed was fairly steady at 180 KIAS with two noticeable excursions to 170 KIAS and 190 KIAS. The latter excursion immediately preceded the onset of the slow decline in airspeed at FL 140 from 180 to 160 KIAS. It began overhead the Kirknewton gliding site which is about 5 nm south of Edinburgh airport and just to the north of the Pentland Hills which rise to 2,000 feet. That was the geographic point at which the icing seems to have begun, and it continued as the aircraft crossed the Firth of Forth. The aircraft was west abeam Glenrothes when the pilot decided to climb.

The strength of the orographic lift which accelerated the aircraft near Kirknewton was probably sufficient to carry super-cooled water droplets up to FL140 and this may explain the presence of severe icing which could have overwhelmed the aircraft's ice protection systems.

Conclusion

On vacating FL140, the aircraft's climb rate was so erratic at 140 KIAS that it seems likely that by then, the aircraft had already gathered sufficient ice to seriously affect its performance. If all the turbocharger inlets had become partially blocked, then manually selecting both engines to alternate air induction should have introduced warmer air into the turbochargers and restored power.

The description of engine operation in the Superstar manual states:

'If manifold pressure continues to decrease after opening the manual alternate air, it is an indication that turbocharger inlets are still restricted and the engine may become normally aspirated through the automatic alternate air door located below the induction air filter'

Normal aspiration reduces the manifold pressure to ambient or less and at FL140 the ambient pressure is about 17.6 inches which is less than half the climb rated manifold pressure. That might explain the inability to climb above FL 160 but it would also have deprived the pilot of pressurisation. There was no change in his voice consistent with donning an oxygen mask so he may not have lost pressurisation completely. Nevertheless, since he lost control at around FL160 and 110 KIAS, and because the aircraft initially turned to the right, a combination of airframe icing and asymmetric power loss seem the most likely explanation for the sustained loss of control. The split in the EDP diaphragm which almost certainly occurred during this flight may have contributed to an asymmetric power problem. Alternatively, the pilot might have become mildly hypoxic and decided to begin an emergency descent. If so, he did not declare an emergency at the time he started to descend, although he did utter the word "SCOTTISH" after control was lost, so he was conscious even if his mental abilities had been impaired by hypoxia. On balance, the tone of his voice and his initial failure to respond to ATC messages suggested that the descent was begun through loss of control rather than a deliberate act followed by loss of control.

At the time of the accident the aircraft had been flying below the freezing level (8,000 feet) for about five minutes and much of the airframe and induction system ice may have melted. The would-be rescuers would have taken at least five minutes to reach the crash site and so the fact that none of them reported seeing or treading on any ice was not surprising. Witness and propeller evidence indicated that power had been restored on at least one engine but there seemed to be insufficient power to climb out of Glen Lyon. The aircraft was out of control when it crashed at low speed from a sharp turning manoeuvre. Before this manoeuvre the pilot may have had partial control, albeit with a power problem which prevented him from climbing, and he finally lost control totally when he attempted to turn around within the confines of the Glen. He had no choice but to attempt the turn since, had he not turned, he would have flown into the side of the hill above the crash site.

Summary

Although he was fit and well, the pilot had already had a challenging day when he arrived at Newcastle Airport. On the ground at Newcastle he appeared tired and he did not spend long studying the forecast en-route weather conditions for the intended flight to Iceland.

Icing conditions over Scotland were forecast up to FL 200 and encountered at FL 140. The aircraft should have been able to cope with light to moderate icing conditions but the post accident fire precluded any functional assessment of the airframe de-icing system. Inspection of the aircraft a few weeks before the ferry flight revealed several technical defects including a fault within the right engine alternate air mechanism which was a part of the aircraft's icing protection systems. The pre-existing deterioration of the diaphragm within the right engine driven fuel pump was unlikely to have been detectable during the inspection.

For reasons unknown the pilot elected not to climb to the flight-planned level of FL200 when clearance was offered and he was re-cleared to cruise at his requested level of FL 140. Radar derived speed data showed that he gradually lost airspeed at FL140 in an icing encounter aggravated by orographic effect as he flew over high ground in the presence of strong southerly winds. When the pilot decided to try and get clear of icing conditions he opted to climb but the aircraft's performance had already been badly affected by icing, probably through a combination of airframe and induction icing. Whilst struggling to climb it is possible that the right engine-driven pump-diaphragm burst. If the electric boost pump was off at the time, the pump failure would have resulted in an instantaneous power loss from the right engine until the electric pump was turned on.

The aircraft appears to have stalled at a speed above the normal stalling speed due to airframe icing. Either the stall or the fuel pump failure precipitated an uncontrolled turn to the right that coincided with the onset of an initially rapid descent. Apparently both aerodynamic and engine control were fully or partially forfeited in a prolonged spiral descent that was probably aggravated by a rearward shift in the centre of gravity position and a marked increase in weight due to ice accretion. The rate of descent diminished as height was lost and some power was restored but the spiral dive terminated within the confines of Glen Lyon where the weather was poor and the daylight fading. The ATC controller did all that he reasonably could to assist the pilot but lacking sufficient power to climb, full aerodynamic control and sufficient visibility for the pilot to see his way out of the Glen, a crash was inevitable.