ACCIDENT

Aircraft Type and Registration:	Diamond DA 40 D, G-ZANY
No & Type of Engines:	1 Thielert TAE 125-01 diesel piston engine
Year of Manufacture:	2003
Date & Time (UTC):	30 December 2006 at 1215 hrs
Location:	Near Southwoodham Ferrers (approximately 8 miles NW of Southend)
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damage to front of aircraft, nose gear and left wing
Commander's Licence:	Private Pilot's Licence
Commander's Age:	61 years
Commander's Flying Experience:	14,455 hours (of which 232 were on type) Last 90 days - 12 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and subsequent enquiries by the AAIB

Synopsis

Whilst conducting steep turns, the engine lost power, forcing the pilot to make an emergency landing in a field. The aircraft landed long and the pilot was unable to prevent it colliding with a boundary hedge. Despite damage to the aircraft the occupants were uninjured. Evidence suggested that the engine had been starved of fuel, possibly by air entering the fuel system, but the cause of this could not be determined with any degree of certainty.

History of the flight

The accident occurred whilst performing a handling exercise on the return leg of a trip from Stapleford Aerodrome, Essex, where the aircraft was based, to Lydd Airport, in Kent.

The passenger, a current PPL holder with over 2,200 flying hours, was the handling pilot for the exercise which was conducted in the vicinity of Hanningfield Reservoir, to the north-west of Southend Airport. All indications were normal until the general handling exercise was performed. Fuel had been transferred from the right to the left tank five minutes previously. The left tank quantity indicated slightly less than half full and the right approximately one third full. The pilot first performed a clean stall and recovery, followed by a steep turn to the right.

He then made a steep turn to the left up to a load factor of approximately 2g, advancing the power lever from around 80% to 100% in one to two seconds. During this manoeuvre the engine momentarily shuddered. He performed a second steep turn to the left, and the engine shuddered once more and, again, momentarily, during subsequent operation of the engine power lever. The commander briefly observed propeller overspeed and engine power exceedance cautions and announced this to the pilot. The pilot lowered the nose of the aircraft to gain airspeed to perform a wingover-type manoeuvre, at which point both occupants became aware that the engine had suffered a significant loss of power.

The Engine Control Unit (ECU) switch was selected to 'ECU 'B[1] in an attempt to resolve the problem, but this proved ineffective. Shortly thereafter, 'ECU A' and 'ECU B' caution annunciations appeared, the engine power indication fell to 7% and the engine ceased to respond to power lever changes. Neither pilot reported seeing or hearing any low fuel annunciations prior to the loss of engine power.

An emergency was declared to Southend Airport and preparations were made for a forced landing in a field. The approach speed was high and the aircraft touched down well into the field; there was insufficient distance available to stop and the aircraft struck a hedge and a small ditch. This caused the nose gear to collapse rearward, damaging the propeller, lower front fuselage and left wing. The aircraft remained upright, there was no fire and the occupants, who were uninjured, exited the aircraft normally. The emergency services attended the scene promptly.

Footnote

[1] The ECU electronically controls the manifold pressure, fuel rail pressure (which determines the quantity of fuel injected) and propeller speed, according to the power lever position. It has two independent channels, designated 'ECU A' and 'ECU B'.

Aircraft information

General

The Diamond DA 40 D is a diesel engine powered, composite construction, four-seat low-wing monoplane aircraft. It is certificated in the JAR-23 'Normal' and 'Utility' airworthiness categories, with bank angles of up to 90 degrees being permitted.

Powerplant

The TAE 125-01 engine is a liquid-cooled, four-cylinder, four-stroke, turbocharged common-rail direct injection diesel engine, designed to run on Jet A-1 fuel. It is rated at 99 kW (135 DIN HP) at 2,300 rpm at sea level, ISA conditions. The engine drives the propeller via a 1:1.69 reduction gearbox; the maximum allowable continuous propeller speed is 2,300 rpm, corresponding to an engine speed of 3,900 rpm. The three-bladed, variable-pitch, wood-composite propeller is hydraulically regulated and the propeller governor system has its own independent oil supply. The engine and propeller are controlled electronically by a digital ECU.

The ECU has two independent channels, designated ECU A and ECU B. The engine is normally controlled and regulated by ECU A, with ECU B provided for redundancy. An ECU 'swap' switch allows the pilot to select between automatic and manual ECU control. The switch is normally set to AUTOMATIC, in which case ECU A assumes control. If a failure is detected, ECU B will automatically take control. If the automatic switch-over should fail, the pilot must manually select ECU B. The ECU has fault recording and data-logging capabilities, to aid in troubleshooting engine faults, and the data can be downloaded for post-flight analysis. The ECU does not monitor or record fuel quantity data.

Engine parameters are presented on two display panels in the cockpit: the Compact Engine Display (CED) and the Auxiliary Engine Display (AED). The CED displays engine parameters, including engine speed and engine load as a percentage (derived from the manifold pressure) and the AED displays fuel system and electrical system information.

Fuel system (Figure 1)

The fuel is contained within aluminium tanks located in each wing. The tanks are mounted between the front and rear wing spars and are relatively long in the spanwise direction, narrow in the chordwise direction and fairly shallow. G-ZANY was equipped with the optional long range tanks and thus has two tanks in each wing. The inner and outer tanks are interconnected by a large diameter hose. Each inboard tank has a capacity of 56.8 litres, of which 53 litres is useable and each outboard tank has a capacity of 20.8 litres. The total usable fuel available with long range tanks is 147.6 litres. The fuel quantities in the main and auxiliary tanks are sensed by capacitance probes and the quantities are indicated on circular LED bar-type gauges. The gauges indicate up to a maximum of 15 USG (57 litres); there is no indication for the fuel quantity in the outer tanks. If the useable fuel in the main tank drops below 3 USG (11.5 litres) +2/-1 USG (+7.6/-3.8 litres), an amber LOW FUEL message will illuminate on the central annunciator panel, accompanied by a momentary aural alert via the intercom. According to the Airplane Flight Manual, the indication is calibrated for straight and level flight and may be triggered in unbalanced turns with fuel levels greater than this threshold. When the main tank is empty, a red warning message will appear, accompanied by a continuous aural tone. The low level caution and warnings are driven by independent sensors.

The engine is supplied with fuel from the left wing inboard tank only, which is designated the main tank. The right inboard 'auxiliary' tank feeds the main tank

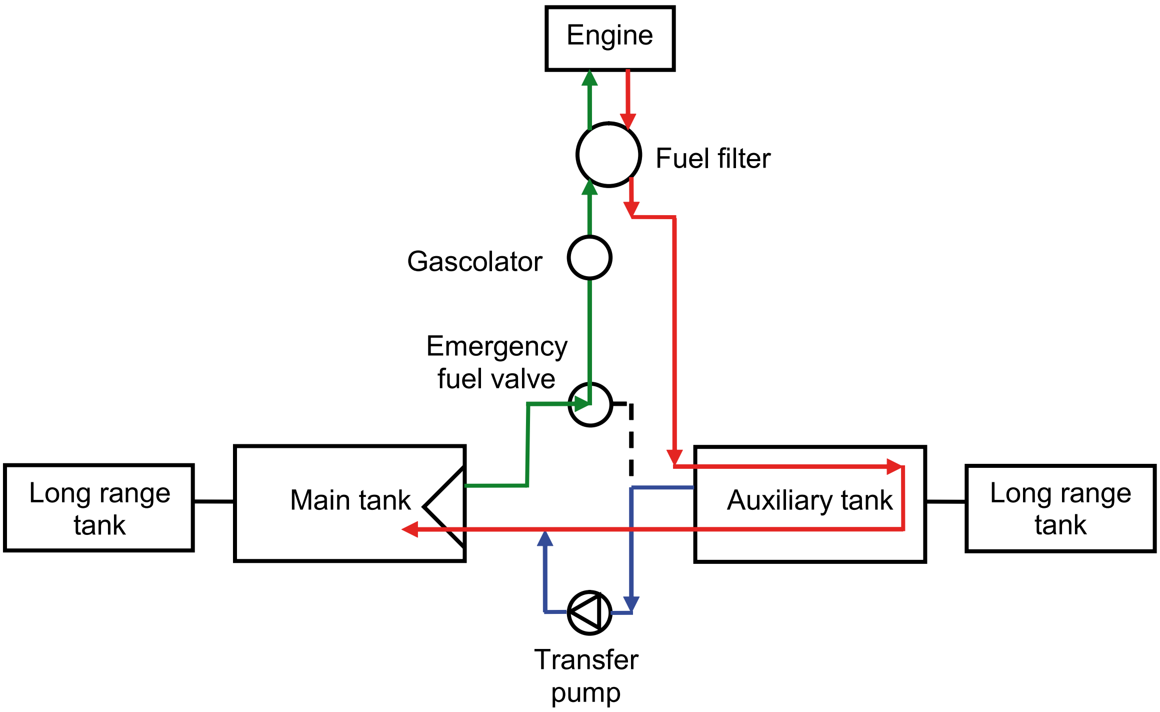

Figure 1

Fuel System Schematic

and the pilot must periodically transfer fuel from the auxiliary tank to the main tank as the engine consumes fuel. The fuel is transferred via an electrically driven transfer pump, operated by a switch in the cockpit. Any unused fuel from the engine fuel rail is returned to the main tank and, as the fuel may be hot, it is cooled by routing it through the auxiliary tank.

The fuel system is not equipped with a boost pump, but the engine is fitted with two engine-driven pumps which draw fuel from the left wing tank. A low pressure pump feeds a high pressure pump, which provides the high pressure fuel to the common rail for the injectors; these inject fuel directly into the cylinders. The fuel pressure in the common rail typically ranges from 600 bar at idle, to 1,350 bar at maximum power. The ECU controls the rail pressure via an electronic valve. This varies the return fuel flow rate in accordance with the power lever position, by comparing the measured or actual common rail fuel pressure with the computed target value, based on the power lever setting. If the difference between the two exceeds a specific threshold, an ECU caution annunciation is triggered.

Prior to reaching the engine, the fuel passes through a gascolator and a filter module. The gascolator is located at the lowest point in the fuel system, under the fuselage, approximately 30 cm forward of the wing leading edge. The filter module is mounted high up in the engine compartment with the fuel inlet and outlet connections being made to the lid of the filter canister.

Each inboard tank incorporates a fuel trap, which comprises an open-topped, sheet aluminium container welded to the tank inboard rib. This is designed to ensure that the engine is always provided with a supply of fuel during transient manoeuvres.

Fault annunciation

The aircraft features a centralised fault annunciation system which presents the pilot with visual and aural cues when certain system failures or conditions are detected. A warning is visually indicated by a flashing red WARNING legend and a flashing red legend for the affected system; both are displayed on a central annunciator panel and are accompanied by a continuous aural tone on the intercom. A caution is annunciated by a yellow CAUTION legend, accompanied by a flashing yellow legend for the affected system, together with a momentary aural tone.

Aircraft fuelling history

A review of the aircraft fuelling records showed that, on 28 December 2006, the aircraft was filled to full (ie, 155 litres, of which 147.6 litres were useable). The commander of the aircraft and an independent witness observed the refuelling and confirmed that the tanks were filled to the brim. The aircraft completed four flights that day, with a total block time of 3.5 hours; it did not then fly again until the day of the accident when it flew the outbound leg to Lydd, with a recorded block time of 45 minutes. The duration of the subsequent accident flight was approximately one hour.

The total recorded block time since previous refuelling to full was therefore 5.25 hours. If an average fuel consumption of 19 litres per hour is assumed, for a cruise power setting of 75% engine load (as quoted in the DA 40 D Airplane Flight Manual), the aircraft should have had an endurance of approximately 7.75 hours with a full useable fuel load of 147.6 litres. Based on available information, at the time of the accident the aircraft should have had fuel remaining on board for approximately 2.5 hours of flight, amounting to approximately 50 litres.

Aircraft examination

General

Several days elapsed before the aircraft could be recovered, after which it was placed in a hangar where it was examined by the AAIB.

Fuel system examination

It was reported by the engineer who drained the fuel tanks prior to recovery that the main (left) tank was found to be almost empty and the auxiliary (right) tank contained an estimated 20 litres of fuel.

The fuel pipes between the main tank and the engine were blown through and found to be free from blockage. The fuel tank vent lines and the fuel transfer pipe between the auxiliary tank and the main tank were also confirmed to be free from blockage. The integrity of the fuel tanks in each wing was checked by sealing the tank openings and lightly pressurising the tanks; no leaks were found.

Borescope inspection of the main tank showed that it was free of debris and that the fuel trap appeared to conform to the manufacturer's drawings. The finger filter in the main tank fuel outlet was removed and found to be clean. The gascolator was also clean, and no evidence of water contamination was found. The drain valve was badly distorted and jammed open, having been struck by the nose landing gear as it collapsed rearwards on impact. A test showed that fuel leaked from the valve at a rate of approximately two litres per hour. The fuel filter element was also clean, but it was noted that the filter canister contained only a small amount of fuel, Figure 2. According to the aircraft manufacturer, it would normally contain between 250 to 300 millilitres of fuel. The fuel transfer pump operated satisfactorily when tested.

Figure 2

Fuel filter canister showing small amount of fuel present, as found

Engine and ECU testing

The engine and ECU were tested at the engine manufacturer's facility in Germany. This was overseen by the AAIB and representatives from the German Federal Bureau of Aircraft Accident Investigation (Bundestelle fuer Flugunfalluntersuchung, BFU). The engine was tested in accordance with the company's production acceptance test procedure and, after purging the fuel lines of air by cranking the engine with the starter motor, it started and ran normally. It produced the nominal rated power of 135 HP and no faults were recorded by the ECU. The engine responded satisfactorily to changes in power demand, even with rapid movements of the power lever.

Additional tests were performed to explore what effect air in the fuel might have on the behaviour of the engine. This was achieved by loosening one of the clamps on the fuel supply hose to the engine and manipulating it until air was drawn into the hose. Whilst it was not possible in the test cell to reproduce exactly the conditions in flight, it was thought to provide a general indication of what might be expected. The engine was found to be very tolerant to air in the fuel supply. Small air bubbles entrained in the fuel passed through the engine with little or no effect. Larger bubbles were also tolerated, although the engine was heard to hesitate, before recovering. It was only when larger 'slugs' of air were introduced into the fuel hose that the engine ran down and stopped.

ECU downloaded data

A copy of the ECU data log for the accident flight was provided to the engine manufacturer for processing and review. The data shows that, until the point of power loss, the measured fuel rail pressure closely matched the target fuel rail pressure, signifying that the engine was responding normally to power lever demands. However, at the point of power loss, the measured fuel rail pressure diverged from the target pressure and fell rapidly to, and remained at, around 130 bar. According to the engine manufacturer, this was indicative of the engine being starved of fuel.

Manufacturer's flight tests

On 26 June 2007, at the AAIB's request, the aircraft manufacturer conducted a flight test to investigate the effect of steep turns with a similar fuel load to that estimated to have been on board G-ZANY at the time of the incident. The test was performed on a new production aircraft with a fuel load of 5 USG (19 litres) in the main tank and 5 USG (19 litres) in the auxiliary tank. Although this aircraft was equipped with standard, rather than the long range tanks, it was considered to be acceptable for comparative purposes.

A series of steep 360º turns to the right and left were performed both with and without slip. In balanced turns of up to 70º bank angle in either direction, the engine ran normally and no abnormal fuel indications were observed. It was possible to perform five consecutive, balanced, steep turns to the left with no adverse effect on the fuel system or engine operation.

When performing 360º steep turns to the left, with slip induced to the outside of the turn by applying rudder, the left fuel indication dropped to 3 USG after 1½ turns; the amber fuel caution illuminated and the aural warning sounded. A profile was flown which included one steep 360º turn to the right, followed by two steep turns to the left, to simulate, as far as possible, the flight conditions leading up to the incident. These were flown firstly with no slip, then with rudder-induced slip to the outside of the left turns. No unusual behaviour was noted with the engine when this was performed without slip.

However, when slip was applied in the left turns, after one 360º orbit the left fuel tank quantity indication fell to 3 USG and the amber low fuel caution annunciation illuminated. After two orbits, the left tank quantity indication dropped to zero and the red low fuel warning annunciation also illuminated. The test was halted after 2½ orbits to the left. The engine performed normally throughout this test, with no speed fluctuations or signs of shudder.

Subsequent incident

On 7 June 2007, a Danish registered DA 40 D landed in a corn field, short of its intended destination at Copenhagen, when the engine failed to respond to throttle lever inputs, and produced only low power. The aircraft was not damaged. After the incident there was found to be 45 litres of fuel in the main tank and 52 litres in the auxilary tank.

Analysis of the ECU data by the engine manufacturer revealed that, about the time of the power loss, the fuel rail pressure had dropped to a minimum of 130 bar. Examination of the aircraft revealed no evidence of mechanical or electrical failures and, after removing and replacing the fuel filter bowl and bleeding the fuel system, the engine started and ran normally. It was concluded by the engine manufacturer that the total loss of power was caused by fuel starvation at the engine fuel pump, and that air may have been introduced into the system.

Analysis

The downloaded data from the ECU show that the engine was performing as expected up to the time that the actual fuel rail pressure dropped to 130 bar; this is consistent with the pilots' reports that the engine performed normally until the general handling manoeuvres were flown. The tests on the engine and ECU did not identify any faults and it is therefore reasonable to assume that the engine and ECU were not the cause of the loss of power.

If the fuelling record information and aircraft utilisation information are accurate, the aircraft should have had sufficient fuel on board for the flight. However, as most of the fuel in the main tank had leaked out via the damaged gascolator drain valve, it was not possible to determine the actual fuel quantity in the main tank at the time of the accident. It is therefore significant that the fuel filter canister was found to contain very little fuel. Given that the aircraft remained upright and that the fuel inlet and outlet are on the top of the filter module, it is unlikely that the fuel had leaked out after the accident. The small volume of fuel found in the module seems to indicate that the engine suffered fuel starvation. This possibility is supported by the ECU data, which shows a large and rapid drop in fuel pressure to 130 bar, well below the normal 600 bar rail pressure when the engine is at idle. This low pressure would be expected if air had been ingested into the fuel system. Detailed examination of the fuel system did not identify any blockages or obvious defects in any of the fuel delivery system components; these were therefore considered unlikely to have caused the loss of engine power.

The possibility that fuel starvation could have occurred due to fuel flowing away from the pickup in the main tank (if the steep turns were inadvertently performed with slip) must be considered. The results of the manufacturer's flight tests showed that unbalanced steep turns can if extreme cause the fuel to move away from the fuel pickup. This was, however, always accompanied by a change in the fuel quantity indication in the main tank and low fuel quantity caution and warning annunciations. Given that the low fuel level cautions and warnings are independently triggered, had the engine suffered fuel starvation due to lack of fuel in the tanks, it would be expected that the pilots would have observed or heard a low fuel annunciation. However, neither pilot could recall any such warnings.

Conclusions

The evidence of the lack of fuel in the fuel filter canister, and the sudden drop in the actual fuel rail pressure observed in the ECU downloaded data, strongly suggests that the engine had been starved of fuel. However, despite extensive investigation, insufficient evidence was available to allow the cause of the fuel starvation to be determined with any degree of certainty, although the possibility that air entered the fuel system could not be dismissed.