Agusta Bell 206B JetRanger II, G-AWMK

AAIB Bulletin No: 6/99 Ref: EW/C97/11/5 Category: 2.2

Aircraft Type and Registration:	Agusta Bell 206B JetRanger II, G-AWMK
No & Type of Engines:	1 Allison 250-C20 turboshaft engine
Year of Manufacture:	1968
Date & Time (UTC):	25 November 1997 at 1005 hrs
Location:	Near Caernarfon, North Wales
Type of Flight:	Training
Persons on Board:	Crew - 2 (Instructor and student)
Injuries:	Crew - None - Passengers - N/A
Nature of Damage:	Local to fuel cell. Heat damage to fuel bladder, splits in bladder and deformation of structure around fuel bladder
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	42 years
Commander's Flying Experience:	14,427 hours (of which 914 were on type)
	Last 90 days - 17 hours
	Last 28 days - 11 hours
Information Source:	AAIB Field Investigation

History of flight

On 24 November 1997 the crew flew G-AWMK from Redhill, Surrey, to North Wales for a training detail the following day. At Halfpenny Green they refuelled after a normal shutdown with no apparent abnormalities. They continued on to Caernarfon, in North Wales, where they performed a 'hot' refuelling, and thence the short trip (about 10 minutes) to their hotel, where the helicopter was parked overnight. The crew had noted nothing unusual during the trip other than that, as the fuel cap was removed for the 'hot' refuelling at Caernarfon, a distinct vapour or mist was noted coming from the fuel tank.

The next day's detail was training in mountain flying, starting from the hotel. At start-up the crew noted low boost pressure from the forward boost pump but later commented that this is not uncommon and the problem cleared itself. After that the helicopter was operating normally, with no problems from either boost pump, and, about 75 minutes into the flight (some of which was spent briefing, with the helicopter on the ground), the instructor was demonstrating approaches into a mountain 'bowl' at about 2,000 feet amsl. There was no evidence of any cumulo-nimbus cloud activity in the area. Thus the helicopter was in a steady turn in light turbulence when both crew heard a "loud bang and a crumpling noise". The instructor thought that they had flown into some turbulence but the student, turning around, saw smoke coming out from behind the rear seat. They immediately flew out of the valley and, when the instructor found that the helicopter was still behaving normally, he decided it was safe and prudent to fly back to the hotel. The crew landed safely and the helicopter was later returned by road to the maintenance base.

G-AWMK was not fitted with the 'range extender' kit and the fuel capacity was displayed as 63 Imp Gallons (about 76 US gallons). The crew estimated that, up to the time of the incident, they would have used approximately 20 US gallons of fuel, from a tank full to the refuelling cap.

Aircraft description

G-AWMK was an Agusta Bell 206B (JetRanger II), built in 1968 as serial number 8073 and had accumulated over 9000 hours of operation at the time of the incident.

The fuel system in G-AWMK was standard for a 206B. The single fuel tank (Figure 1) is of the 'bladder' type, immediately aft of, and under, the rear bench seat. Fuel is supplied to the engine fuel system by two electric boost pumps mounted in the base of the tank, feeding to a common supply hose which is connected to a fitting at the top of the tank. Thence fuel passes (Figure 2) through the fuel shut-off valve, the airframe fuel filter, the engine fuel pump and filter to the engine fuel control. Excess fuel returns to the fuel tank through a purge line hose, which passes through the tank and is attached at the base of the tank to the drain valve.

'MK was originally fitted with conventional fuel boost pumps in the tank, where maintenance of the pump would require draining the fuel from the tank. These pumps had been replaced in 'MK (as in other 206 JetRangers) with the Parker Airborne Division 'cartridge/canister' fuel pump (part number 206-062-681-101), allowing the cartridge pump element to be replaced without draining the tank.

Examination of the aircraft

The helicopter was undamaged from the incident apart from the fuel bladder and the structure surrounding it (Figure 3). There was distinct upward deformation of the shelf structure immediately over the bladder and heavy deformation of the rear bench seat, with upward movement of the seat pan and forward movement of the seat back. These deformations were consistent with an over-pressure of the bladder. There have been instances in aircraft of over-pressurisation of fuel tanks caused by blocked vent lines: the vent line in 'MK was examined and was free of obstruction.

There were three splits found in the bladder, all three in the upper portion, above the level of the fuel at the time of the incident. Figure 4 shows the inner surface of the fuel bladder, with the front face folded forwards, showing two of the splits. The splits were 10 to 15 cm long and extended through areas where the bladder membrane was of single thickness only, leaving the 'doubler' portions of bladder material (such as the chafing strips and lacing supports) intact. All three bladder splits were on the right-hand side of the tank, close to the fuel hoses and in the same lateral plane as the aft boost pump.

There was further evidence of combustion in the tank (in the form of sooting on the inner surfaces of the fuel filler cap) and there were sooting deposits on the exposed portion of the bladder interior (Figure 5). There was also blistering damage on the interior bladder surface, consistent with heat transfer from some form of combustion. The blistering damage covered less than 25% of this surface and was concentrated around the 3 splits in the bladder.

In the area where the two fuel hoses crossed there were distinct signs of heating and of abrasion on the hoses, where they had rubbed against each other. This point was above the aft boost pump and above the level of fuel at the time of the incident.

A fuel sample (reportedly Jet A1) was secured from the refuelling facility at Caernarfon airport and fuel samples drawn from 'MK during defuelling were submitted to DERA Pyestock for analysis. The analysis showed both samples as conforming to the Jet A1 specification, with satisfactory conductivity.

The aircraft was equipped with a Janitrol heater, mounted above the shelf over the fuel bladder, aft of the rear wall of the bladder. The crew reported that the heater had been operating throughout the training detail and during the previous day, except for the leg from Caernarfon to the hotel. The Janitrol heater installation was normal and there were no indications of unusual heat transfer from the heater to the bladder.

Detailed examination and testing

Fuel hoses

When the supply line and purge line hoses in the tank were examined they were found to be conventional, with a rubber/polymer hose reinforced with steel braid on the outside. These two long lengths of hose were not plastic coated whereas the shorter length, normally immersed in fuel between the boost pumps, had a clear plastic sheath (Figure 5).

As noted above, the supply line and purge line hoses each had an area of chafing where they crossed within the fuel tank. On each hose this area of chafing was the centre of a portion of the hose which had been blackened and become stiff. The supply line hose (Figure 6a) was 15 mm diameter and the abrasion had occurred over a length of about 25 mm, the blackening had extended over a length of about 90 mm and the abrasion had generally broken strands in just the top layer of steel braiding. The purge line hose (Figure 6b) was 10 mm diameter and the area of abrasion was similar to the supply hose but the effect of the abrasion had been more severe, breaking more layers of the braiding of the purge line hose.

The hoses and the fuel bladder were submitted for detailed analysis at DERA. This analysis confirmed that the steel braid had worn as a result of abrasion between the two hoses and the localised heating damage at the area of contact suggested that this was the source of the flame front. The more extensive damage to the purge line hose indicated that there had been a prolonged smouldering but it was not possible to ascertain whether this was a cause or a result of the explosive event.

Fuel pumps

After its return to the maintenance base, the helicopter had been taken out of the hangar for defuelling. This was done, as usual, using the boost pumps. During this operation it was noted that there was some distinct mist/vapour within the tank and it was then seen that the aft boost pump had a generous fountain of fuel coming from the orifices at the top. These orifices are used as the exit for the pump's cooling fuel and the fountain effect appeared to be due to the absence of the small red 'umbrella' check valve which prevents fuel from leaving the bladder when the pump cartridge is removed. The check valve was not found anywhere within the tank and there was no ready explanation as to how it might have migrated from the tank. As a safety measure, the remainder of the fuel was drained through the base of the tank.

The two boost pumps (Figure 7) were examined and tested at a European licensee of the US pump manufacturer. The examination showed no evidence of any damage to the pumps and the tests showed performance of both pumps passing the normal acceptance test. The tests also showed that the absence of the umbrella check valve on the aft pump did not make a significant difference to the performance of the pump.

The observation during the defuelling operation of the fountain from the aft pump (without the umbrella check valve) prompted a series of tests at DERA Farnborough, where the pumps were, in turn, mounted in a chamber replicating the internal volume of the fuel tank. The pumps were then run under varying conditions, also varying the head of fuel above the pump, with and without the umbrella check valve in place.

The DERA tests showed the pumps as having satisfactory delivery performance with and without the umbrella check valve. With the valve in place, the cooling fuel was ejected from the orifices on top of the pump in an even and horizontal fan. With the valve missing the effect was different and with 100 mm (or greater) of fuel over the pump, there was simply a disturbance over the pump. Below 100 mm the fuel was ejected vertically in a fountain of increasing elevation as the fuel level decreased: with 25 mm of fuel over the pump the fountain reached 600 mm (Figure 8) and, as the top of the pump cleared the fuel, the fountain exceeded 1 m, hitting the top of the tank.

Calculation by the AAIB of the fuel level at the time of the incident indicate that there would have been an average of some 90 to 120 mm of fuel above the aft boost pump at the time of the incident. However, this is an estimate based on a number of assumptions and would only represent an average level: in turbulent conditions the normal fuel 'sloshing' within the single tank would, intermittently, allow the vertical fountain efflux from the pump.

Electrical bonding

The general electrical bonding of the aircraft had been checked during the initial examination and had been satisfactory. The electrical continuity of the hose and fittings of the two fuel lines within the fuel bladder was later checked. The purge line hose, which had conventional grey steel nozzle and nipple fittings at the ends, had good electrical continuity but it was noted that the blue and red anodised fittings on the fuel supply line (Figure 5) acted as insulators. This prevented electrical continuity between the hose and its connections to the boost pumps (at the base of the tank) and the outlet to the engine (at the top of the tank).

It was confirmed by the hose manufacturer that the particular fittings were from the "Aeroquip 601 Hose" product line, designed for use in medium pressure hose applications and conforming to the Military Specification MIL-H-83797: these fittings have been used very widely within the aerospace industry. In the smaller diameters (such as the purge line hose in G-AWMK) the nipple fittings are steel and thus provide electrical continuity. In the larger diameters, however, (such as the supply line hose) the nipple fittings are Aluminium alloy with an anodised finish and will, until the finish becomes worn, be non-conductive.

It was further confirmed that the Military Specification (MIL-H-83797) does not contain specific provision regarding electrical conductivity along the hose or across the end fittings. The hose manufacturer states that this conductivity can be provided, when requested by the customer, and that this is done for particular applications. Indeed, more recent designs of hose and fittings include specific provision for this conductivity. The AAIB discussed this topic with other aircraft manufacturers: their view was that fuel hoses within fuel tanks should be electrically bonded and that the majority of designs apply this principle, either by ensuring electrical continuity within the hose assemblies or by adding extra bonding leads and clamps.

In fact, the two fuel lines within the fuel bladder were not replacement parts obtained from the helicopter manufacturer (of G-AWMK) as the fuel lines had been assembled by the operator's maintenance organisation, using Aeroquip materials, within the terms of their CAA approval.

Examination of other helicopters

During the investigation a number of other Agusta Bell 206B aircraft were examined at the AAIB and elsewhere to determine the arrangement of their fuel systems. It was noted that at least two other boost pumps were lacking their umbrella check valve. There was anecdotal evidence that these valves may, in some cases, be mistakenly discarded during installation, incorrectly identified as 'packing blanks'.

It was also noted that there was diversity in fuel hose configuration between different aircraft. In some cases the hoses were of the same type as in 'MK but with a 'P'-clip arrangement preventing any abrasion between the hoses. Other aircraft had a different and longer purge line hose, which did not come close to the supply line hose. The instructions covering the conversion to the 206B configuration appear to reflect this diversity, with the Parts illustration (within the Illustrated Parts breakdown) showing the provision of 'P'-clips between the long, and otherwise unsupported, lengths of fuel hose within the fuel tank but with no reference to this in the written instructions.

The applicable technical bulletin for the change to the cartridge/canister fuel boost pumps was Agusta's Bolletino Tecnico no. 206-162, derived from Bell Technical Bulletins 206-80-45 and 206-82-60. This technical bulletin also made no reference to the 'P'-clip arrangement between the fuel hoses within the tank.

Discussion

Although there have been recorded cases of fuel tank deflagrations during refuelling operations, there do not appear to have been other instances of this type of event occurring in-flight within the Agusta and Bell 206 fleets. Instances of in-flight fuel tank fires and explosions are very rare and much of the current research was initiated as a result of the loss of the Boeing 747 operating as TWA Flight 800 off Long Island in July 1996. It is believed that, in that accident, the fuel tank explosion had come about because of a highly combustible fuel-air mixture in the centre wing tank, as a result of fuel heating by aircraft air-conditioning equipment and a spark of undetermined origin.

One notable instance in which a light helicopter fuel tank did explode was the loss of an MBB BK117, C-GIRB, at Buttonville Airport, Ontario on 28 January 1989. The Canadian Air Safety

Board (CASB) investigated the accident in depth. The report concluded that the most probable scenario was the generation of a heated flammable fuel-air vapour in one tank (and hence the fuel vent system) due to the draining of heated fuel from the engine fuel return lines following engine shutdown. The ignition source was believed to be a static discharge generated between the fuselage and an unbonded portion of the fuel vent pipe.

Operating over North Wales in November, and with no substantial external heating, the temperature in the fuel tank of G-AWMK would appear to have been well below the normal 'static' flammability level for Jet A-1 fuel (about 40°C). However, research has shown that this flammability level can be markedly lowered by 'dynamic' conditions, where the fuel is being agitated. In G-AWMK it is very possible that such agitating conditions were provided, in a localised manner, by a combination of the flight in turbulent conditions and the action of the aft fuel boost pump, operating without its umbrella check valve.

It is not possible to be definite about the source of ignition but the combustion appears to have initiated around the point where the two fuel hoses were abrading within the tank, in the area above the aft fuel boost pump. Although the purge line hose had electrical continuity with the airframe, it appears that the supply line hose did not have continuity and there was, therefore, the potential for a build-up of static charge.

Airworthiness requirements for helicopters and aeroplanes include provisions for the proper electrical continuity and bonding for airframes and systems, including fuel system components, but there is a diversity between the levels of detail prescribed for different categories of aircraft. For instance, in JAR-25 (Joint Airworthiness Requirements - Large Aeroplanes) the requirements of JAR 25X899 (Electrical Bonding and Protection against Lightning and Static Electricity) and JAR 25.954 (Fuel System Lightning Protection) are supported by extensive and detailed advisory material (ACJ 25X899 and ACJ 25.954) within the same document. This material interprets the requirements and suggests acceptable means of compliance.

In contrast, the provisions of JAR-27 (Joint Airworthiness Requirements - Small Rotorcraft) are limited in reference to lightning protection (JAR 27.610 and 27.954) and do not refer to static charge.

There has been extensive work, by industry and the airworthiness authorities, into protection against static charge and lightning following the loss of TWA Flight 800. There is a clear case to extend this work into reviewing the provisions for the helicopter fleet, both under JAR-29 (Large Rotorcraft) and JAR-27 (Small Rotorcraft).

Safety recommendations

This incident, an in-flight deflagration within an Agusta Bell 206 helicopter, appears to be unique and it was not possible to determine the exact mechanism by which the event was initiated. However, the absence of the umbrella check valve on the aft boost pump and the abrading action between the two unsupported fuel hoses appear significant and their relative positions within the tank, adjacent to the bladder splits and blistering, indicate that one, or both, were involved in the combustion. It is prudent to remove these anomalies within the fleet by ensuring that the boost pumps have the umbrella check valve properly installed and that there is no abrasion between the fuel hoses within the fuel tank. The AAIB makes the following two Safety Recommendations concerning inspections:

Recommendation 99-2

It is recommended that the RAI and the FAA institute an inspection within the Agusta and Bell 206 fleets to ensure that any Parker Airborne Division 'cartridge/canister' boost pumps are properly equipped with umbrella check valves and the CAA takes such measures as are necessary to ensure inspection of the UK fleet.

Recommendation 99-3

It is recommended that the RAI and the FAA institute an inspection within the Agusta and Bell 206 fleets to ensure that the fuel hoses within the fuel tanks are properly supported and protected from abrasion and the CAA takes such measures as are necessary to ensure inspection of the UK fleet.

The AAIB makes a further Safety Recommendation concerning airworthiness requirements. As noted earlier, it is of concern that the topic of electrical bonding between components receives little attention within the civil airworthiness requirements for Small Rotorcraft, which are often used for Public Transport and for flying under IFR. This topic deserves further attention:

Recommendation 99-9

It is recommended that the JAA and the CAA ensure that the structure and scope of JAR-25 (Joint Airworthiness Requirements - Large Aeroplanes) are applied to JAR-27 (Joint Airworthiness Requirements - Small Rotorcraft) with reference to protection against static electricity and against lightning.