Australian Government
Australian Transport Safety Bureau

Loss of control involving Robinson R44 helicopter VH-HWQ

Bulli Tops, New South Wales | 21 March 2013

Investigation

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Cover photo: **Brenden Scott**

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Addendum

Page	Change	Date
35 and 36	Clarification of European Aviation Safety Agency initial response to identified safety issues	24 July 2015

Safety summary

What happened

VH-HWQ

Source: Brenden Scott

At about 1207 on 21 March 2013, a Robinson Helicopter Company R44 helicopter (R44), registered VH-HWQ, landed at a grassed area adjacent to a function centre at Bulli Tops, New South Wales. Shortly after landing, the helicopter was observed to simultaneously lift off, yaw right through 180° and drift towards nearby trees. The helicopter struck branches of the trees before descending, impacting the ground nose low and rolling onto its right side. A short time after coming to rest a fire started and engulfed the helicopter. The pilot and three passengers were fatally injured.

What the ATSB found

The circumstances of this accident were consistent with the helicopter lifting off following a deliberate or inadvertent collective input. The helicopter's main rotor blades subsequently contacted nearby trees resulting in a loss of control and impact with the ground. The impact sequence resulted in a substantial fuel leak that was followed by an intense fire. This accident was similar to two other relatively recent fatal accidents in Australia involving R44s fitted with all-aluminium fuel tanks in which there was a fatal post-impact fire (PIF) following an otherwise survivable impact. Statistical analysis of helicopter accidents that occurred in Australia and the United States (US) between 1993 and 2013 identified a significantly higher proportion of PIF involving R44s than for other similar helicopter types. That analysis also identified that, despite the introduction of requirements for newly certificated helicopters to have an improved crash-resistant fuel system (CRFS) some 20 years previously, several helicopter types were still being manufactured without a CRFS and that many of the existing civil helicopter fleet were similarly not fitted with a CRFS.

What's been done as a result

Following this accident the Civil Aviation Safety Authority (CASA) took action to increase compliance with the helicopter manufacturer's Service Bulletin 78B (SB-78B), requiring the fitment of bladder-type fuel tanks and other fuel system improvements. While recognising the action taken by CASA, due to concern that a significant number of Australian owners and operators had at that stage not taken steps to comply with the service bulletin, and were very unlikely to be able to do so by the required date of 30 April 2013, the ATSB released safety recommendation AO-2013-055-SR-001 to CASA that further action be taken. In response CASA released airworthiness directive AD/R44/23 requiring all owners of R44 helicopters in Australia to comply with SB-78B by the required date. Several other national airworthiness authorities (the South African Civil Aviation Authority, the Civil Aviation Authority of New Zealand and the European Aviation Safety Agency) subsequently mandated compliance with SB-78B. At the time of publishing this report the State of Design and Manufacture of the R44 helicopter had not mandated compliance with SB-78B.

The ATSB has issued a safety recommendation to the US Federal Aviation Administration (FAA) that they take action to ensure all R44 operators and owners comply with the manufacturer's Service Bulletin SB-78B and fit bladder-type tanks to improve resistance to post-impact fuel leaks. In addition, the ATSB also recommend that the FAA and European Aviation Safety Agency take action to increase the number of existing and newly-manufactured helicopters that are fitted with a crash-resistant fuel system.

Safety message

This accident highlights the catastrophic consequences of fuel-fed post-impact fire and that the most effective defence is to prevent the fire from occurring at impact by containing the fuel on board, preventing ignition, or both. In that context, the ATSB strongly encourages the fitment of a crash-resistant fuel system where possible.

Contents

The occurrence

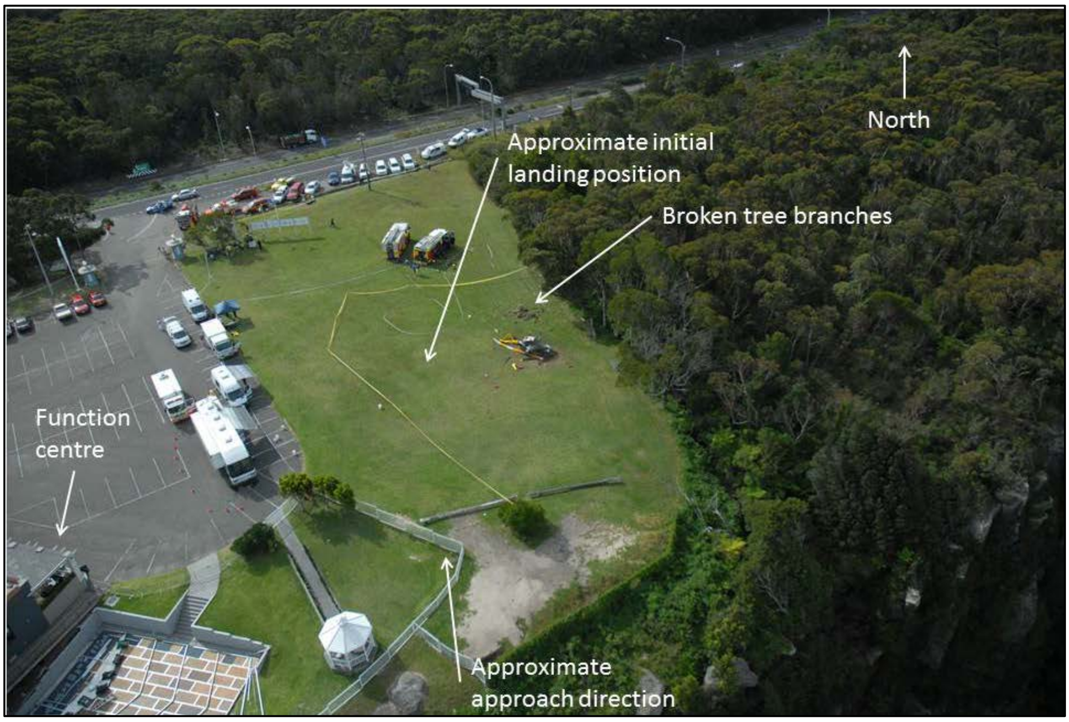
On 21 March 2013, a Robinson Helicopter Company R44 helicopter (R44), registered VH-HWQ, departed Bankstown Airport on a private flight to a function centre at Bulli Tops, near Wollongong, New South Wales (NSW) (Figure 1). On board were the pilot and three passengers.

At about 1207 Eastern Daylight-saving Time[1], the pilot landed at a grassed area adjacent to the function centre. Witnesses reported that the R44 approached the landing area from the south-east and touched down centrally in the grassed area facing in a north-westerly direction. A witness standing adjacent to the landing area stated that the engine sound did not reduce following the landing and that from her position she could see the front-seat occupants of the helicopter.

That witness recalled that, about 30 seconds after touching down, there appeared to be a deliberate movement by one of the front-seat occupants, with someone appearing to push forward forcefully with both hands, or move their upper body quickly forward, followed immediately by the helicopter rapidly lifting off and simultaneously yawing to the right through about 180°. The helicopter was then observed to move towards trees on the north-eastern side of the landing area until the main rotor blades struck a number of tree branches (Figures 1 and 2). The witness stated that, following the contact with the trees, the pilot appeared to be trying really hard to control the helicopter.

A number of other witnesses also observed the helicopter land on the grassed area; however, their vantage points were to the rear of the helicopter and did not permit them to view the occupants once the helicopter landed. A number of these witnesses reported that the engine noise did not reduce between the initial landing and the helicopter again becoming airborne.

Figure 1: Bulli Tops function centre and grass landing area



Source: New South Wales Police Force (labels added by the ATSB)

Following the tree contact, the helicopter was observed to descend onto the grass in a right side down, nose-low attitude and roll onto its right side. A number of the nearby witnesses approached

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[1] Eastern Daylight-saving Time was Coordinated Universal Time (UTC) + 11 hours.

the helicopter to render assistance to the occupants. The first person to reach the helicopter recalled that a large quantity of fuel was pouring out from underneath the helicopter and that soon after, a fire started on the grass under the rotor mast and the cabin area and rapidly engulfed the helicopter. A number of people attempted to extinguish the fire and assist the occupants but, due to the fire's intensity, without success. The pilot and three passengers were fatally injured and the helicopter was destroyed.

Figure 2: Helicopter wreckage with the broken tree branches in the background

Source: ATSB

Context

Pilot information

The pilot held an Australian Private Pilot (Helicopter) Licence that was issued by the Civil Aviation Safety Authority (CASA) in September 2011. The pilot was appropriately endorsed to operate the R44.

The pilot's flying logbook indicated that, prior to the flight he had accrued 174.7 hours flight time, of which 21.9 hours were in R44 helicopters. The logbook and other operational documentation provided to the ATSB indicated that the pilot had previously operated into the grassed area at Bulli Tops in an R44 on 27 July 2012 and 27 August 2012.

Several of the pilot's instructors indicated that the pilot normally conducted a weight and balance sheet check before each flight and had the figures double-checked by an experienced instructor at the school each time to ensure they were correct. The pilot was reported to have taken this action for the flight to Bulli Tops on 21 March 2013.

Helicopter information

Helicopter specifications

The R44 is a four-seat, single main and tail rotor helicopter that is powered by a six-cylinder piston-engine, and equipped with skid-type landing gear. The accident helicopter (Figure 3), a R44 Raven 1, serial number 1445 was manufactured in the United States (US) in December 2004. An Australian Certificate of Airworthiness for the helicopter was issued on 11 February 2005.

Figure 3: VH-HWQ

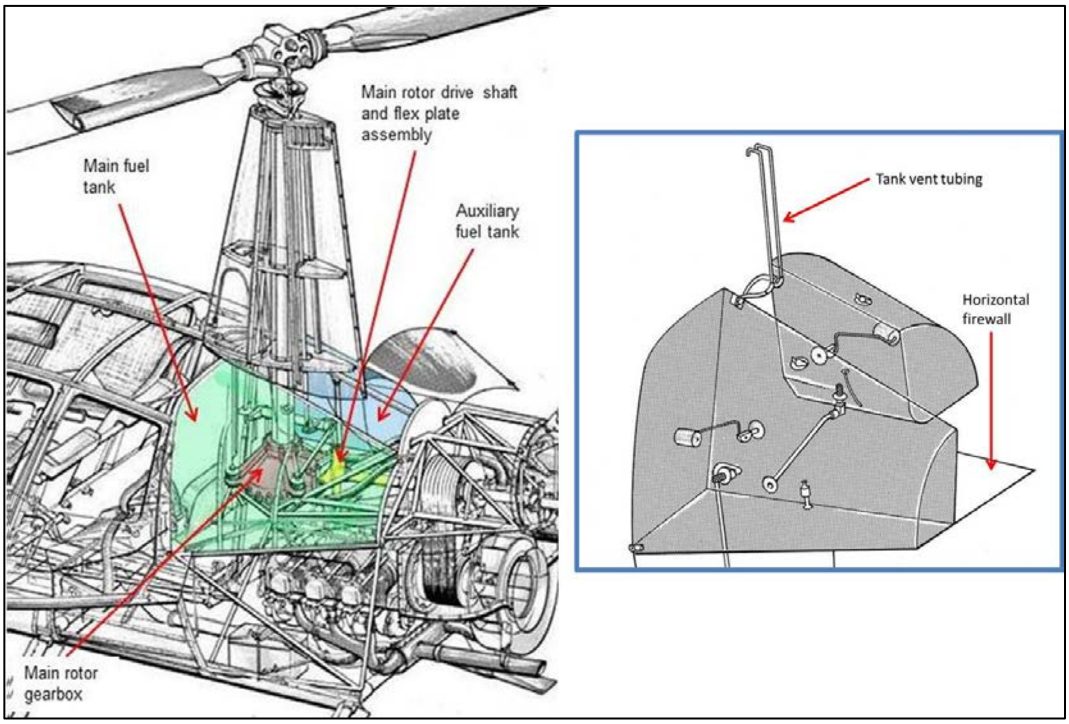
Source: Brenden Scott

Fuel system

The piston engine fitted to R44 helicopters operates on aviation gasoline (Avgas). The combination of Avgas fuel vapour and oxygen is a volatile mixture that can easily ignite in the presence of flames, sparks or sufficiently hot surfaces. Pre-mixed Avgas fuel vapours will also self (auto) ignite at temperatures above about 430 °C.

The R44 was originally manufactured with two all-aluminium fuel tanks installed above the engine on either side of the main rotor gearbox (Figure 4). Both tanks were interconnected by rigid-tubing fuel lines, with the right-side-mounted auxiliary tank draining into the left-side-mounted main tank. The main tank had a maximum capacity of 120 L and the auxiliary tank a maximum of 70 L. Both tanks vented to atmosphere in the area inside the main rotor mast fairing, above the tanks (Figure 4).

Figure 4: R44 helicopter fuel tanks surrounding the lower main rotor gearbox assembly and main rotor driveshaft. Inset - fuel tank system diagram showing the inter-tank plumbing and vent tubes



Source: Flight International; David Hatchard

Fuel system revisions

On 20 December 2010, the helicopter manufacturer issued R44 Service Bulletin 78 (SB-78) requiring that R44 helicopters with all-aluminium fuel tanks be retrofitted with bladder-type tanks as soon as practical, but no later than 31 December 2014. The background information to the service bulletin stated:

> To improve the R44 fuel system's resistance to a post-accident fuel leak, this retrofit must be performed as soon as possible.

The manufacturer advised that, compared to the all-aluminium tanks, the bladder-type tanks provided improved resistance to post-accident fuel leaks due to their improved cut and tear resistance and the ability of the bladders to sustain large deformations without rupture. SB-78 also incorporated the fitment of:

- reinforced fuel filler caps, to increase their ability to retain fuel under internal pressure loads
- rollover vent valves, designed to minimise fuel spillage should the helicopter come to rest at an attitude that permitted fuel to reach a fuel tank vent opening.

On 21 February 2012, following an R44 accident that occurred on 4 February 2012 at Jaspers Brush, New South Wales,[2] the manufacturer issued a revision to SB-78, Service Bulletin 78A (SB-78A). That revision reduced the time frame for compliance with the bladder-type tank fitment by 12 months to 31 December 2013.[3] On 15 June 2012, the manufacturer forwarded a letter of offer to all R44 Dealers, Service Centres and Owners, advising them of a financial incentive to install the S-78A fuel tank kits 'on or before 31 December 2012'.

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[2] ATSB aviation occurrence investigation report AO-2012-021, available at www.atsb.gov.au.

[3] SB 78A applied to R44 models with serial numbers 0001 to 2064, and R44 II models with serial numbers 10,001 to 12,890.

Subsequently, on 28 September 2012, the manufacturer again brought forward the compliance date with the issue of Service Bulletin 78B. That revision amended the date of compliance to 30 April 2013. The manufacturer advised that about 4,000 helicopters were manufactured with the all-aluminium fuel tanks and, at the time of writing, about 2,600 bladder-type tank retrofit kits had been delivered or installed worldwide.

Coincident with the release of SB-78A, the manufacturer also released SB-82, requiring the replacement of the rotor brake switch with a sealed unit to reduce the chance of a possible ignition source in the event of a fuel leak.[4] The time of compliance for SB-82 was 'within the next 150 flight hours or by 31 May 2012, whichever occurred first'.

Prior to the issue of SB-78/SB-78A/SB-78B, the manufacturer had issued service bulletins 67[5], 68 and 69 (SB-67, SB-68 and SB-69) that were also designed to reduce the likelihood of post-accident fuel leaks. SB-67 and SB-68 involved modifications that increased the allowable movement of the fuel lines during an accident to reduce the likelihood of them fracturing. Service bulletin 69 (SB-69) was a modification to improve retention of the gascolator[6] sediment bowl under impact loads.

At the time of the accident, VH HWQ had been modified to include SB-68, SB-69 and SB-82. The bladder-type fuel tank retrofit had not been incorporated (see the section titled *Maintenance history*).

Flight control system

The flight controls in an R44 helicopter control the pitch angle of the main rotor and tail rotor blades through mechanical linkages. The cyclic control, operated by the respective pilot's right hand, varies the angle of each main rotor blade individually to tilt the main rotor disc and control the attitude of the helicopter and hence the lateral direction in-flight, or the position over the ground when in the hover. Pilot movement of the cyclic hand grip is transferred via an arm to a centrally-mounted control column (Figure 5).

Figure 5: Typical R44 cockpit flight controls, pilot's cyclic (left cyclic hand grip removed)

Source: ATSB

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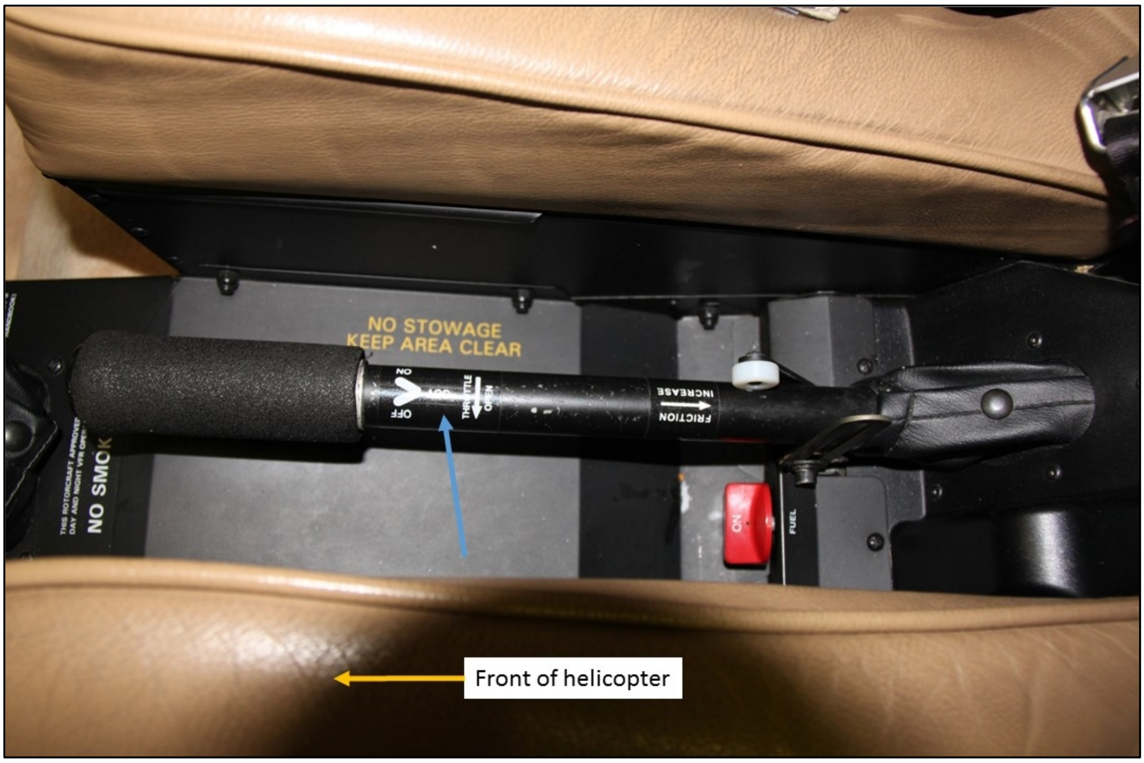
[4] SB 82 applied to R44 models with serial numbers 0001 to 2126, and R44 II models with serial numbers 10,001 to 13,139.

[5] Service bulletin 67 was not applicable to VH-HWQ.

[6] Fuel filter fitted at the lowest point of the fuel system.

The collective control, raised or lowered by the pilot's left hand, varies the pitch of both main rotor blades together to increase or reduce rotor thrust for climb or descent. The two interconnected pilot's collective levers are positioned to the left of each front seat and incorporate a twist-grip engine throttle (Figure 6). Raising the collective increases the pitch on the main rotor blades, resulting in an increase in the lift and drag produced. In order to overcome the increased drag, the R44 incorporates a throttle correlator device that increases the throttle as the collective is raised and reduces throttle as the collective is lowered.

Figure 6: Typical R44 cockpit flight controls, right-seat pilot's collective lever (blue arrow)



Source: ATSB

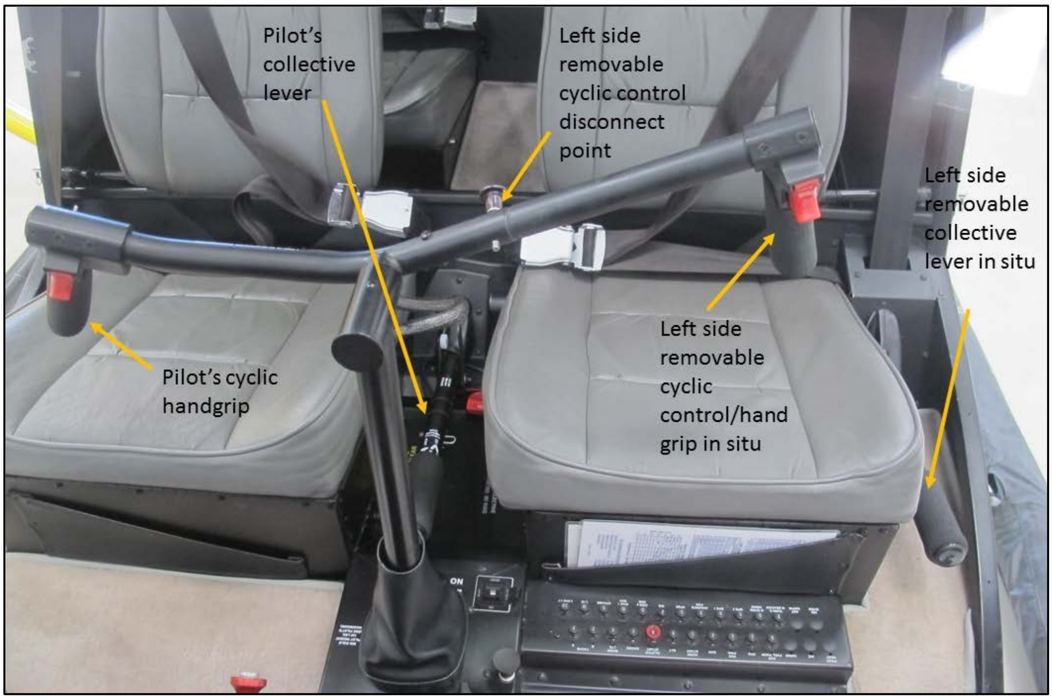
The tail rotor controls consist of two sets of tail rotor pitch control pedals, one set located on the cockpit floor to the front of the respective pilot's seat. These vary the pitch angle of the tail rotor blades and allow the pilot to control yaw, or in other words to rotate the nose left or right in the hover, or to balance the helicopter in flight.

Reconfiguration of the flight controls

The left cockpit flight controls in the R44 can be removed from the helicopter as operationally required (Figures 5, 7 and 8). This can include when carrying a passenger in the left-front seat, with the aim of reducing the risk of this passenger inadvertently activating or otherwise fouling the controls, in order to carry additional cargo, and so on.

The left collective control is normally connected to a stub situated inside a protective dust boot (Figures 7 and 8). When the collective control is removed, the boot remains attached to an aluminium cover, limiting access to the collective control stub. The helicopter manufacturer indicated that the stub extends approximately 5 mm beyond the aluminium cover when the collective is fully-raised and 15 mm at mid position or when fully-lowered. The extension facilitated re-connection of the collective control.

Figure 7: Typical R44 cockpit flight controls showing removable left cyclic hand grip and collective lever



Source: Robinson Helicopter Company (labels added by the ATSB)

Figure 8: Typical R44 cockpit flight controls showing the removable left collective lever

Source: Robinson Helicopter Company (labels added by the ATSB)

At the time of the accident, the left cockpit flight controls, including the tail rotor pedals, were not fitted to VH-HWQ.

Hydraulic system

All R44 helicopters, with the exception of the Astro model,[7] include hydraulically-boosted main rotor flight controls. The pilot's operating handbook (POH) requires the hydraulic system to be operational for flight and described the R44 hydraulic system as follows:

> Hydraulically-boosted main rotor flight controls eliminate cyclic and collective feedback forces. The hydraulic system consists of a pump, three servos, a reservoir, and interconnecting lines...The pump is mounted on and driven by the main rotor gearbox to maintain hydraulic pressure in the event of an engine failure. A servo is connected to each of the three [flight control] push pull tubes that support the main rotor swashplate. The reservoir...includes a filter, pressure relief valve, and pilot controlled pressure shut off valve...The pressure shut off valve is solenoid actuated and controlled by the hydraulic switch [HYD/OFF] on the pilot's cyclic [Figure 5].

Selection of the HYD/OFF switch to OFF isolates hydraulic system pressure to the servos. The solenoid is fail-safe whereby, in the absence of other failures in the system, the hydraulics are restored to the flight control servos in the event of an electrical system failure.

In respect of the identification of a hydraulic system failure, the *Emergency Procedure* section of the POH stated:

> Hydraulics system failure is indicated by heavy or stiff cyclic and collective controls. Control will be normal except for the increase in stick forces.

The hydraulic system did not, and was not required to incorporate an independent cockpit indication, such as a visual and/or aural caution or warning, to assist in the identification of a hydraulic system failure.

Flight control-related manufacturer Safety Notices

The R44 POH contained a number of safety notices in relation to the operation of the helicopter. In particular, Robinson Helicopter Company Safety Notice SN-17 advised that:

> NEVER EXIT HELICOPTER WITH ENGINE RUNNING
>
> Several accidents have occurred when pilots momentarily left their helicopters unattended with the engine running and rotors turning. The collective can creep up, increasing both pitch and throttle, allowing the helicopter to lift off or roll out of control.

Collective friction can be applied by the pilot in an effort to maintain the as-set position of the collective lever (for example, at flat pitch, or fully down, after landing). However, in relation to the risk of collective 'creep' in an unattended helicopter, the manufacturer explained that:

> SN-17 was last revised in 1994 when both the R22 and R44 had manual main rotor flight controls. These collective systems use a spring to balance the feedback forces inflight. On the ground, however, the spring force plus vibration may exceed collective friction and the collective may creep up. With hydraulic main rotor controls there is no collective spring, so the collective will not creep up. With hydraulics switched off, it takes significant force to raise the collective.

Despite this advice, the manufacturer recommended that pilots should still not leave their helicopters unattended with the engine running. This included in helicopters equipped with hydraulically-boosted flight controls.

Main rotor RPM governor system

Helicopter rotor systems are subject to large variations in flight loads during normal operation that, depending on the engine throttle setting, will tend to increase or decrease rotor RPM. To assist pilots maintain the desired constant, and most efficient rotor RPM during normal manoeuvring, R44 helicopters include a governor system that varies the engine throttle in response to differing flight loads.

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[7] The R44 Astro was manufactured with a pilot adjustable cyclic trim to reduce the main rotor feedback forces.

The POH described the operation of the governor system in the R44 as follows:

> The governor senses engine RPM [engine crankshaft revolutions per minute] changes and applies corrective input forces to the throttle; when RPM is low, it tends to increase the throttle and vice versa. The inputs to the throttle are through a friction clutch which can be easily overridden by the pilot. The governor is only active above 80% engine RPM and can be switched on or off by the pilot using the toggle switch on the end of the right [pilot's] seat collective control.
>
> The governor is designed to assist the pilot in controlling RPM in the normal operating range [101 to 102 per cent rotor RPM]. It may not prevent over or under-speed conditions generated by aggressive flight maneuvers.

Maintenance history

The helicopter's maintenance release was valid until 18 December 2013 or 2,200 hours in service, whichever came first. Prior to the flight, the helicopter had accrued 2,178 airframe hours and there was no outstanding maintenance.

The maintenance provider for the helicopter advised that SB-78B (see the previous section titled *Fuel system revisions*), had been scheduled to be carried out by 30 April 2013. This was also annotated in the 'Maintenance required' column of the helicopter's maintenance release.

Helicopter weight and performance

The pilot's weight and balance calculations, which were also checked by an experienced instructor that day, indicated that the helicopter departed Bankstown Airport at the maximum allowable gross weight of 1,089 kg, and within the centre of gravity limits. The helicopter manufacturer's performance data indicated that, given the ambient conditions and estimated weight of the helicopter at the time of the accident, the helicopter was capable of hovering out of ground effect[8] in zero wind conditions.

Helicopter testing

At the request of the ATSB as part of this investigation, the helicopter manufacturer conducted an assessment of the behaviour of the R44 when subjected to various flight control inputs, at different operating RPM, while on the ground. The assessment was carried out using an R44 Raven 1 helicopter at the maximum operating weight of 2,400 lbs (1,089 kg), an ambient temperature of 90 °F (32 °C) and an elevation of 100 ft (30 m) above mean sea level.

The following results were obtained by the manufacturer's test pilot with the governor and hydraulic-boost systems selected ON and the RPM selected between 60 and 70 per cent, as detailed in the *Shutdown Procedures* section of the POH:

- At the idle RPM of 57 per cent, a medium pull up on the collective resulted in the helicopter becoming light on the skids and yawing right at an upward collective movement of 1.9 in (4.8 cm).[9] The helicopter did not leave the ground, even at full collective and although the throttle correlator increased the RPM as the collective was raised, the RPM remained below 80 per cent. The same results were obtained on pavement and grass.
- With the RPM set at 57 per cent, an aggressive pull to full up on the collective resulted in the helicopter becoming light on the skids and yawing right more aggressively (controllable with full left tail rotor pedal), but the helicopter did not become airborne. The RPM again remained below 80 per cent and the same results were obtained on pavement and grass.

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[8] Helicopters require more power to hover out of ground effect due to the absence of a cushioning effect created by the main rotor downwash striking the ground. The distance is usually defined as more than one main rotor diameter above the surface.

[9] The measurements attained were of the upward movement of the collective lever when measuring the movement (or travel) of the screw head on the pilot's collective friction slider.

- In both of the above tests the collective position was held for 3 seconds, which the manufacturer assessed was long enough for a pilot to react to either situation.
- At an RPM of 70 per cent, the helicopter became airborne as the collective was slowly raised to 2.6 in (6.6 cm). The RPM increased as collective was raised, due to the normal action of the correlator, with the governor engaging as the RPM reached 80 per cent and increasing the RPM to the normal operating range of 101 to 102 per cent.
- In addition to the above tests, the manufacturer advised that a forward movement of the cyclic control only, at the helicopter's normal operating RPM of 101 to 102 per cent, would result in a noticeable increase in main rotor vibration, but the helicopter was unlikely to leave the ground.

Meteorological information

Witnesses at the site reported that the weather at the grassed area was fine with good visibility and that there was a light breeze from the north-west. These reports were consistent with wind indications in photographs and video imagery taken at the site soon after the accident.

Wreckage and impact information

Accident site

The accident site was an open grassed area, orientated north-west/south-east, which sloped down to the south-east at about 4°. The area was bordered by a tarmac car park on the western side, a line of trees on the eastern side and a powerline and highway to the north (Figure 1).

Based on guidance material in Civil Aviation Advisory Publication (CAAP) 92-2(2) *Guidelines for the establishment and operation of onshore Helicopter Landing Sites*,[10] the area met the requirements of a 'basic' helicopter landing site (HLS) and, as such, was a suitable landing area for the flight. Information received from experienced helicopter pilots who had previously operated into the HLS indicated that the normal approach to land was over the escarpment and toward the powerline. They further stated that it was not uncommon to have three or four helicopters use the HLS at the same time.

Witnesses described the helicopter landing in about the centre of the grassed area. This would have placed the tips of the helicopter's main rotor blades approximately one to one and a half main rotor diameters from the line of trees on the eastern side of the area.

Site and wreckage examination

Examination of the tree branches that were struck by the helicopter indicated that the helicopter's skid-landing gear was about 1 m above the ground at that time. This was consistent with observations by one of the witnesses.

The wreckage was contained within a relatively small area and all of the helicopter's major components were identified at the accident site (Figure 9). The helicopter came to rest on its right side and facing downhill on a magnetic heading of 103° (Figures 1 and 2).

There was evidence of two main rotor strikes on the tail boom, which was severed during the accident sequence. A large section of tail rotor drive shaft was located approximately 15 m to the south-west of the main wreckage, consistent with its high-energy liberation following impact with the main rotor. Both main rotor blades remained attached to the main rotor head and displayed rearward and upward bending.

Examination of the flight controls found no pre-existing defect. However, significant portions of the flight controls were consumed by the post-impact fire. In addition, the hydraulic reservoir and associated components and the cyclic-mounted HYD/OFF switch were destroyed in the fire. This

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[10] Available at www.casa.gov.au.

precluded a full assessment of their immediate post-impact condition. The fire also destroyed the cabin area.

During the impact sequence the main rotor mast and gearbox assembly moved, forcing the rotating flex plate assembly on the clutch shaft out of alignment.[11] The displaced assembly then heavily contacted the upper frame structure and firewall assembly. The extent of the post-impact fire damage meant that it was not possible to determine whether the flex plate assembly also breached the metal skin of one or both fuel tanks. The metal to metal contact during the impact sequence may have provided an ignition source for the leaking fuel. Other possible sources of ignition included hot engine components or electrical system arcing. Due to the degree of fire damage, identification of the ignition source was not possible.

Overall, the witness and physical evidence were consistent, indicating a relatively low-energy impact. Assessment of the wreckage, although hampered by the extent of the post-impact fire damage, did not identify any pre-existing defects with the helicopter.

Figure 9: Main wreckage

Source: ATSB

Medical and pathological information

Post-mortem examination of the pilot did not reveal any evidence of a physiological condition that would have contributed to the occurrence. The examining pathologist reported that the fatal injuries sustained by the pilot and passengers were due to the effects of fire.

Toxicological analysis indicated that none of the occupants were affected by alcohol or drugs.

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[11] The flex plate allowed for small misalignments of the rotating clutch shaft as it transmitted engine power to the main and tail rotor gearboxes and for drive shaft movement during clutch engagement/disengagement.

Survival aspects

In respect of the danger posed by post-impact fires, Robinson Helicopter Company Safety Notice SN 40 of July 2006 advised:

> POSTCRASH FIRES
>
> There have been a number of cases where helicopter or light plane occupants have survived an accident only to be severely burned by fire following the accident. To reduce the risk of injury in a postcrash fire, it is strongly recommended that a fire retardant Nomex flight suit, gloves, and hood or helmet be worn by all occupants.

The manufacturer of clothing containing NOMEX® fibre described its effectiveness as follows:[12]

> Inherently flame-resistant, fabric made of NOMEX® will not continue to burn after the flame source is removed. It also creates an insulating barrier against the heat of a fire, slowing the transfer of heat and giving the wearer time to escape. Something else to consider: NOMEX® chars when exposed to intense heat, increasing the protective barrier and reducing the chance of injuries from burns.

In this instance the intensity of the ongoing fire, and the impeded egress due to the orientation of the helicopter, meant that the use of such equipment would probably not have reduced the severity of the outcome.

Organisational and management information

US Federal Aviation Administration regulation of helicopter fuel systems

R44 certification basis

The R44 helicopter was certified as a *Normal Category Rotorcraft* and provided with Type Certificate (TC) number H11NM on 10 December 1992[13] in accordance with the US Code of Federal Regulations (CFRs). This required the R44 to comply with 14 CFR Part 27 *Airworthiness Standards: Normal Category Rotorcraft* of 1 February 1965, including Amendments 27-1 through to 27-24.

Application for type certification of other than a transport category aircraft is effective for 3 years unless the applicant shows, at the time of application, that a longer period is required for design, development and testing, and that extension is approved by the US Federal Aviation Administration (FAA). The helicopter manufacturer advised that the certification of the R44 was completed within the required 3-year time frame.

R44 all-aluminium fuel tank testing

In order to ensure that the R44 powerplant complied with its certification basis, the all-aluminium fuel tanks were required to satisfy several sections of the Part 27 requirements relating to fuel systems. These included specific requirements such as fuel tank expansion space, tank sumps, filler connections, tank vents as well as testing of the tank.

Section 27.965 *Fuel tank tests* required a number of tests of the tank's integrity (see appendix B). These included vibration and movement simulations for tank designs/installations that had large unsupported or unstiffened flat areas or with other features whose failure or deformation could cause leakage. The R44's fuel tank design was not considered susceptible to leakage via these mechanisms and therefore those tests were not conducted.

As the R44 fuel tanks were a 'conventional metal tank', Section 27.965 required them to withstand an internal pressure equal to the pressure developed during maximum limit acceleration or

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[12] www2.dupont.com/Government/en_US/assets/downloads/MilitaryBrochure.pdf (last accessed on 3 May 2013).

[13] The R44 Type Certificate Data Sheet, number H11NM, was issued on 10 December 1992. The R44 Production Certificate, number 424WE was issued on 11 February 1993.

emergency deceleration with a full tank of fuel, but not less than 3.5 psi, without failure or leakage. The metal R44 tanks satisfied this requirement during certification.

US FAA introduction of crash-resistant fuel system requirements

On 5 October 1990 the FAA introduced Notice of Proposed Rulemaking (NPRM) 90-24 *Airworthiness Standards: Crash Resistant Fuel Systems in Normal and Transport Category Rotorcraft*. That NPRM highlighted the hazards of a post-impact fire (PIF) leading to fatalities in an otherwise survivable rotorcraft accident.

Following the NPRM, the FAA introduced amended crash-resistant fuel system requirements for those categories of helicopters. This included the introduction on 2 November 1994 of Section 27.952 *Fuel system crash resistance* (see appendix C), which summarised:

> Unless other means acceptable to the Administrator are employed to minimise the hazards of fuel fires to occupants following an otherwise survivable impact (crash landing), the fuel systems must incorporate the design features of this section. These systems must be shown to be capable of sustaining the static and dynamic deceleration loads of this section, considered as the ultimate loads acting alone, measured at the system component's centre of gravity, without structural damage to system components, fuel tanks, or their attachments that would leak fuel to an ignition source.

Section 27.952 applied to any helicopter seeking a type certificate under Part 27 after that date. One of the requirements outlined in Section 27.952 was a drop test of each, or the most critical fuel tank. This entailed the tank(s) being filled with water to at least 80 per cent capacity and being dropped from a height of at least 50 ft (15.2 m) onto a non-deforming surface. No leakage was permitted as a result of the impact.

There was no retrospectivity in respect of helicopter types certified under the earlier requirements, unless an unsafe condition was considered to exist.

The bladder-type fuel tanks developed by the helicopter manufacturer to replace the all-aluminium tanks in accordance with Service Bulletins SB-78, -78A and -78B (see the section titled *Fuel system revisions*) complied with the drop test requirements of Section 27.952. In respect of the other requirements of that section, the FAA advised that:

> Compliance was neither shown nor found with any of the other requirements described in Section 27.952. Neither showing nor finding of compliance to all requirements of Section 27.952 was necessary because the FAA considered installation of the bladder-type fuel tanks a non-required safety enhancing measure. The installation was not required by airworthiness directive since the originally certified aluminum fuel tanks on the R-44 were determined safe in accordance with original certification basis.

European Aviation Safety Agency regulation of helicopter fuel systems

The European Aviation Safety Agency (EASA) regulations relating to helicopter fuel systems essentially mirrored the FAA requirements. The EASA equivalent to FAA Section 27.952, CS 27.952 *Fuel system crash resistance*, introduced on 14 November 2003, is contained within the *Certification Specification for Small Rotorcraft CS-27*. As in the case of the FAA certification requirements, helicopter types that were certified under earlier EASA requirements did not have to comply with the newer standards.

Research into helicopter accidents with post-impact fire

Previous US Army research and development

As a result of significant concern regarding the number of fire-related fatalities in helicopter accidents, the US Army required all new helicopters from 1970 to be fitted with a crashworthy fuel system (CWFS)[14] and it undertook a program to retrofit existing helicopters with a CWFS. Knapp and others (1981) reviewed US army helicopter accident statistics that demonstrated the significance of the post-impact fire (PIF) problem and the effectiveness of a CWFS. Key results included:

- In the period 1967 to 1969 (before the requirement for a CWFS), PIF was involved in 83 per cent of the non-survivable accidents and 13 per cent of the survivable accidents. PIF contributed to 31 per cent of all fatalities, including 37 per cent of the fatalities in survivable accidents.[15]
- In the period 1970 to 1976 for helicopters without a CWFS, PIF was involved in 69 per cent of the non-survivable accidents and 4 per cent of the survivable accidents. PIF contributed to 16 per cent of all fatalities, including 22 per cent of the 154 fatalities in survivable accidents.
- In the period 1970 to 1976 for helicopters with a CWFS, PIF was involved in 36 per cent of the non-survivable accidents and 1 per cent of the survivable accidents. PIF contributed to only 1 of the total 129 fatalities, and none of the 44 fatalities in the survivable accidents.

The authors stated that a major factor in the reduction of the proportion of PIFs between the late 1960s and the 1970s for helicopters not fitted with a CWFS was the rapid retrofit program of helicopters considered to be of highest risk.

US National Transportation Safety Board 1980 study

In 1980, the US National Transportation Safety Board (NTSB) conducted a study of PIF in general aviation aircraft (including aeroplanes and helicopters) between 1974 and 1978. It found that 8 per cent of all accidents resulted in PIF. In addition, 59 per cent of the accidents with PIF resulted in fatalities and only 13 per cent of other accidents resulted in fatalities.

The NTSB broadly classified accidents in terms of whether they were ‘severe’, such as involving a collision with terrain or stall/spin, or ‘less severe’, such as a hard landing or wheels-up landing. Twelve per cent of the severe accidents resulted in PIF, and 62 per cent of these PIF accidents were associated with fatalities, with fatalities in only 13 per cent of the severe accidents without PIF. Two per cent of the less severe accidents resulted in PIF, and 19 per cent of these PIF accidents were associated with fatalities, with fatalities in only 1 per cent of the less-severe accidents without PIF. The NTSB concluded that fire rather than impact was the major contributor to fatalities in accidents with PIF in general aviation aircraft.

Based on this data, the NTSB made several recommendations to the US Federal Aviation Administration (FAA), including to require latest technology crash-resistant fuel lines and fuel tanks in newly certified aircraft (recommendations A-80-90 and A-80-91), require newly-manufactured aircraft after a prescribed date to comply with the amended regulations (A-80-92), and assess the feasibility of retrofitting crash-resistant fuel system (CRFS) components to existing aircraft (A-80-94). The FAA consulted with the aviation industry and issued a Notice of Proposed Rulemaking (NPRM) regarding improved crashworthiness certification requirements for normal category aeroplanes, but ultimately no regulatory changes resulted from the NTSB recommendations.

Research and recommendations in the 1980s

Coltman and others (1985) examined US civil helicopter accidents between 1974 and 1978. They stated that sufficient data was available to estimate impact conditions for only 311 of the 1,351 accidents, and PIF was involved in 21 per cent of these accidents. PIF was involved in 14 per cent of the 247 accidents considered survivable or partially survivable and 52 per cent of

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[14] A CWFS, as used in in the US military, is designed to a higher standard than a crash-resistant fuel system (CRFS), as used in some civilian helicopter types.

[15] The definition of survivable was related to impact forces and did not consider hazards such as fire or drowning.

the 56 accidents considered non-survivable.[16] For survivable accidents involving helicopters without a CRFS, fire was considered to have contributed to 30 per cent of the 60 fatalities.

In 1985, the NTSB noted that the FAA had been working closely with general aviation aeroplane manufacturers to improve the crashworthiness of these aircraft, but that comparable efforts had not yet been undertaken for helicopters. In a letter to the FAA, the NTSB stated:

> The U.S. Army has developed and used helicopter crashworthiness design guidelines successfully; the FAA and industry have tested CRFS and have developed the design parameters needed for the development of regulatory standards; and the helicopter manufacturers have designed, constructed, and tested essentially all of the other components necessary to bring civilian helicopters into compliance with the state-of-the-art in helicopter occupant safety. The existing body of knowledge about, and the technological capabilities for, improving helicopter crashworthiness are sufficient to dictate that state-of-the-art crashworthiness design now be incorporated into the helicopter fleet.

The NTSB letter also noted that even though CRFSs were available to retrofit some civilian helicopter types, owners and operators rarely chose to do so due to the cost and weight considerations. The NTSB recommended that the FAA enhance the certification requirements for civil helicopters to include enhanced fuel systems as well as address other crashworthiness aspects (recommendation A-85-69).

Research supporting new crash-resistant fuel system certification requirements

In 1990, the US FAA issued an NPRM to introduce CRFS design and test criteria to the airworthiness standards for normal and transport category helicopters (see the section titled *US FAA introduction of crash-resistant fuel system requirements*).[17] The background section stated:

> A postcrash fire (PCF) is the number one cause of fatalities and injuries in an otherwise survivable impact resulting from a rotorcraft accident. It is estimated that annually 5 percent of the occupants in survivable rotorcraft accidents are killed or injured by a PCF. These types of fatalities and traumatic injuries would be substantially reduced by adopting the design and test criteria proposed in this notice. Nearly all PCF's are caused by crash-induced fuel leaks that quickly come in contact with ignition sources during or after impact… A crash resistant fuel system, CRFS, would not be expected to prevent all fires; however, a CRFS would, in the majority of impact survivable cases, either prevent a PCF or delay the sudden massive fire, or fireball, long enough to allow the occupants to escape…

In the section on evaluating the benefits of a CRFS, the NPRM stated:

> To evaluate this proposed rule, NTSB accident data from January 1, 1983, to December 31, 1987, were used provided a passenger or a crewmember was seriously injured or killed as a result of the accident, and provided the rotorcraft accident was a crash landing or a collision with an object… During this 5-year period, there were 295 severe rotorcraft accidents that resulted from crash landings or from collisions with an object. In 143 of these accidents (44 of which involved postcrash fires), none of the occupants survived. There was at least one survivor in the other 152 accidents (19 of which involved postcrash fires).
>
> There was a high fatality rate (77 percent) in accidents that had a postcrash fire... In the survivable accidents involving postcrash fires, 23.4 percent of the occupants were killed and 63.0 percent were seriously injured. In survivable accidents without postcrash fires, 15.7 percent of the occupants were killed and 47.6 percent were seriously injured…
>
> A review of the crashworthiness study done for the U.S. Army showed that 50 percent of all rotorcraft accidents with postcrash fires were survivable on impact. This suggests that some of the civilian rotorcraft accidents in which there were no survivors were also survivable on impact.

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[16] The existence of fire for the remaining 8 accidents was unknown.

[17] Normal category helicopters include those with a maximum take-off weight up to 7,000 pounds (3,200 kg) and up to nine seats, with US certification requirements detailed in Part 27 of the US Federal Aviation Regulations. The certification requirements for (larger) transport category helicopters are detailed in Part 29.

Following the NPRM, amended requirements for CRFSs were introduced in October 1994 for all new rotorcraft designs in Federal Aviation Regulation 27.952 (normal category) and 29.752 (transport category).

Research after the introduction of the new certification requirements

Robertson and others (2002) conducted a review of the development of CRFS in helicopters. They reviewed helicopter accidents in the NTSB database and noted that the post-impact fire (PIF) problem was still occurring. However, they did not conduct a detailed analysis as they believed there was insufficient data available in most accident reports regarding key parameters such as the descriptions of injuries, crash damage, CRFS configuration, and fuel and ignition sources. The report stated:

> Postcrash fires account for a high percentage of injuries and fatalities in aircraft accidents that would, in the absence of such fires, be survivable. The successful development and implementation of crash-resistant fuel systems by the U.S. Army in its rotorcraft fleet has proven that technology is available to virtually eliminate fire fatalities in otherwise survivable helicopter accidents. The transference of this technology to civil helicopters has been slow in several decades since the Army implemented this technology. Although the level of crash resistance in some civil helicopters has been improved over the years, progress has been uneven.

Hayden and others (2005) examined the proportion of accidents that resulted in a PIF for Bell 206 helicopters and Aérospatiale (now Airbus Helicopters) AS350 helicopters, given that they were of similar size and that Bell 206s after 1981 were manufactured with a CRFS.[18] The PIF proportion for Bell 206s manufactured up to 1981 (7 per cent) was higher than for Bell 206s manufactured after 1981 (4 per cent). Similarly, the PIF proportion for Aérospatiale AS350s manufactured after 1981 (11 per cent) was higher than that for Bell 206s.[19]

Transportation Safety Board of Canada safety issue investigation

In 2006, the Transportation Safety Board (TSB) of Canada published a safety issues investigation report into PIFs resulting from accidents involving powered aircraft with a maximum take-off weight less than 5,700 kg (both aeroplane and helicopter). The investigation reviewed accidents in Canada from 1976 to 2002, and concluded that PIF occurred in 521 accidents, or 4 per cent of all accidents. The PIF accidents resulted in 728 fatalities, and the likelihood of fatalities was 5 times higher in a PIF accident than an accident not involving PIF.

The TSB reviewed post-mortem examination reports and related information for the 521 PIF accidents to differentiate injuries related to fire and impact. Overall, 128 of the accidents (25 per cent) were considered otherwise survivable. Fire was identified as either partly or solely responsible for at least 205 (28 per cent) of the 728 fatalities that occurred in the PIF accidents. The cause of death was unavailable or undetermined for 129 of the 728 fatalities.

The 521 PIF accidents included 94 helicopter accidents, and 43 of these accidents (46 per cent) resulted in fatalities.[20] In 14 accidents (at least 33 per cent of the fatal PIF accidents), fire contributed to one or more fatalities. [21] None of these 14 helicopters, or any of the other helicopters that experienced a PIF, was fitted with a CRFS.

The TSB stated:

> There are a large number of small aircraft already in service and the defences against PIF in impact-survivable accidents involving these aircraft are and will remain inadequate unless

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[18] Bell called this form of CRFS an 'impact resistant fuel system'. As it was introduced prior to 1994, it was not certified by the FAA.

[19] This study used the NTSB's coding of 'ground' fire as an indicator of a PIF. However, ground fires can also include other types of fires that occur unrelated to an impact. The study excluded accidents involving in-flight fire.

[20] Some of this data was not contained in the original report but was supplied by the TSB.

[21] The study found that fire contributed to 27 fatalities and impact contributed to 46 fatalities, with the cause of the other 28 fatalities being undetermined. Therefore the proportion of fatal PIF accidents where fire contributed to fatalities was likely to be higher than 33 per cent.

> countermeasures are introduced to reduce the risk. The most effective ways to prevent PIF in accidents involving existing small aircraft are to eliminate potential ignition sources, such as hot items, high-temperature electrical arcing and friction sparking, and prevent fuel spillage by preserving fuel system integrity in survivable crash conditions. Technology that is known to reduce the incidence of PIF by preventing ignition and containing fuel in crash conditions may be selectively retrofitted to existing small aircraft, including helicopters certified before 1994.

The TSB recommended that design standards be introduced for newly-certified aeroplanes to reduce the incidence of PIF. For existing aircraft (aeroplanes and helicopters), it issued recommendation A06-10, which stated:

> To reduce the number of post-impact fires in impact-survivable accidents involving existing production aircraft weighing less than 5700 kg, Transport Canada, the Federal Aviation Administration, and other foreign regulators conduct risk assessments to determine the feasibility of retrofitting aircraft with the following:
>
> - selected technology to eliminate hot items as a potential ignition source;
> - technology designed to inert the battery and electrical systems at impact to eliminate high-temperature electrical arcing as a potential ignition source;
> - protective or sacrificial insulating materials in locations that are vulnerable to friction heating and sparking during accidents to eliminate friction sparking as a potential ignition source; and
> - selected fuel system crashworthiness components that retain fuel.

The TSB’s latest assessment of responses by Transport Canada and the FAA to this recommendation (6 March 2013) stated that the risks identified had not abated and remained significant. It noted that no action had been taken or proposed that would reduce or eliminate the deficiency, and it classified the responses to date as ‘unsatisfactory’.

US Federal Aviation Administration comparison of post-impact fire proportions for different helicopter types

Following the accident involving VH-COK in 2012,[22] the Civil Aviation Safety Authority (CASA) advised the US FAA that it was evaluating the potential for issuing an Australian Airworthiness Directive regarding R44 fuel tanks, and it asked the FAA for information regarding the FAA’s intentions. In January 2013 the FAA advised CASA that it had conducted a review of PIFs for the R44 and ‘similar, small reciprocating engine powered multipurpose helicopters’. The results showed that the proportion of accidents that resulted in PIF for the R44 was similar to that of several other helicopter types designed in the same timeframe as the R44. The FAA concluded that therefore there was no unique unsafe condition with the basic design of the R44 fuel system and no corrective action was required. The FAA noted that a helicopter that is compliant with the fuel system crashworthiness rule (FAR 27.952) is safer than one that is not compliant, but that the absence of FAR 27.952 compliance did not constitute an unsafe condition.

The ATSB requested further information from the FAA regarding the nature and results of its analysis. The FAA advised that an examination of the crashworthiness of fuel systems would ideally involve looking at the proportion of accidents with the following scenario:

- the helicopter crashes
- the crash (impact) is survived
- there is a PIF
- the fatalities are due to the PIF and not the impact.

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[22] ATSB aviation occurrence investigation report AO-2012-021, available at www.atsb.gov.au.

However, it concluded that making these determinations was very difficult as most reports of accidents involving PIF did not document whether the impact was survivable or, if there were fatalities, whether the fatalities were the result of the impact or PIF. It also concluded that making such determinations after the fact was challenging and perhaps impossible. Given these limitations, the FAA based its analysis on the proportion of all accidents that resulted in a PIF. It acknowledged that there were many assumptions and limitations associated with such an analysis. These included:

- The NTSB database only recorded whether a fire occurred in-flight or on the ground. Ground fires would include a PIF but could also include other types of fires, such as those unrelated to the fuel system.
- The PIF proportion did not consider the overall accident rate and therefore the PIF per flight hour rate of a helicopter.
- There are no defined standards as to what proportion of accidents resulting in PIF is safe or unsafe.

Nevertheless, the FAA concluded that examining the proportion of accidents resulting in PIF could provide a relatively meaningful comparison of helicopter models even with the associated limitations and assumptions, and that if the R44 proportion was ‘greatly different from other similar helicopters that fly similar missions, further safety studies and actions may be warranted’.

The FAA’s analysis examined accidents involving US-registered, non-amateur-built helicopters with reciprocating (piston) engines for the period 1 January 1982 through to 1 November 2012. The PIF proportion for the R44 was not found to be statistically different to some other types, and a deeper level of analysis was not deemed necessary.

US Federal Aviation Administration review of post-mortem reports and related accident information

In December 2013, the FAA completed another study looking at the extent to which PIF contributed to fatalities in normal and transport category helicopter accidents over a 5-year period between 13 October 2008 and 27 September 2013. The study reviewed post-mortem examination reports and related accident information, although post-mortem reports were generally only available for pilots and passengers with a pilot licence.

Overall, there were 93 fatal accidents where the required data was able to be reviewed, and PIF was involved in 34 of these accidents (37 per cent). There were PIFs in 33 of the 82 fatal accidents (40 per cent) involving helicopters without a certified CRFS, and 1 of the 11 accidents involving helicopters with a certified CRFS (9 per cent).

The FAA found that fire contributed to a fatality in 8 of the 34 fatal PIF accidents (24 per cent), and this included 6 of the 31 fatal PIF accidents (19 per cent) involving helicopters that were certified in the normal category. Given that some passenger fatalities were not considered, this proportion was probably an underestimate.

The FAA compared the R44 with other helicopter models certified in the normal category without a CRFS. Of the 16 fatal R44 accidents, 8 resulted in a PIF (50 per cent). For the other 57 fatal accidents, 22 resulted in a PIF (39 per cent). Fire contributed to a fatality in 2 of the 8 fatal R44 accidents with PIF (25 per cent),[23] and 4 of the 22 other fatal PIF accidents involving other types without a certified CRFS (18 per cent). The FAA noted that the R44 had a similar proportion of fatal accidents involving PIF as some other common helicopter types, and a similar proportion of fatal PIF accidents where fire contributed to a fatality as some other common helicopter types. It concluded that its data suggested no statistical difference between the R44 and other common

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[23] The FAA study did not differentiate between R44s with or without a bladder-type tank. The 8 fatal PIF accidents involving R44s included 2 R44s with bladder-type tanks, and fire was assessed as contributing to a fatality in 1 of these 2 accidents.

types without a certified CRFS. It also noted that 'Due to relatively small numbers in this data set, the significance of these findings is difficult to assess'.

Australian Transport Safety Bureau review of post-impact fire accidents

General results

The ATSB examined the proportion of accidents resulting in PIF for civil light helicopters in Australia and the US for the period 1993 to 2013.[24] Key results are presented in this section, with more detailed results and explanations provided in appendix A.

Overall, there were 3,761 helicopter accidents. About 10 per cent of the accidents were clearly not relevant for examining PIF issues and were excluded from analysis,[25] and only fires that occurred after an impact and led to significant damage were included as a PIF.[26] Overall, there were 260 PIFs in the 3,387 relevant accidents, a PIF proportion of 8 per cent. The PIF proportion increased for accidents with any injury (15 per cent), accidents with a serious/fatal injury (24 per cent) and accidents with at least one fatality (38 per cent).

Overall, 175 of the 260 PIF accidents (67 per cent) resulted in fatalities. As noted in many previous studies, determining the extent to which fatal accidents were survivable or the extent to which fire may have contributed to fatalities is often difficult based on only reviewing accident reports. Nevertheless, the following information was able to be determined:

- For the 26 fatal PIF accidents in Australia, a review of the post-mortem examination reports, accident reports and related information identified that fire probably contributed to at least one fatality in 9 of the accidents (35 per cent), with insufficient information to determine the role of PIF in 2 of the accidents. Fire was considered likely to have contributed to 17 of the 19 fatalities in the 9 accidents. This included the 8 fatalities in the 3 R44 accidents involving VH-HFH,[27] VH-COK and VH-HWQ.
- As noted above, the FAA determined that fire probably contributed to a fatality in 6 of the 31 fatal PIF accidents involving light helicopters in the US between 13 October 2008 and 27 September 2013. Excluding the period covered by the FAA study, there were 113 fatal PIF accidents in the US between 1993 and 2013.[28] A review of the NTSB reports identified that post-mortem examinations indicated that fire probably contributed to a fatality in 11 of the 113 accidents (10 per cent). This figure was likely to be a significant underestimate as the NTSB reports did not always provide information about cause of death, and where provided it usually focussed on the pilot(s). The combined results of the Australian sample (at least 9 of 26 accidents), the 2006 TSB study (at least 14 of 43 accidents) and the FAA study of post-mortem examinations (at least 6 of 31 accidents) indicate that fire is likely to contribute to fatalities in at least 30 per cent of fatal PIF accidents involving light helicopters.
- There were survivors in 8 of the 27 fatal PIF accidents in the combined Australian and US data where fire was assessed as probably contributing to fatalities. There were also survivors in 16 of the other 148 fatal PIF accidents. It is important to note that even though some occupants may survive an impact, the impact may not be survivable for others due to factors such as the impact angle and the occupant's location in the helicopter.

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[24] The analysis was restricted to helicopters that were certified in the normal category or were ex-military helicopters on the civil aircraft register and in the same weight range. Amateur-built helicopters were not included.

[25] Excluded accidents included those with no helicopter damage, fuel exhaustion, impact with water, in-flight fire or a normal landing followed by a grass fire due to a hot exhaust.

[26] In addition, fires that were reported to have initiated, or the related explosion occurred, more than 90 seconds after impact were not considered to be a PIF for the purposes of this review.

[27] ATSB aviation occurrence investigation report AO-2011-016, available at www.atsb.gov.au.

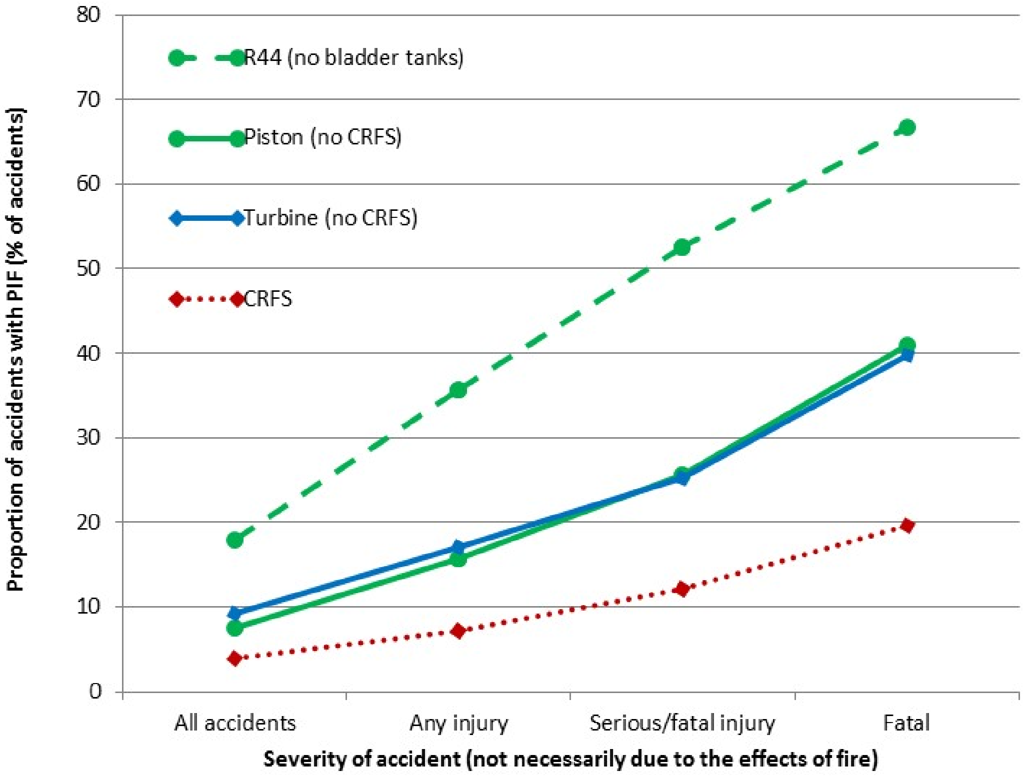
[28] There were 37 fatal PIF accidents during the period covered by the FAA study but only 31 of these were able to be included in that study.

Comparison of helicopters with and without a CRFS

Figure 10 shows the PIF proportions for piston-engine helicopters and turbine-engine helicopters without a CRFS, as well as helicopters fitted with a CRFS (almost all turbine-engine).[29] Helicopters with a CRFS had a significantly lower proportion of PIFs for all accidents (4 per cent) than helicopters without a CRFS (8 per cent). The proportion was also lower for accidents with different levels of severity, particularly for serious/fatal injury accidents (12 versus 25 per cent) and fatal accidents (20 versus 40 per cent). Ex-military helicopters with a CWFS had a particularly low proportion of PIF for fatal accidents (6 per cent) compared to other helicopters with a CRFS (26 per cent).

None of the 26 fatal PIF accidents in Australia involved an aircraft fitted with a CRFS. In terms of the US data, for the period covered by the FAA study, the FAA found that fire did not contribute to a fatality in the single accident involving a helicopter with a certified CRFS but it did contribute to a fatality in 6 of the 30 fatal PIF accidents involving helicopters without a certified CRFS. However, using the ATSB's classification of CRFS, one of these 6 helicopters was an ex-military helicopter that probably had a CWFS, even though it was not certified under civil regulations. Using the ATSB's classification of a CRFS, fire contributed to a fatality in 5 of the 28 accidents involving helicopters without a CRFS and 1 of the 3 helicopters with a CRFS in the FAA sample. For the 113 fatal PIF accidents in the US outside of the period covered by the FAA study, there were indications that the fire contributed to a fatality in at least 11 of the 107 fatal PIF accidents involving a helicopter without a CRFS (10 per cent) and none of the 6 fatal PIF accidents in a helicopter fitted with a CRFS (0 per cent).

Figure 10: Post-impact fire proportions for all helicopters



Source: ATSB

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[29] In contrast to the FAA study, the ATSB's classification of a helicopters with a CRFS was not restricted to those with a certified CRFS. The ATSB classification also included ex-military helicopters with a CWFS and Bell 206 helicopters manufactured after 1981 (in line with the study by Hayden and others (2005). Further details are provided in appendix A.

Robinson R44 post-impact fires

In Australia, there were 47 relevant accidents during the period 1993-2013 involving R44 helicopters without bladder-type tanks, and 7 of these accidents involved PIF. Six of these accidents resulted in fatalities. In the US during the period 1993–2013, there were 159 accidents involving R44 helicopters without bladder-type tanks, and 30 of these accidents involved PIF. Of these 30 accidents, 22 resulted in fatalities.

In summary, during the period 1993–2013 in Australia and the US, PIF was involved in 37 of the 206 accidents involving R44 helicopters not fitted with bladder-type tanks (18 per cent). The PIF proportion for accidents resulting in serious or fatal injuries was 52 per cent, and the proportion for fatal accidents was 67 per cent (Figure 10).

Two of the fatal PIF accidents in Australia (VH-COK and VH-HWQ) involved relatively low-energy impacts, and post-mortem examination reports for both accidents indicated that fire contributed to the fatalities. It also appeared that some of the fatal PIF R44 accidents in the US involved survivable or relatively low-energy impacts. The FAA study found that fire contributed to at least one fatality in 1 of the 6 fatal PIF accidents involving R44s without bladder-type tanks, and in 3 of the other 16 fatal PIF accidents outside the period of the FAA study. The NTSB reports provided post-mortem examination results that indicated that fire contributed to at least one of the fatalities.[30] All of these accidents in the US where fire appeared to contribute to fatalities occurred between 2007 and 2012.

Up to the end of 2013 in Australia and the US, the number of accidents involving R44s with bladder-type tanks was not sufficient to provide a reliable comparison. PIF was involved in 1 of the 21 accidents (5 per cent). As it was not possible to identify whether some of the helicopters involved in non-PIF accidents had bladder-type tanks retrofitted, it is likely that this proportion was lower.

In April 2015, the Robinson Helicopter Company advised that, since the release of SB-78 in December 2010, it was aware of 87 accidents around the world involving R44s fitted with bladder-type tanks and PIFs were involved in 10 of these accidents (11 per cent). Thirty accidents resulted in serious or fatal injuries, and 7 of these accidents resulted in a PIF (23 per cent). There were 23 fatal accidents, and 7 of these accidents resulted in a PIF (30 per cent). These figures were similar to the average for all light helicopters without a CRFS excluding the R44 (see appendix A).

Comparison of the R44 with other types

In general, piston-engine helicopters are lighter and have a smaller capacity than turbine-engine helicopters. However, the R44, with its 4-seat capacity, is often used in a similar role to some turbine-engine helicopters. Therefore, it is useful to compare the R44 with both piston-engine and turbine-engine helicopter types.

As can be seen in Figure 10, the R44 without bladder-type tanks had a significantly higher PIF proportion than the average for other piston- or turbine-engine helicopters without a CRFS at each level of accident severity. For serious/fatal injury accidents, the R44 proportion (52 per cent) was twice the average of all other helicopters not fitted with a CRFS (23 per cent). For fatal accidents, the R44 proportion was also substantially higher than the average of all other helicopters not fitted with a CRFS (67 versus 37 per cent).

Figure 11 shows the PIF proportions for the R44 and six other helicopter types without a CRFS and with a sufficient number of accidents to conduct reliable comparisons. Key results included:

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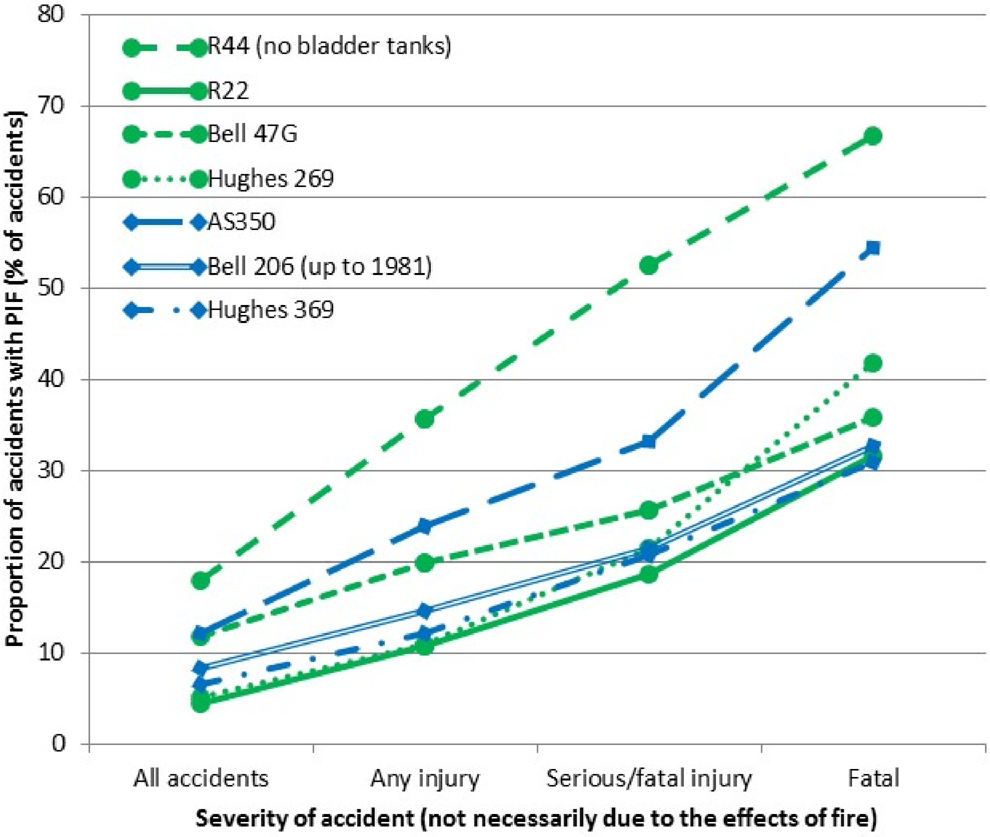
[30] This included 1 of the 6 fatal R44 accidents involving R44s without bladder-type tanks that occurred during the period of the FAA study. There was also one US fatal PIF R44 accident with survivors, and subsequent information indicated that fire probably contributed to at least one fatality in this accident.

- The R44 had a higher PIF proportion for all accidents (18 per cent) than the other common types. However, the differences between the R44 and the Bell 47G piston-engine helicopter (12 per cent) and the R44 and the Eurocopter AS350 turbine-engine helicopter[31] (12 per cent) were not statistically significant.[32]
- The R44 had a higher PIF proportion for serious/fatal injury accidents (52 per cent) than all the other common helicopter types.
- The R44 had a higher PIF proportion for fatal accidents (67 per cent) than all the other common types, but the difference between the R44 and the AS350 (55 per cent) was not statistically significant.

Figure 11: Post-impact fire proportions for common helicopter types



Source: ATSB

For the Australian accidents, fire contributed to a fatality in 3 of the 6 fatal PIF accidents involving R44s without bladder-type tanks (50 per cent) and 6 of the 20 accidents involving other helicopter types (30 per cent). In the FAA study, fire contributed to a fatality in 1 of the 6 fatal PIF accidents involving R44s without bladder-type tanks (17 per cent) and 4 of the 22 accidents involving other helicopter types without a CRFS (18 per cent). For the US data outside the period covered by the FAA study, the NTSB reports indicated that fire probably contributed to a fatality in at least 3 of the 16 fatal PIF accidents involving R44s without bladder-type tanks (19 per cent) and 8 of the 91 fatal PIF accidents involving other helicopter types without a CRFS (9 per cent).

Comparing the R44 with other helicopter types without a CRFS in terms of the proportion of fatal PIF accidents where fire contributed to a fatality is problematic due to the small number of fatal

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[31] For this report the AS350 includes all Aérospatiale and Eurocopter AS350 models and the related Eurocopter EC130 B4.

[32] In this report, statistically significant means that the chance of the difference being present due to chance alone was less than 5 per cent.

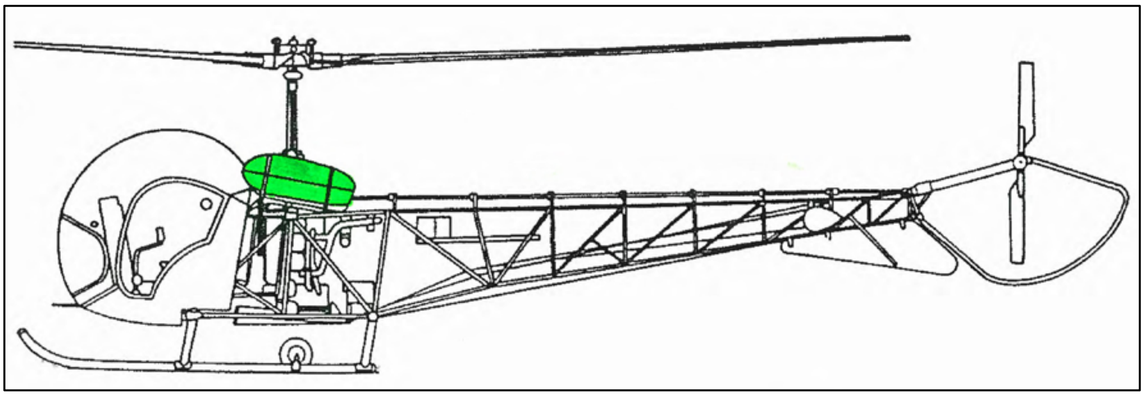
PIF accidents for each type. The combined results of examining the Australian fatal PIF accidents, the FAA study, and the review of NTSB reports outside of the period covered by the FAA study, indicated that fire probably contributed to a fatality in at least 7 of the 28 accidents involving R44s without bladder-type tanks (25 per cent), 3 of the 24 accidents involving R22s (14 per cent), 1 of the 14 accidents involving Bell 47Gs (7 per cent), 4 of the 13 accidents involving Hughes 269s (31 per cent), 3 of the 20 accidents involving AS350s (15 per cent), 3 of the 21 accidents involving Bell 206s (14 per cent) and 1 of the 10 accidents involving Hughes 369s (10 per cent).

Other helicopter types

Some of the Bell 47G PIF accidents were associated with a relatively low-energy impact, similar to the results for the R44. The PIF proportion for the 47G was higher than other piston-engine models (excluding the R44) for all accidents. However, most of the 47G PIF accidents were not associated with serious outcomes and the PIF proportion for accidents involving any injury, serious/fatal injury or fatality was not different to that for other piston-engine helicopter types without a CRFS. This difference in results relative to the R44 may be due to the 47G, with a single row of seats, being easier to egress for survivors in some types of accidents.

The 47G has two ‘saddle’ fuel tanks mounted high behind the cockpit bubble (Figure 12), and it was reported that these were relatively easy to breach during an impact (Dugan and Delamer 2005). Bell released Service Bulletin 47-76-6 in 1976 to replace the Bell 47G fuel system with a more crashworthy type, including tanks that were wrapped with nylon fabric and had frangible fittings. This service bulletin was not associated with an airworthiness directive in the US or Australia. According to the type certificate holder, many Bell 47Gs were retrofitted with new tanks but a lower proportion were retrofitted with the frangible fittings.

Figure 12: Bell 47, left fuel tank highlighted in green (typical), which is duplicated on the right



Source: Bell Helicopter Company

The Airbus Helicopters AS350 appeared to have higher PIF proportions compared to the other common turbine-engine types with a similar size and role (that is, the Bell 206 manufactured up to 1981 and the Hughes 369), although not all of the differences for each level of accident severity were statistically significant. However, the PIF proportions for other turbine-engine helicopters without a CRFS combined were similar to that of the AS350 (see appendix A).

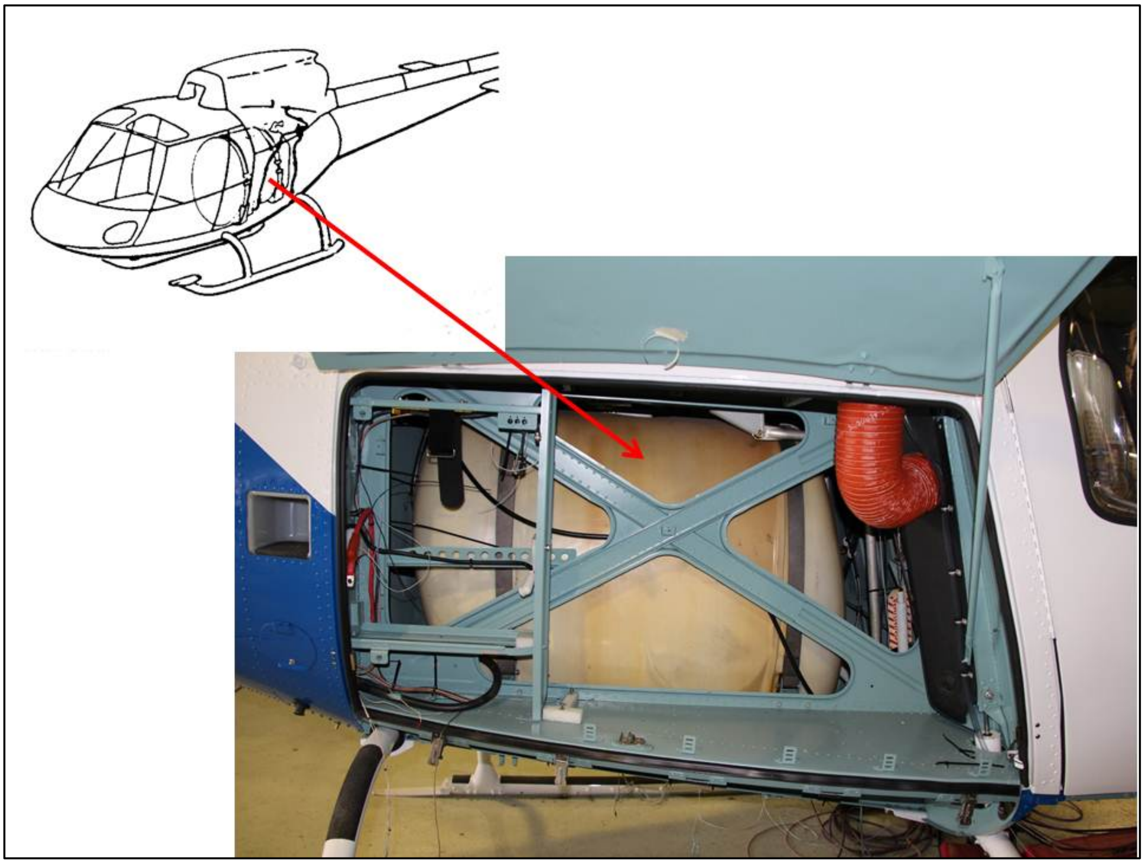
The AS350 manufacturer reported that it conducted a similar analysis of its worldwide database and found similar PIF proportions as the ATSB for accidents in the US and Australia. However, it noted that doing the same analysis for the rest of the world (about two thirds of the world fleet) found a significantly lower PIF proportion for the AS350.

Very few (if any) of the AS350’s PIF accidents in the US and Australia appeared to be associated with a relatively low-energy impact, and many of the 24 fatal PIF accidents appeared to be non-survivable. However, there were indications that fire contributed to fatalities in 3 US accidents,[33] and there were survivors in 4 other fatal PIF accidents. These results were broadly similar to the Bell 206 and the Hughes 369 helicopters.

The AS350 fuel system includes a single, polyamide (plastic) fuel tank located in the centre of the fuselage behind the cabin rear seats (Figure 13). The tank is positioned between the helicopter's body structure 'X' bulkheads and held in situ by two metal straps with adjustable turnbuckles. The tank has a lower energy absorbing design than that required by the current regulation but was in accordance with the regulation applicable during its certification.

The Airbus Helicopters EC130 T2 was certified after 1994 and had a CRFS that is compliant with FAR 27.952. Airbus Helicopters advised that the EC130 T2's CRFS included an 'energy absorbing fuel tank' and related components (Figure 14), and that this system was also available as an option for newly-manufactured AS350 B3e models. Additionally, Airbus Helicopters reported that their intention was to have a CRFS available for all new single-engine helicopters and to be in a position to retrofit existing AS350/EC130 helicopter versions with a CRFS (see the section titled *Safety issues and actions*).

Figure 13: AS350 fuel tank in situ



Source: ATSB, inset Airbus Helicopters

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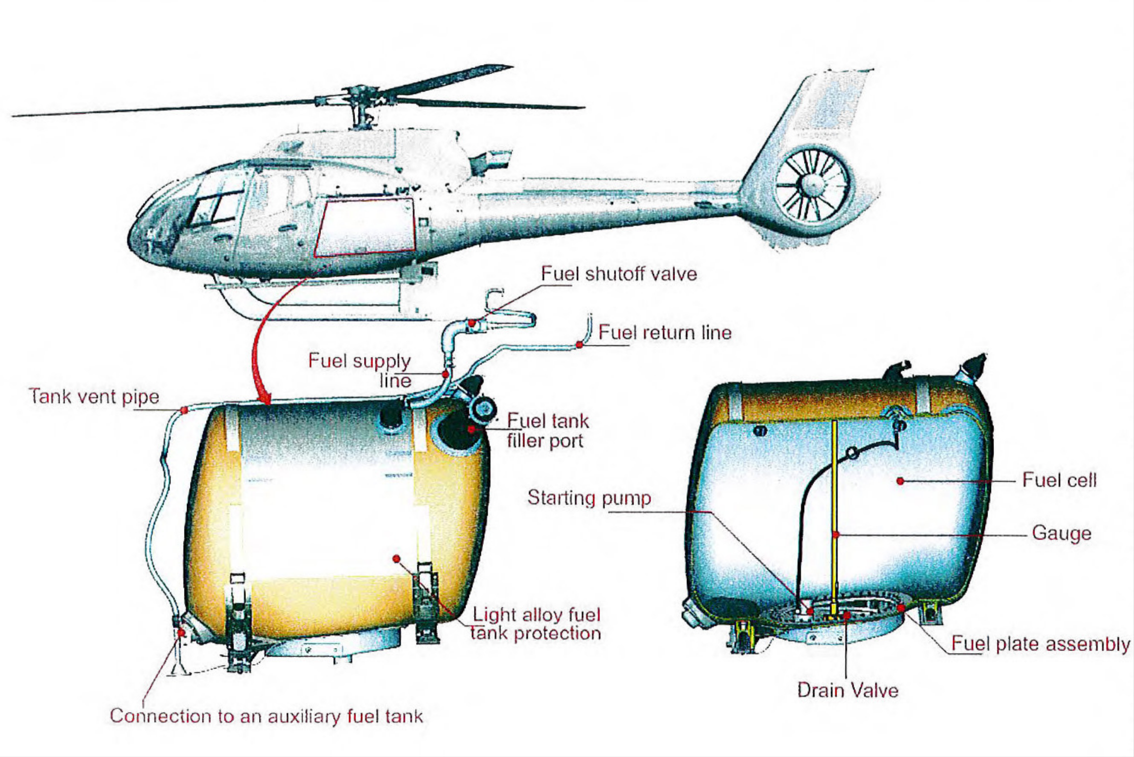
[33] NTSB reports indicated that fire may have contributed fatalities in 3 other AS350 accidents that occurred during the period covered by the FAA study, but the FAA concluded that fire did not contribute to a fatality in at least 2 of these accidents.

Figure 14: EC130 T2/B4/AS350B3 energy absorbing fuel tank



Source: Airbus Helicopters

There were some other helicopter types without CRFS that may have had a relatively high proportion of PIFs, but the low number of accidents associated with each type meant that there was little confidence in the results. Further details are provided in appendix A.

Safety analysis

Introduction

This analysis will examine the operational and technical factors and risks surrounding the accident in the context of the pilot being qualified for the flight and the helicopter being operated within weight and centre of gravity limitations and in benign weather. In addition, statistical analysis of the proportion of post-impact fires affecting R44 helicopters compared to other helicopter types will be discussed, together with the regulatory framework associated with the fitment of crash-resistant fuel systems.

Development of the accident

The initial approach and landing to the centre of the available grass area was reported by multiple witnesses to have been controlled and uneventful. Those observations indicated that, at that time, the helicopter was serviceable and were consistent with the pilot operating the helicopter normally to an area with which he was familiar.

It was stated by a number of witnesses that, following the initial landing, there was no reduction in the sound of the helicopter, consistent with constant engine and rotor system operating RPM. That was contrary to the expected decrease had the pilot been intending to allow the engine to cool due to the normal reduction in RPM as part of the shutdown procedure detailed in the R44 pilot's operating handbook (POH). Maintaining operating RPM indicated that consideration was being given to repositioning the helicopter or that the pilot had been distracted from the normal shut down process.

Based on the witness descriptions, about 30 seconds after the initial landing the helicopter again became airborne and yawed significantly to the right in what appeared to be a much less controlled manner than that previously observed. This indicated that the pilot's control of the helicopter had changed significantly or the pilot had not expected the helicopter to become airborne. Based on the testing and advice from the helicopter manufacturer, the helicopter could only have become airborne via a collective input while the rotor system was operating at high RPM, which was unlikely to have occurred via a flight control system malfunction. No evidence of any flight control defect was identified during the examination of the wreckage; however, the degree of fire damage prevented a full assessment of that system.

In the absence of a malfunction, the helicopter most likely became airborne following a collective input by the pilot, or possibly as a result of an inadvertent input from the front-seat passenger. As no flight controls were fitted to the front-left seat, any passenger movement of the collective would only have been possible via the pilot's collective. The witness description of an apparent forceful forward bodily movement by one of the front-seat occupants, immediately prior to the helicopter becoming airborne, indicated a possible relationship between those two events. However, the nature of the movement of the occupant(s) was inconsistent with the action of raising the collective and the degree of force normally applied to helicopter flight controls.

In respect of any forceful movement by a front-seat occupant, the ATSB considered whether the hydraulic-boost system switch on the pilot's collective may have been inadvertently selected OFF following the initial landing. In this respect, the manufacturer advised that the helicopter's hydraulic components cannot fail or malfunction in a manner that would raise the collective and cause un-commanded flight. In addition, as only the main rotor system was hydraulically boosted, the tail rotor pedal feel would have remained unchanged had there been a loss of hydraulic pressure. However, together with the unguarded nature of the switch, and given the absence of any visual or aural indication of disengagement, this meant that the pilot would only have become aware of any associated change in the flight control handling characteristics on making a collective or cyclic control input. Operation of the helicopter without hydraulic assistance may account for the described behaviour of the helicopter, especially if the pilot had been surprised by an unexpected change in handling characteristics. However, the significant increase in force to raise the collective in that circumstance would have alerted the pilot that the flight control ‘feel’ had changed. Similarly, any movement of the cyclic to control the position of the helicopter over the ground would also have resulted in changed control feel.

It was not possible to determine whether the hydraulic-boost system was engaged at the time of the accident.

The ATSB also considered the possibility that the accident may have been the result of a handling error by the pilot. Although that scenario could not be excluded, it was inconsistent with the described control of the helicopter during the initial approach and landing. In addition, the pilot’s post-mortem and witness observations indicated that it was unlikely the pilot suffered an incapacitating event, in turn with the potential to have affected his control of the helicopter.

While there was insufficient evidence to determine the circumstances that led to the helicopter becoming airborne following the initial landing, the proximity of the trees provided little time for the pilot to correct any drift from the original landing position before the main rotor blades struck the trees. Based on the witness observations, immediately following the tree strike the helicopter became uncontrollable and descended to the ground before rolling onto its right side. During the impact sequence the fuel system developed a significant leak that ignited into an intense post-impact fire (PIF).

Survivability

The available evidence indicated a relatively low-energy impact which, in the absence of the PIF, was unlikely to have led to fatalities. That assessment was supported by the results of the post-mortem examination, which showed that the occupants were fatally injured due to the effects of fire.

A safety issues investigation by the Transportation Safety Board (TSB) of Canada found that PIF had similarly contributed to injuries and fatalities in otherwise survivable accidents involving small aeroplanes and helicopters.[34] In relation to PIF survivability the investigation stated:

> …the odds of [fatal injury] were 14 times higher when a fire occurred after a crash than one where it did not.
>
> …the available tolerance/escape time in a 400 °F [204 °C] environment would be approximately 20 seconds…
>
> Occupants are normally seated in closer proximity to fuel in small aircraft than in larger aircraft. Also, the aircraft skin burn-through time is less in smaller aircraft due to reduced skin thicknesses.

and, in respect of the difficulty of extinguishing a PIF, that:

> For fire suppression to be an effective defence against fire-related injuries or fatalities where occupants are unable to evacuate an aircraft on their own following an accident, the fire must be suppressed or extinguished before the fire-related injuries or fatalities occur. This may not be possible in the case of most post-impact fuel-fed fires involving small aircraft. More often than not, small-aircraft accidents occur at sites other than …airports. Even when a small-aircraft accident occurs at a …designated airport and a fuel-fed PIF erupts at impact, the predictable escape time of 17 seconds is significantly less that the demonstrated ARFF [Aviation Rescue and Fire Fighting] response time of three minutes[35]. This indicates that there is much greater benefit to taking whatever engineering initiatives are necessary to prevent PIFs than there is to relying on potential rescue actions where fire occurs.

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[34] TSB Aviation Safety Issues Investigation Report SII A05-01 *Post-impact fires resulting from small aircraft accidents.* (ISBN 0-662-43937-6).

[35] ICAO Annex 14 - Aerodromes, lists a recommended rescue and firefighting service response time for aerodromes as not exceeding 3 minutes to any point of each operational runway, in optimum visibility and surface conditions.

> …
>
> Volatile liquid fuel is the combustible material of greatest significance in PIF accidents. Considering the propensity for rapid propagation and the catastrophic consequences of fuel-fed PIF, the most effective defence against PIF is to prevent the fire from occurring at impact, either by containing fuel or preventing ignition, or both.

The observations of the TSB investigation were consistent with the available firefighting equipment at the landing area at Bulli Tops and the attempts by the witnesses and other people in the area to extinguish the fire. Despite the valiant efforts of these people, the fire could not be suppressed with multiple handheld extinguishers. The intensity of the fire would have been difficult to suppress no matter what handheld device was used, reinforcing the finding by the TSB that the most effective defence against PIF is to prevent the fire from occurring at impact.

Crash resistance of the R44 fuel system

Review of light helicopter accident statistics

The fatal accident involving VH-HWQ was the third in Australia since 2011 involving R44 helicopters where a PIF occurred following an otherwise survivable impact. Several similar accidents have occurred in the United States (US).

The ATSB's review of accidents involving light helicopters in Australia and the US from 1993 to 2013 shows that the R44 (without bladder-type tanks fitted) had a higher proportion of accidents involving PIF than the average for other piston- or turbine-engine helicopter types without a crash-resistant fuel system (CRFS).

The ATSB review looked at the PIF proportions at different levels of accident severity. Of these, the proportion of serious/fatal injury accidents that result in PIF is probably the best statistic to use for comparing the crash resistance of different helicopter types, where sufficient data is available. Many accidents with nil or minor injuries involve minimal impacts, and a high proportion of fatal accidents with PIF (up to 70 per cent) involve high-energy, non-survivable impacts. For serious/fatal injury accidents, the R44's PIF proportion (52 per cent) was more than double the average for the other types without a CRFS (23 per cent), and it was significantly higher than any of the other common helicopter types.

Following the ATSB preliminary report into the accident involved VH-HWQ (released in April 2013), regulators in several countries, including Australia's Civil Aviation Safety Authority (CASA), concluded that the R44 fuel system design represented an unsafe condition, and accordingly they issued an Airworthiness Directive (AD) for owners and operators to comply with R44 Service Bulletin SB-78. However, the US Federal Aviation Administration (FAA) determined that an unsafe condition did not exist and it did not issue a similar AD. As the US is the State of Design, an AD issued by the FAA would normally be expected to be adopted by all national airworthiness authorities.

The FAA's initial decision was based on an analysis of the proportion of all accidents that resulted in a PIF, which found that the R44 was similar to other helicopter types with a similar certification base. In contrast, the ATSB's analysis used a different sample of accidents, excluded some types of accidents with limited relevance to examining PIF, had a more restricted definition of PIF, and examined PIF proportions for accidents with different levels of injury severity.

The FAA subsequently conducted a study that focussed on reviewing post-mortem results for fatal helicopter accidents over a 5-year period. It concluded that the R44 had a similar proportion of fatal accidents with a PIF as some other common helicopter types without a CRFS. The ATSB's analysis, which involved a much larger sample size of fatal PIF accidents, did find significant differences. In addition, the FAA study found that the R44 had a similar proportion of fatal PIF accidents where fire contributed to a fatality as some other common helicopter types without a CRFS. Data examined by the ATSB for Australian accidents, and using the NTSB reports for US accidents outside of the period covered by the FAA study, indicated that the R44 may have a higher proportion of fatal PIF accidents where fire contributed to a fatality than most of the other common types. Due to the low sample size for each helicopter type, the significance of these results regarding PIF's contribution to fatalities is difficult to assess. However, it seems clear that the R44's higher proportion of serious/fatal injury accidents that resulted in a PIF was not simply due to the R44 having a higher proportion of non-survivable, high-energy impacts.

In summary, the R44 has a significantly higher proportion of serious/fatal injury accidents that result in a PIF than other common helicopter types, and the proportion of fatal PIF accidents where fire contributed to a fatality appears to be at least similar if not higher than other common types. Together with evidence from several fatal R44 accidents that PIFs occurred with relatively low-energy impacts, the ATSB believes there is compelling evidence to conclude that there was a significant safety issue associated with the original, certified design of the R44's fuel system. In other words, the design of the helicopter's fuel system places its occupants at an unnecessarily high level of fire-related injury risk in the event that an impact occurred.

Manufacturer action

The Robinson Helicopter Company (RHC) advised that, following the identification of an increasing trend in the number of R44 rollover accidents that resulted in PIF, various upgrades were incorporated in the R44 fuel system. This included the introduction of bladder-type tanks in newly-manufactured aircraft from August 2009.

SB-78 for retrofitting bladder-type tanks in the R44 was issued in December 2010. Although there have been a limited number of accidents involving R44 helicopters that have had the bladder-type tanks fitted, initial indications are that the fuel system enhancements will reduce PIF risk.

The popularity of the R44 initially grew gradually, with a large increase in the number of models purchased from about the mid-2000s. From 1993 to 2005 (13 years), there were only 65 relevant R44 accidents in the US and Australia, and the overall proportion involving PIF was 12 per cent. This contrasts with 139 accidents in the 7 years from 2006 to 2013, with 22 per cent resulting in PIF. In addition, most of the salient examples where fire appeared to contribute to fatalities occurred after 2006 in the US and from 2011 to 2013 in Australia. In other words, the extent of the apparent problem may not have been easy to detect based on accident history. The manufacturer also noted that owners, operators and aviation authorities were not required to report accidents to the manufacturer. In addition, it noted that fire can consume critical information needed to help determine the reasons for accidents, and that in many accidents it is difficult to determine whether an accident would be survivable if a fire had not occurred.

Crash-resistant fuel system requirements

The R44 met the applicable certification requirements at the time it was designed, which prior to 1994 included minimal specifications regarding a CRFS. Although a small number of helicopter types designed to these requirements had some form of CRFS, and most of those designed after 1994 have a certified CRFS, the majority of the light helicopter fleet still does not have a CRFS.

The ATSB's review of accidents involving light helicopters in Australia and the US from 1993 to 2013 shows that accidents involving helicopters without a CRFS have a significantly higher proportion of PIFs than helicopters with a CRFS. For fatal PIF accidents, the difference is substantial (40 per cent versus 20 per cent), particularly given that a proportion of fatal accidents involve high-energy impacts that are often likely to result in a fire regardless of the fuel system. There are about eight fatal PIF accidents involving light (normal category) helicopters without a CRFS occurring each year in the US and Australia, and various studies show that fire probably contributes to fatalities in at least 30 per cent of fatal PIF accidents involving helicopters not fitted with a CRFS, with an average of two fire-related fatalities in each accident. Enhancing the crash resistance of helicopter fuel systems, both for light helicopters and transport helicopters, will ultimately prevent a substantial number of fatalities in otherwise survivable accidents.

There appears to be significant variability in the PIF proportions for helicopter types not fitted with a CRFS, indicating that fuel system designs for some of these types are inherently more crash resistant than others. There are also helicopter types other than the R44 without a CRFS that appear to have a relatively high proportion of accidents resulting in a PIF, though not to the same extent as the R44. Some of these helicopter types are still being manufactured without a CRFS. Given that it is 20 years since CRFS certification requirements were introduced in 1994, it would seem reasonable to now require that any helicopter type currently being manufactured should meet equivalent requirements, or have a demonstrated equivalent level of safety.

Retrofitting helicopters that have been already manufactured is generally a more difficult proposition, particularly in cases where enhanced designs for elements of a CRFS have not yet been developed for a particular type. In 2006, the TSB of Canada recommended that regulators consider risk assessments to determine the feasibility of retrofitting general aviation aircraft (aeroplanes and helicopters) with CRFS. The ATSB strongly endorses this recommendation, and urges regulators and manufacturers to proactively address the ongoing risk posed by PIF in existing helicopters. In particular, efforts should be directed at improving crash resistance for helicopter types that appear to have a higher proportion of PIFs, are more commonly used, have suitable retrofitting solutions available, and/or carry more passengers.

Findings

From the evidence available, the following findings are made with respect to the loss of control involving Robinson Helicopter Company R44 Raven 1 helicopter, registered VH-HWQ, which occurred at Bulli Tops, New South Wales on 21 March 2013. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Safety issues, or system problems, are highlighted in bold to emphasise their importance. A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

Contributing factors

- Soon after landing, the helicopter lifted off from the landing area as a result of either intentional or inadvertent collective flight control input and, a short time after, the main rotor blades contacted nearby trees before the helicopter descended to the ground and rolled onto its right side.
- The helicopter’s fuel system was breached during the low-energy impact sequence before leaking fuel ignited, resulting in an intense post-impact, fuel-fed fire.
- The pilot and passengers were fatally injured by the effects of the post-impact fire.

Other factors that increased risk

- **Accidents involving Robinson R44 helicopters without bladder-type fuel tanks fitted result in a significantly higher proportion of post-impact fires than accidents involving other similar helicopter types. In addition, the existing Australian regulatory arrangements were not sufficient to ensure all R44 operators and owners complied with the manufacturer's Service Bulletin SB-78B and fitted these tanks to improve resistance to post-impact fuel leaks. [Safety issue]**
- **Accidents involving Robinson R44 helicopters without bladder-type fuel tanks fitted result in a significantly higher proportion of post-impact fires than accidents involving other similar helicopter types. In addition, the existing United States regulatory arrangements are not sufficient to ensure all R44 operators and owners comply with the manufacturer's Service Bulletin SB-78B and fit these tanks to improve resistance to post-impact fuel leaks. [Safety issue]**
- **Although certification requirements for helicopters to include a crash-resistant fuel system (CRFS) were introduced in 1994, several helicopter types certified before these requirements became applicable are still being manufactured without a CRFS. [Safety issue]**
- **Many of the existing civil helicopter fleet are not fitted with a crash-resistant fuel system, or do not have an equivalent level of safety associated with post-impact fire prevention. [Safety issue]**

Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Fitment of bladder-type fuel tanks to R44 helicopters[36]

Number:	**AO-2013-055-SI-01**
Issue owner:	Civil Aviation Safety Authority
Operation affected:	General aviation
Who it affects:	All owners and operators of R44 helicopters

Safety issue description:

Accidents involving Robinson R44 helicopters without bladder-type tanks fitted result in a significantly higher proportion of post-impact fires than for other similar helicopter types. In addition, the existing Australian regulatory arrangements were not sufficient to ensure all R44 operators and owners complied with the manufacturer's Service Bulletin SB-78B and fitted these tanks to improve resistance to post-impact fuel leaks.

Proactive safety action taken by the Civil Aviation Safety Authority

On 27 March 2013, CASA stated:

> CASA has highlighted to registered operators the operation of CAR 42A. At page 1.1 of the Robinson Maintenance Schedule it states Service Bulletin compliance is mandatory. Registered operators of R44 helicopters who have elected, or are otherwise required, to use the manufacturer's maintenance schedule must comply with the abovementioned SB's by 30 April 2013. If they do not, the aircraft cannot be flown.

and that:

> CASA will also, as soon as possible, write to all operators of Robinson R44 helicopters to identify if any of them are subject to an approved system of maintenance that does not include a requirement to comply with service bulletins. If any such systems do not contain such a requirement, CASA will consider directing that the system be changed under CAR 42Q to require compliance with service bulletins.

Action number: AO-2013-055-NSA-002

ATSB action in response

The ATSB noted that Australian owners and operators of Robinson R44 aircraft had shown a greater rate of compliance with the manufacturer's Service Bulletin SB-78B than had occurred on a worldwide basis. The ATSB also noted CASA's understanding that existing regulatory requirements were such that compliance with SB-78B was already mandatory for the vast majority

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[36] A chronology of safety actions in respect of the installation of bladder-type tanks in the R44 is at appendix E.

of R44 helicopters in Australia. However, the ATSB remained concerned that a significant number of Australian owners and operators had not yet taken steps to comply with the service bulletin and were therefore very unlikely to be able to comply by the required date of 30 April 2013.

ATSB safety recommendation to the Civil Aviation Safety Authority

Action number: AO-2013-055-SR-001

Action status: Released 3 April 2013

The ATSB recommends that CASA take further action to ensure that owners and operators of Robinson R44 helicopters are aware of the relevant regulatory requirements and comply with the manufacturer's service bulletin SB-78B to replace all-aluminium fuel tanks with bladder-type tanks on Robinson R44 helicopters.

Subsequent safety action by the Civil Aviation Safety Authority

On 29 April 2013, in response to significant and growing concerns relating to the safety of Australian registered R44 helicopters still fitted with the existing aluminium fuel tanks, CASA issued Airworthiness Directive (AD) AD/R44/23 *R44 Bladder Fuel Tank Retrofit* (appendix D). That AD required compliance with Robinson Helicopter Company SB-78B by 30 April 2013. Any Australian registered R44 helicopters without the bladder-type tanks fitted after that date were not permitted to be operated until they were compliant.

Current status of the safety issue

Issue status: Adequately addressed

Justification: AD/R44/23 *R44 Bladder Fuel Tank Retrofit* by CASA mandated the fitment of bladder-type fuel tanks in Australian-registered R44s in accordance with SB-78B.

Number:	**AO-2013-055-SI-02**
Issue owner:	United States Federal Aviation Administration
Operation affected:	General aviation
Who it affects:	All owners and operators of R44 helicopters

Safety issue description:

Accidents involving Robinson R44 helicopters without bladder-type tanks fitted result in a significantly higher proportion of post-impact fires than for other similar helicopter types. In addition, the existing United States regulatory arrangements are not sufficient to ensure all R44 operators and owners comply with the manufacturer's Service Bulletin SB-78B and fit these tanks to improve resistance to post-impact fuel leaks.

Response to the safety issue by the United States Federal Aviation Administration

The Federal Aviation Administration (FAA) advised that, based on the results of their own analysis, and a belief that the ATSB's analysis methodology was invalid, they fundamentally disagreed with the ATSB's conclusion that accidents involving R44 helicopters without bladder-type tanks resulted in a significantly higher proportion of post-impact fires (PIF) than for other similar helicopter types. As such, no advice of safety action was provided by the FAA in response to this safety issue.

ATSB action in response

Following receipt of this advice from the FAA, the ATSB reviewed its PIF analysis methodology. The review concluded that the method used by the ATSB to analyse PIF occurrences, and the resulting conclusion that R44 helicopters without bladder-type tanks fitted result in a significantly higher proportion of PIF than for other similar helicopter types, were valid.

ATSB safety recommendation to the United States Federal Aviation Administration

Action number: AO-2013-055-SR-025

Action status: Released

The ATSB recommends that the United States Federal Aviation Administration take action to ensure that owners and operators of Robinson R44 helicopters comply with the manufacturer's service bulletin SB-78B to replace all-aluminium fuel tanks with bladder-type tanks on Robinson R44 helicopters.

Proactive safety action taken by other international civil aviation regulators

On 17 May 2013 the South African Civil Aviation Authority issued emergency AD 2013-001 re R44 Bladder Fuel Tanks, which mandated compliance with SB-78B.

On 27 June 2013 the Civil Aviation Authority of New Zealand issued AD DCA/R44/30 Bladder Fuel Tanks – Retrofit requiring replacement of the all-aluminium fuel tanks by the next helicopter overhaul, or by 27 December 2013, whichever occurred first.

On 19 March 2014 the European Aviation Safety Agency (EASA) issued AD 2014-0070 Fuel-Tank-Replacement. That AD had an effective date of 2 April 2014 and mandated the incorporation of SB-78B into all affected R44 helicopters in the European Community, its Member States and any European third countries that participate in the activities of EASA under Article 66 of that Regulation.

Helicopters not manufactured with a crash-resistant fuel system

Number:	**AO-2013-055-SI-03**
Issue owner:	United States Federal Aviation Administration
Operation affected:	General aviation
Who it affects:	All owners and operators of helicopters not fitted with crash-resistant fuel systems

Safety issue description:

Although certification requirements for helicopters to include a crash-resistant fuel system (CRFS) were introduced in 1994, several helicopter types certified before these requirements became applicable are still being manufactured without a CRFS.

Response to safety issue by the United States Federal Aviation Administration

The FAA advised that they agreed with this safety issue and that it was consistent with the results of their own research. However, no advice of intended safety action in relation to this issue was provided.

ATSB safety recommendation to the United States Federal Aviation Administration

Action number: AO-2013-055-SR-026

Action status: Released

The ATSB recommends that the United States Federal Aviation Administration take action to increase the number of helicopters manufactured in accordance with the 1994 certification requirements for helicopters to include a crash-resistant fuel system.

Number:	**AO-2013-055-SI-03**
Issue owner:	European Aviation Safety Agency
Operation affected:	General aviation
Who it affects:	All owners and operators of helicopters not fitted with crash-resistant fuel systems

Safety issue description:

Although certification requirements for helicopters to include a crash-resistant fuel system (CRFS) were introduced in 1994, several helicopter types certified before these requirements became applicable are still being manufactured without a CRFS.

Response to safety issue and/or Proactive safety action taken by the European Aviation Safety Agency

In accordance with international convention, a copy of the draft investigation report was provided to the European Aviation Safety Agency (EASA) via the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation civile (BEA). As part of their response to the draft report EASA provided the ATSB with data received from Airbus Helicopters. This data related to accidents involving AS350/EC130 model helicopters in which there was a post-impact fire (see the section titled *Australian Transport Safety Bureau review of post-impact fire accidents - Other helicopter types*). EASA concluded that, based on the data from Airbus Helicopters, there was no evidence that an unsafe condition existed with regard to AS350/EC130 helicopters.

EASA further advised that it actively supported the certification of AS350/EC130 helicopter fuel systems with improved crashworthiness characteristics and was supportive of the certification or validation of similar retrofit kits for other helicopter types. While EASA's support of crash-resistant fuel systems (CRFS) is appreciated, the ATSB is concerned that the fitment of such systems remains optional.

Given the proven safety improvement provided by CRFS, the ATSB believes that regulatory agencies such as EASA should, where CRFS are available for installation, mandate their fitment to helicopter types that are still being manufactured. Therefore, the ATSB issues the following safety recommendation.

ATSB safety recommendation to the European Aviation Safety Agency

Action number: AO-2013-055-SR-030

Action status: Released

The ATSB recommends that the European Aviation Safety Agency take action to increase the number of helicopters manufactured in accordance with the 1994 certification requirements for helicopters to include a crash-resistant fuel system.

Existing helicopters not fitted with a crash-resistant fuel system

Number:	**AO-2013-055-SI-04**
Issue owner:	United States Federal Aviation Administration
Operation affected:	General aviation
Who it affects:	All owners and operators of aircraft not fitted with crash-resistant fuel systems

Safety issue description:

Many of the existing civil helicopter fleet are not fitted with a crash-resistant fuel system, or do not have an equivalent level of safety associated with post-impact fire prevention.

Response to safety issue and/or Proactive safety action taken by the United States Federal Aviation Administration

No response was received from the United States Federal Aviation Administration in relation to this safety issue, or advice given of any safety action in response.

ATSB safety recommendation to the United States Federal Aviation Administration

Action number: AO-2013-055-SR-028

Action status: Released

The ATSB recommends that the United States Federal Aviation Administration take action to increase the number of existing helicopters that are fitted with a crash-resistant fuel system or have an equivalent level of safety in respect of post-impact fire.

Number:	**AO-2013-055-SI-04**
Issue owner:	European Aviation Safety Agency
Operation affected:	General aviation
Who it affects:	All owners and operators of aircraft not fitted with crash-resistant fuel systems

Safety issue description:

Many of the existing civil helicopter fleet are not fitted with a crash-resistant fuel system, or do not have an equivalent level of safety associated with post-impact fire prevention.

Response to safety issue and/or Proactive safety action taken by the European Aviation Safety Agency

As part of their response to the draft report, EASA advised that it actively supported the certification of AS350/EC130 helicopter fuel systems with improved crashworthiness characteristics and was supportive of the certification or validation of similar retrofit kits for other helicopter types. While EASA's support of crash-resistant fuel systems (CRFS) is appreciated, the ATSB is concerned that the fitment of such systems remains optional.

Given the proven safety improvement provided by CRFS, the ATSB believes that regulatory agencies such as EASA should, where CRFS are available for retrofit, mandate their fitment. Therefore, the ATSB issues the following safety recommendation.

ATSB safety recommendation to the European Aviation Safety Agency

Action number: AO-2013-055-SR-029

Action status: Released

The ATSB recommends that the European Aviation Safety Agency take action to increase the number of existing helicopters that are fitted with a crash-resistant fuel system or have an equivalent level of safety in respect of post-impact fire.

Advice from Airbus Helicopters

Although not in response to this accident, as part of their directly involved party response to the ATSB's draft investigation report, Airbus Helicopters advised that a service bulletin detailing the retrofit of a crash-resistant fuel system (CRFS) to its AS350 B3/EC130 B4 model helicopters was available and in the progress of certification. Development of a technical solution to retrofit earlier AS350 B2 model helicopters with a CRFS had also commenced. Airbus Helicopters advised that once a retrofit was developed it would be possible to fit a CRFS to all AS350 models, since all early AS350 versions could be upgraded to B2 models via existing service bulletins.

Airbus Helicopters also advised that a CRFS was certified and available as an option for inclusion in newly-manufactured AS350 B3e model helicopters.

Other safety action

Hydraulic-boost switch guard

No safety issue was identified in respect of the hydraulic boost switch in the R44. However, proactive safety action was taken by the Robinson Helicopter Company during the investigation to reduce the likelihood of inadvertent de-selection of the hydraulic-boost switch and the increased pilot workload associated with the loss of hydraulic assistance. This involved the development of a guard around the hydraulic-boost switch on the right pilot's cyclic hand grip that will be incorporated in all new production R44s (Figure 15).

Figure 15: Hydraulic-boost system switch guard

Source: Robinson Helicopter Company

General details

Occurrence details

Date and time:	21 March 2013 – 1207 EDT	
Occurrence category:	Accident	
Primary occurrence type:	Loss of control	
Type of operation:	Private	
Location:	Bulli Tops, New South Wales	
	Latitude: 34°18.2' S	Longitude: 150°54.6' E

Pilot details

Licence details:	Private Pilot (Helicopter) Licence, issued September 2011
Endorsements:	R22, R44
Medical certificate:	Class 2, renewed November 2012 (reading correction to be available)
Aeronautical experience:	175 hours total, 21.9 hours on R44
Last flight review:	29 August 2011

Aircraft details

Manufacturer and model:	Robinson Helicopter Company R44	
Registration:	VH-HWQ	
Operator:	Private	
Serial number:	1445	
Manufacture date:	2004	
Total time:	2,178 hours	
Persons on board:	Crew – 1	Passengers – 3
Injuries:	Crew – 1 fatal	Passengers – 3 fatal
Damage:	Destroyed	

Sources and submissions

Sources of information

The sources of information during the investigation included the:

- New South Wales Police Force and Coroner
- witnesses to the accident
- helicopter maintainer and manufacturer
- Civil Aviation Safety Authority (CASA)
- Transportation Safety Board of Canada (TSB)
- United States (US) National Transportation Safety Board (NTSB)
- US Federal Aviation Administration (FAA).

References

Coltman, JW, Bolukbasi, AO & Laananen, DH 1985, *Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria*, US Department of Transportation report number DOT/FAA/CT-85/11.

Hayden, MS, Shanahan, DF, Chen, LH & Baker, SP 2005, ‘Crash-resistant fuel system effectiveness in civil helicopter crashes’, *Aviation, Space, and Environmental Medicine*, vol. 76, pp. 782-785.

Knapp, SC, Allemond, P & Karney, DH 1981, *Helicopter crashworthy fuel systems and their effectiveness in preventing thermal injury*, US Army Aeromedical Research Laboratory (USAARL) report number 81-4.

National Transportation Safety Board 1980, *General Aviation Accidents: Postcrash Fires and How to Prevent or Control Them*, Special study NTSB-AAS-80-2.

Robertson, SH, Johnson, NB, Hall, DS & Rimson, IJ 2002, *A study of helicopter crash-resistant fuel systems*, US Department of Transportation report number DOT/FAA/AR-01/76.

Transportation Safety Board of Canada 2006, *Post-impact fires resulting from small-aircraft accidents*, Aviation Safety Issues Investigation Report SII A05-01.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the operator, maintainer and manufacturer of the helicopter, CASA, the NTSB, the FAA, the Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA), the TSB, Airbus Helicopters and the European Aviation Safety Agency.

Submissions were received from the manufacturer of the helicopter, CASA, the NTSB, the FAA, the Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA), the TSB, Airbus Helicopters and the European Aviation Safety Agency. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Appendices

Appendix A: Review of helicopter post-impact fire statistics

Overview of process

The ATSB database was searched for all helicopter accidents that occurred in Australia from 1993 to 2013. Potential cases of post-impact fire (PIF) were identified by reviewing those accidents coded as 'post-impact fire' and searching the summary and report for key words such as 'fire' or 'burn'. Each potential case was reviewed to determine whether a PIF had occurred.

The United States (US) National Transportation Safety Board (NTSB) provided a listing of all helicopter accidents that occurred in the US from 1993 to 2012. Potential cases of PIF were identified by reviewing those accidents coded as 'ground' fire and searching the synopsis and full narrative for keywords such as 'fire' or 'burn'. Each potential case was reviewed to determine whether a PIF had occurred. Accidents for 2013 were identified by reviewing available information on the NTSB's online aviation accident database and potential PIF cases were identified by searching for keywords.

The review period started at 1993 as NTSB reports prior to 1993 contained less descriptive data. In addition, no Robinson R44 helicopters were manufactured prior to 1993.

The review focussed on light helicopters; that is, helicopters that were certified in the normal category or were ex-military helicopters on the civil aircraft register and in the same weight range, with a maximum take-off weight less than 3,200 kg and with up to nine seats. Amateur-built helicopters were not included. Brief descriptions of the common helicopter types are provided in Table A1.

The review used the following definitions:

- Accident: an occurrence that results in serious or fatal injuries, and/or the helicopter is substantially damaged or destroyed. Each helicopter involved in a collision with another aircraft was considered as a separate occurrence.
- PIF: accident involving a fire that, as far as could be determined, started after an impact and caused significant damage.
- Small fire: accident involving a fire that, as far as could be determined, started after an impact but did not result in significant damage, or the fire initiated, or the elated explosion occurred more than 90 seconds after impact. In some cases the limited damage was due to the fire being extinguished quickly. Many of these fires were reported as occurring in the helicopter's engine or exhaust area.

Consistent with previous studies, in many cases it was very difficult, based on the available information, to determine whether a fatal PIF accident was survivable if the fire had not occurred. Accordingly, the primary variable of interest was the proportion of accidents that had a PIF. To improve the validity of the data, certain types of accidents with no relevance to understanding PIF were excluded. These included accidents with nil or minor damage to the helicopter, fuel exhaustion, impact or submersion in water, in-flight fire, a normal landing (or landing with no impact damage) followed by fire, or the fuel tank being breached prior to impact. There were 3,764 helicopter accidents in the combined Australian and US data, and about 10 per cent were able to be excluded, leaving a total sample of 3,387 relevant accidents.[37]

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[37] The 377 (10 per cent) of excluded accidents included one case of PIF. This involved a Bell 47J helicopter in Australia. The accident was the result of fuel exhaustion, although fuel was being carried in portable fuel containers. This accident is not included in the number of PIFs.

It is likely many other accidents were not relevant for examining PIF as they did not involve significant impact to relevant areas of the helicopter. However, it was difficult to identify and exclude such accidents reliably and efficiently.

In general, more severe injuries indicate impacts with high levels of energy. With no injuries or only minor injuries there is more chance of including accidents with low energy impacts. A high proportion of accidents with fatal injuries are likely to involve high-energy impacts that are not survivable. However, given that fire probably contributes to fatalities in at least 30 per cent of fatal accidents with PIF, fatal accidents still need to be included in any assessment.

Therefore the review examined the proportion of accidents with PIF for accidents with different levels of injury severity. These were:

- all (relevant) accidents: all accidents after excluding those noted above as not relevant
- any injury accidents: any of the relevant accidents that resulted in at least one minor, serious or fatal injury
- serious/fatal injury accidents: any of the relevant accidents that resulted in at least one serious or fatal injury
- fatal accidents: any of the relevant accidents that resulted in at least one fatality.

Table A1: Descriptions of helicopter types

Model	Details
Aérospatiale AS313	Turbine-engine. 5 seats. Includes 313, 315 and 318 models. First certified 1958.
Aérospatiale AS316	Turbine-engine. 7 seats. Includes 316 and 319 models. First certified 1961.
Agusta A109	Twin turbine-engine. 8 seats. First certified 1981.
Bell 47D	Piston-engine. 3 seats. Includes Bell 47D models and equivalent military versions (such as the OH-13E). First certified 1948.
Bell 47G	Piston-engine. 3 seats. Includes Bell 47G models, equivalent military versions (such as the OH-13H), and derivative models such as the Continental Copters Tomcat and Texas Helicopter M74. Different fuel system design to the Bell 47D. First certified 1953.
Bell 206	Turbine-engine. Includes all Bell 206 Jetranger (5 seats) and Bell 206L Longranger (6 seats). First certified 1964. Helicopters manufactured after 1981 were fitted with a crash-resistant fuel system (CRFS), though this was not certified. Bell Service Instructions were issued in 1994 that enabled a CRFS to be fitted to older models. Neither a Service Bulletin nor an Airworthiness Directive was issued. The manufacturer advised that only a small proportion of the fleet were retrofitted.
Bell 407	Turbine engine. 7 seats. First certified 1996. Certified to meet the requirements of Federal Aviation Regulation (FAR) 27.952.
Bell OH-58	Military version of the Bell 206. Most if not all were fitted or retrofitted with a military standard crashworthy fuel system.
Brantly B-2	Piston-engine. 2 seats. First certified 1959.
Enstrom F-28	Piston-engine. Typically 3 to 4 seats. Includes F-28 and 280 models. First certified 1965.
Eurocopter AS350	Turbine-engine. Includes all Aérospatiale and Eurocopter AS350 models (5 seats) and the EC130 B4 model (7 seats), which has a similar fuel system. First certified 1977. The EC130 T2, which was certified in 2012 with a certified CRFS, is not included.
Eurocopter AS355	Twin turbine-engine. 6 seats. Includes all Aérospatiale and Eurocopter AS355 models. First certified 1980.
Eurocopter EC120	Turbine-engine. 5 seats. First certified 1997. Certified with CRFS.
Hiller UH-12	Piston-engine. 2 or 3 seats. First certified 1948.
Hiller FH-1100	Turbine-engine. 5 seats. First certified 1964.
Hughes 269	Piston-engine. 3 seats. Includes Hughes 269, Hughes TH-55, Schweizer 269/300, Sikorsky 300 models. First certified 1955.
Hughes 369	Turbine-engine. 5 seats. Includes all Hughes, McDonnell Douglas and MD Helicopters 369,

Model	Details
	500, 520 and 530 models. First certified 1964.
Hughes OH-6	Military version of the Hughes 369. Most if not all were fitted or retrofitted with a military standard crashworthy fuel system.
Kaman 1200	Turbine-engine. 1 seat, used for external loads. First certified 1994.
Messerschmitt-Boelkow-Blohm BO-105	Twin turbine-engine. 5 seats. First certified 1970.
MD Helicopters MD 600	Turbine-engine. 8 seats. First certified 1997. Certified to meet the requirements of FAR 27.952.
Robinson R22	Piston-engine. 2 seats. First certified 1979.
Robinson R44	Piston-engine. 4 seats. First certified 1992. Helicopters known to have been fitted with bladder-type tanks are listed as a separate category in the results.
Other piston-engine models without a CRFS	Includes Bell 47H (1 relevant accident) and Bell 47J (6).
Other turbine-engine models without a CRFS	Includes AS341 (5 relevant accidents), Agusta 119 (6), Enstrom 480 (6), MD 900 (5), Westland Wasp (3).
Other models with a CRFS	Includes Bell 427 (1 relevant accident), Bell ARH-70 (1), Eurocopter 135 (7), Guimbal Cabri (1), PZL SW4 (1) and Robinson R66 (2). All turbine-engine except the Cabri. All certified to meet the requirements of FAR 27.952 or equivalent.

Post-impact fire proportions

Table A2 shows the number of accidents and instances of PIF for the accidents in Australia from 1993 to 2013, and Table A3 presents the same data for the combined Australian and US samples for the same time period. Only data for helicopters with at least 10 relevant accidents or with a PIF or small fire were included separately. As the data becomes less reliable with smaller sample sizes, PIF proportions are not shown for helicopter types with less than 25 accidents.

Table A4 shows the data for the combined Australia and US samples for any injury, serious/fatal injury and fatal accidents. Data is only presented for specific models with at least 15 relevant accidents.

Table A2: Helicopter accidents and PIFs in Australia for 1993 to 2013

Helicopter type		Total accidents	Relevant accidents	PIF	PIF proportion	Small fires
Piston, no CRFS	Robinson R22	292	273	13	4.8%	
	Bell 47G	78	67	8	11.9%	1
	Hughes 269	72	64	8	12.5%	
	Robinson R44 (no bladder)	62	47	7	14.9%	
	Hiller UH-12	9	9	0		1
	Robinson R44 (bladder)	7	6	0		
	Brantly B-2	3	2	1		
	Other models	7	5	0		
	All models	530	473	37	7.8%	2
Turbine, no CRFS	Bell 206 (up to 1981)	76	67	5	7.5%	1
	Hughes 369	26	21	0	0%	
	Eurocopter AS350	23	21	1	4.8%	
	Eurocopter AS355	4	3	1		
	Other models	4	3	0		
	All models	133	115	7	6.1%	1
All models without CRFS		663	588	44	7.5%	3
CRFS	Bell 206 (after 1981)	12	8	0		
	Other models	9	6	0		
	All models with CRFS	22	14	0	0%	0
Total (all models)		685	602	44	7.3%	3

Table A3: Helicopter accidents and PIFs in Australia and the US 1993 to 2013

Helicopter type		Total accidents	Relevant accidents	PIF	PIF proportion	Small fires
Piston, no CRFS	Robinson R22	827	779	35	4.5%	0
	Hughes 269	403	383	20	5.2%	1
	Bell 47G	358	330	39	11.8%	7
	Robinson R44 (no bladder)	242	206	37	18.0%	0
	Enstrom F-28	125	113	8	7.1%	1
	Hiller UH-12	140	130	7	5.4%	3
	Bell 47D	41	37	1	2.7%	0
	Brantly B-2	34	32	4	12.5%	0
	Robinson R44 (bladder)	23	21	1		1
	Other models	9	7	0		0
	All models	2,202	2,038	152	7.5%	13
Turbine, no CRFS	Bell 206 (up to 1981)	448	383	32	8.4%	5
	Hughes 369	302	259	17	6.6%	6
	Eurocopter AS350	251	230	28	12.2%	9
	Agusta A109	26	22	4		0
	Eurocopter AS355	25	22	5		2
	MBB BO-105	24	19	3		2
	Aérospatiale AS315	21	18	1		1
	Hiller FH-1100	20	16	3		1
	Kaman 1200	12	12	1		0
	Aérospatiale AS316/319	10	10	0		0
	Hughes OH-6 (modified)	1	1	1		0
	Other models	26	25	0		0
	All models	1,166	1,017	95	9.3%	26
All models without CRFS		3,368	3,055	247	8.1%	39
CRFS	Bell 206 (after 1981)	174	144	7	4.9%	6
	Bell OH-58	77	73	0	0%	1
	Bell 407	61	47	3	6.4%	1
	Hughes OH-6	35	28	1	3.6%	1
	MD600	19	17	1		1
	Eurocopter EC120	13	10	0		0
	Robinson R66	2	2	1		0
	Other models	15	11	0		0
	All models with CRFS	396	332	13	3.9%	11
Total (all models)		3,764	3,387	260	7.7%	50

Comparisons

Statistical testing was done to compare various groups of helicopters or helicopter types.[38] The combined Australia and US data was used in order to maximise the sample size.

Helicopters fitted with a CRFS had a statistically different PIF proportion than helicopters without a CRFS. This was true for all four levels of accident severity.

The data for the R44 without bladder-type tanks[39] was compared with other common helicopter types and various groups of helicopters. The number of accidents for some tests was relatively low, which influenced the ability to find a statistically significant difference. Accordingly some groups were combined. The R44's higher PIF proportions were statistically different to the following types or groups at each of the four levels of accident severity:

- all piston-engine helicopters without a CRFS combined other than the R44
- all turbine-engine helicopters without a CRFS combined
- R22
- Hughes 269
- piston-engine helicopters without a CRFS combined other than the common models in this group (R44, R22, Hughes 269 and Bell 47G)
- Hughes 369.

Other testing found that, compared to the R44 without bladder-type tanks:

- the Bell 47G was different for the any injury, severe/fatal injury and fatal accident levels, but not for all accidents
- the Hiller UH-12 was different for all accidents, any injury accidents and serious/fatal injury accidents, but the number of accidents was too small to reliably compare fatal accidents
- the Enstrom F-28 and Bell 47D were different for all accidents, but the number of accidents was too small to reliably do other comparisons
- the AS350 was different for severe/fatal injury accidents but not for the other comparisons
- turbine-engine helicopters without a CRFS combined other than the common models in this group (Bell 206, Hughes 369 and AS350) was different for severe/fatal injury accidents but not for the other comparisons.

The Bell 47G's PIF proportion was significantly higher for all accidents compared to all other piston-engine helicopters without a CRFS combined (excluding the R44). However, there was no difference at the other levels of accident severity.

Comparisons between the AS350 and other turbine-engine helicopters without a CRFS found that the AS350:

- had a statistically higher PIF proportion compared to all other turbine-engine helicopters without a CRFS combined for any injury accidents and fatal accidents, but not for all accidents and serious/fatal injury accidents
- was different to the Hughes 369 for all accidents, any injury accidents and fatal accidents, but not for serious/fatal injury accidents
- was different to the Bell 206 (up to 1981) for fatal accidents, but not for the other comparisons
- was not different to the other turbine-engine helicopters without a CRFS combined other than the common models in this group (Bell 206 and Hughes 369) at any of the four levels of accident severity.

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[38] Statistical comparisons were done using the $\chi 2$ (Chi squared) test for independent groups. In this report, 'statistically significant' means that the chance of the difference being present due to chance alone was less than 5 per cent.

[39] All references to the R44 in this section are without bladder-type tanks.

Less common helicopter types of interest

In terms of the piston-engine helicopters other than the R44 and Bell 47G, the Brantley B-2 appeared to have a relatively high proportion of PIFs for all accidents (4 out of 32 accidents, or 12.5 per cent). In addition, 3 of the 5 fatal accidents involved PIFs, and in one of these cases fire probably contributed to a fatality. Compared to the R44, the Brantly B-2 PIF proportions were not different at any level of accident severity, but the low numbers of accidents meant that the reliability of the comparisons was hard to evaluate.

PIF accidents involving less common turbine-engine helicopters without a CRFS primarily involved the:

- Agusta Westland AW109 (4 PIFs in 22 accidents, with 4 PIFs in 8 fatal accidents)
- Eurocopter AS355 (5 PIFs in 22 accidents, with 5 PIFs in 6 fatal accidents)
- Hiller FH-1100 (3 PIFs in 16 accidents, with 2 PIFs in 6 fatal accidents)
- Messerschmitt-Boelkow-Blohm BO-105 (3 PIFs in 19 accidents, with 3 PIFs in 8 fatal accidents).

Of these 14 fatal PIF accidents, most if not all appeared to be not survivable, although there was a survivor in 1 of the 3 fatal BO-105 accidents. There were no indications that fire contributed to a fatality in any of the 14 accidents. Overall, the number of accidents was too low to indicate whether these helicopter types had a higher than normal proportion of PIFs.

The United Kingdom (UK) Air Accidents Investigation Branch (AAIB) previously raised concerns regarding AS355 PIFs. It noted that PIFs had occurred in 5 out of 19 AS355 accidents it had investigated and none of the 11 AS350 accidents that it had investigated between 1985 and the late 1990s.[40] It also issued a recommendation[41] that the UK Civil Aviation Authority (CAA), in conjunction with the French Direction générale de l'aviation civile (DGAC), 'assess the record of post-crash fire occurrence for the AS355 helicopter and consider the necessity for crashworthiness improvement measures'. The CAA replied that:

> Three independent but related reviews of post-crash fire occurrences have been carried out by the manufacturer, DGAC and the CAA respectively. Each of these reviews has concluded that the record of post-crash fires in otherwise survivable AS355 accidents is not dissimilar from other light helicopters of similar vintage. Neither is there any evidence that the AS355 fails to meet the level of safety intended by the Type Certification basis. On this basis it has been concluded that there are no practicable crashworthiness improvement measures which could economically be applied.

Transport category helicopters

Although the focus of the ATSB review was on normal category helicopters, the equivalent data for transport category helicopters was also reviewed. During the period 1993 to 2013 in Australia and the US, there were 248 relevant accidents, which included 37 accidents with PIF (14.9 per cent). The PIF proportion for helicopters without a CRFS was 17.4 per cent and the proportion for helicopters with a CRFS was 9.7 per cent.

The overall PIF proportion for the 103 accidents involving serious/fatal injuries was 22.3 per cent. The proportion for helicopters without a CRFS was 36.4 per cent and the proportion for helicopters fitted with a CRFS was 18.8 per cent.

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[40] AAIB report into the accident involving Eurocopter AS355N Ecureuil II, G-EMAU, on 9 October 1998.

[41] AAIB safety recommendation 2000-2, issued as part of the AAIB report into the accident involving Aerospatiale AS355 F1 Ecureuil II, G-MASK, on 26 July 1998.

Table A4: Helicopter accidents with injuries and PIFs in Australia and United States 1993 to 2013

Helicopter type		Accidents with any injury				Accidents with serious/fatal injury				Accidents with fatality			
		All accidents	Relevant accidents	PIF	PIF proportion	All accidents	Relevant accidents	PIF	PIF proportion	All accidents	Relevant accidents	PIF	PIF proportion
Piston engine, no CRFS	Robinson R22	312	289	31	10.7%	171	156	29	18.6%	91	79	25	31.6%
	Hughes 269	174	164	18	11.0%	85	79	17	21.5%	36	31	13	41.9%
	Bell 47G	160	146	29	19.9%	81	74	19	25.7%	41	39	14	35.9%
	Robinson R44 (no bladder)	114	98	35	35.7%	73	61	32	52.5%	51	42	28	66.7%
	Hiller UH-12	63	58	4	6.9%	24	19	1		7	6	1	
	Enstrom F-28	47	40	8	20.0%	22	16	5		8	6	3	
	Robinson R44 (bladder)	9	8	1		6	5	1		5	5	1	
	Other models	33	29	5	17.2%	20	16	5		12	9	4	
	All models	912	832	131	15.7%	482	426	109	25.6%	251	217	89	41.0%
Turbine engine, no CRFS	Bell 206 (up to 1981)	240	199	29	14.6%	145	117	25	21.4%	83	67	22	32.8%
	Hughes 369	166	139	17	12.2%	99	82	17	20.7%	52	42	13	31.0%
	Eurocopter AS350	130	113	27	23.9%	87	72	24	33.3%	56	44	24	54.5%
	Other models	97	82	18	22.0%	69	59	17	28.8%	47	38	17	44.7%
	All models	633	533	91	17.1%	400	330	83	25.2%	238	191	76	39.8%
All models without CRFS		1,545	1,365	222	16.3%	882	756	192	25.4%	489	408	165	40.4%
CRFS	Bell 206 (after 1981)	90	65	6	9.2%	51	34	5	14.7%	27	16	4	
	Bell OH-58	43	41	0	0%	26	24	0		12	12	0	
	Bell 407	35	24	3	12.5%	26	16	3		22	12	3	
	Hughes OH-6	19	15	1		12	8	1		6	4	1	
	Other CRFS models	28	21	2	9.5%	13	8	2		11	7	2	
	All models with CRFS	215	166	12	7.2%	128	90	11	12.2%	78	51	10	19.6%
Total (all models)		1,760	1,531	234	15.3%	1,010	847	208	24.6%	567	459	175	38.1%

Appendix B – US FAA fuel tank tests requirements

The United States Federal Aviation Administration (FAA) fuel tank tests requirements can be accessed at the FAA website www.faa.gov under the following hierarchy of documents (numbered here for ease of reference):

1. Code of Federal Regulations Title 14 – Aeronautics and Space.
2. Chapter 1 - Federal Aviation Administration, Department of Transportation.
3. Part 27 - Airworthiness Standards: Normal Category Rotorcraft.
4. Subpart E – Powerplant.
5. Section 27.965 - Fuel tank tests.

The Section 27.965 test requirements include that:

> (a) Each fuel tank must be able to withstand the applicable pressure tests in this section without failure or leakage. If practicable, test pressures may be applied in a manner simulating the pressure distribution in service.
>
> (b) Each conventional metal tank, nonmetallic tank with walls that are not supported by the rotorcraft structure, and integral tank must be subjected to a pressure of 3.5 p.s.i. unless the pressure developed during maximum limit acceleration or emergency deceleration with a full tank exceeds this value, in which case a hydrostatic head, or equivalent test, must be applied to duplicate the acceleration loads as far as possible. However, the pressure need not exceed 3.5 p.s.i. on surfaces not exposed to the acceleration loading.
>
> (c) Each nonmetallic tank with walls supported by the rotorcraft structure must be subjected to the following tests:
>
> > (1) A pressure test of at least 2.0 p.s.i. This test may be conducted on the tank alone in conjunction with the test specified in paragraph (c)(2) of this section.
> >
> > (2) A pressure test, with the tank mounted in the rotorcraft structure, equal to the load developed by the reaction of the contents, with the tank full, during maximum limit acceleration or emergency deceleration. However, the pressure need not exceed 2.0 p.s.i. on surfaces not exposed to the acceleration loading.
>
> (d) Each tank with large unsupported or unstiffened flat areas, or with other features whose failure or deformation could cause leakage, must be subjected to the following test or its equivalent:
>
> > (1) Each complete tank assembly and its support must be vibration tested while mounted to simulate the actual installation.
> >
> > (2) The tank assembly must be vibrated for 25 hours while two-thirds full of any suitable fluid. The amplitude of vibration may not be less than one thirty-second of an inch, unless otherwise substantiated.
> >
> > (3) The test frequency of vibration must be as follows:
> >
> > > (i) If no frequency of vibration resulting from any r.p.m. within the normal operating range of engine or rotor system speeds is critical, the test frequency of vibration, in number of cycles per minute must, unless a frequency based on a more rational calculation is used, be the number obtained by averaging the maximum and minimum power-on engine speeds (r.p.m.) for reciprocating engine powered rotorcraft or 2,000 c.p.m. [cycles per minute] for turbine engine powered rotorcraft.
> > >
> > > (ii) If only one frequency of vibration resulting from any r.p.m. within the normal operating range of engine or rotor system speeds is critical, that frequency of vibration must be the test frequency.
> > >
> > > (iii) If more than one frequency of vibration resulting from any r.p.m. within the normal operating range of engine or rotor system speeds is critical, the most critical of these frequencies must be the test frequency.

(4) Under paragraphs (d)(3)(ii) and (iii) of this section, the time of test must be adjusted to accomplish the same number of vibration cycles as would be accomplished in 25 hours at the frequency specified in paragraph (d)(3)(i) of this section.

(5) During the test, the tank assembly must be rocked at the rate of 16 to 20 complete cycles per minute through an angle of 15 degrees on both sides of the horizontal (30 degrees total), about the most critical axis, for 25 hours. If motion about more than one axis is likely to be critical, the tank must be rocked about each critical axis for 12½ hours.

(Secs. 313(a), 601, and 603, 72 Stat. 752, 775, 49 U.S.C. 1354(a), 1421, and 1423; sec. 6(c), 49 U.S.C. 1655(c))

[Amdt. 27-12, 42 FR 15045, Mar. 17, 1977]

Appendix C – US FAA fuel system crash resistance requirements

The United States Federal Aviation Administration (FAA) fuel system crash resistance requirements can be accessed at the FAA website www.faa.gov under the following hierarchy of documents (numbered here for ease of reference):

1. Code of Federal Regulations Title 14 – Aeronautics and Space.
2. Chapter 1 - Federal Aviation Administration, Department of Transportation.
3. Part 27 - Airworthiness Standards: Normal Category Rotorcraft.
4. Subpart E – Powerplant.
5. Section 27.952 - Fuel system crash resistance.

The Section 27.952 test requirements include that:

> Unless other means acceptable to the Administrator are employed to minimize the hazard of fuel fires to occupants following an otherwise survivable impact (crash landing), the fuel systems must incorporate the design features of this section. These systems must be shown to be capable of sustaining the static and dynamic deceleration loads of this section, considered as ultimate loads acting alone, measured at the system component's center of gravity, without structural damage to system components, fuel tanks, or their attachments that would leak fuel to an ignition source.
>
> (a) *Drop test requirements.* Each tank, or the most critical tank, must be drop-tested as follows:
>
> (1) The drop height must be at least 50 feet.
>
> (2) The drop impact surface must be nondeforming.
>
> (3) The tank must be filled with water to 80 percent of the normal, full capacity.
>
> (4) The tank must be enclosed in a surrounding structure representative of the installation unless it can be established that the surrounding structure is free of projections or other design features likely to contribute to rupture of the tank.
>
> (5) The tank must drop freely and impact in a horizontal position ±10°.
>
> (6) After the drop test, there must be no leakage.
>
> (b) *Fuel tank load factors.* Except for fuel tanks located so that tank rupture with fuel release to either significant ignition sources, such as engines, heaters, and auxiliary power units, or occupants is extremely remote, each fuel tank must be designed and installed to retain its contents under the following ultimate inertial load factors, acting alone.
>
> (1) For fuel tanks in the cabin:
>
> (i) Upward—4g.
>
> (ii) Forward—16g.
>
> (iii) Sideward—8g.
>
> (iv) Downward—20g.
>
> (2) For fuel tanks located above or behind the crew or passenger compartment that, if loosened, could injure an occupant in an emergency landing:
>
> (i) Upward—1.5g.
>
> (ii) Forward—8g.
>
> (iii) Sideward—2g.
>
> (iv) Downward—4g.
>
> (3) For fuel tanks in other areas:
>
> (i) Upward—1.5g.
>
> (ii) Forward—4g.

(iii) Sideward—2g.

(iv) Downward—4g.

(c) *Fuel line self-sealing breakaway couplings.* Self-sealing breakaway couplings must be installed unless hazardous relative motion of fuel system components to each other or to local rotorcraft structure is demonstrated to be extremely improbable or unless other means are provided. The couplings or equivalent devices must be installed at all fuel tank-to-fuel line connections, tank-to-tank interconnects, and at other points in the fuel system where local structural deformation could lead to the release of fuel.

(1) The design and construction of self-sealing breakaway couplings must incorporate the following design features:

(i) The load necessary to separate a breakaway coupling must be between 25 to 50 percent of the minimum ultimate failure load (ultimate strength) of the weakest component in the fluid-carrying line. The separation load must in no case be less than 300 pounds, regardless of the size of the fluid line.

(ii) A breakaway coupling must separate whenever its ultimate load (as defined in paragraph (c)(1)(i) of this section) is applied in the failure modes most likely to occur.

(iii) All breakaway couplings must incorporate design provisions to visually ascertain that the coupling is locked together (leak-free) and is open during normal installation and service.

(iv) All breakaway couplings must incorporate design provisions to prevent uncoupling or unintended closing due to operational shocks, vibrations, or accelerations.

(v) No breakaway coupling design may allow the release of fuel once the coupling has performed its intended function.

(2) All individual breakaway couplings, coupling fuel feed systems, or equivalent means must be designed, tested, installed, and maintained so that inadvertent fuel shutoff in flight is improbable in accordance with §27.955(a) and must comply with the fatigue evaluation requirements of §27.571 without leaking.

(3) Alternate, equivalent means to the use of breakaway couplings must not create a survivable impact-induced load on the fuel line to which it is installed greater than 25 to 50 percent of the ultimate load (strength) of the weakest component in the line and must comply with the fatigue requirements of §27.571 without leaking.

(d) *Frangible or deformable structural attachments.* Unless hazardous relative motion of fuel tanks and fuel system components to local rotorcraft structure is demonstrated to be extremely improbable in an otherwise survivable impact, frangible or locally deformable attachments of fuel tanks and fuel system components to local rotorcraft structure must be used. The attachment of fuel tanks and fuel system components to local rotorcraft structure, whether frangible or locally deformable, must be designed such that its separation or relative local deformation will occur without rupture or local tear-out of the fuel tank or fuel system components that will cause fuel leakage. The ultimate strength of frangible or deformable attachments must be as follows:

(1) The load required to separate a frangible attachment from its support structure, or deform a locally deformable attachment relative to its support structure, must be between 25 and 50 percent of the minimum ultimate load (ultimate strength) of the weakest component in the attached system. In no case may the load be less than 300 pounds.

(2) A frangible or locally deformable attachment must separate or locally deform as intended whenever its ultimate load (as defined in paragraph (d)(1) of this section) is applied in the modes most likely to occur.

(3) All frangible or locally deformable attachments must comply with the fatigue requirements of §27.571.

(e) *Separation of fuel and ignition sources.* To provide maximum crash resistance, fuel must be located as far as practicable from all occupiable areas and from all potential ignition sources.

(f) *Other basic mechanical design criteria.* Fuel tanks, fuel lines, electrical wires, and electrical devices must be designed, constructed, and installed, as far as practicable, to be crash resistant.

(g) *Rigid or semirigid fuel tanks.* Rigid or semirigid fuel tank or bladder walls must be impact and tear resistant.

[Doc. No. 26352, 59 FR 50386, Oct. 3, 1994]

Appendix D – Australian Civil Aviation Safety Authority, AD/R44/23

COMMONWEALTH OF AUSTRALIA
CIVIL AVIATION SAFETY AUTHORITY

Civil Aviation Safety Regulations 1998 (CASR)
Regulation 39.001(1)

AIRWORTHINESS DIRECTIVE

For the reasons set out in the background section, the CASA delegate whose signature appears below issues the following Airworthiness Directive (AD) under subregulation 39.001(1) of CASR 1998. The AD requires that the action set out in the requirement section (being action that the delegate considers necessary to correct the unsafe condition) be taken in relation to the aircraft or aeronautical product mentioned in the applicability section: (a) in the circumstances mentioned in the requirement section; and (b) in accordance with the instructions set out in the requirement section; and (c) at the time mentioned in the compliance section.

Robinson R44 Series Helicopters

AD/R44/23 **R44 Bladder Fuel Tank Retrofit** **9/2013**

Applicability: All R44 helicopters referred to in the Robinson Helicopter Company Service Bulletin listed in the Requirement section below.

Requirement: Comply with Service Bulletin (SB) SB-78B entitled *Bladder Fuel Tank Retrofit* (which incorporates SB-68) dated 28 September 2012 (the SB).

Note: Later revisions of the above reference documents are considered as an acceptable means of compliance with this AD.

Compliance: Unless already complied with, the SB must be complied with before further flight after 30 April 2013.

This Airworthiness Directive becomes effective on 30 April 2013.

Background: This Airworthiness Directive requires R44 helicopters fitted with all-aluminium fuel tanks to be retrofitted with bladder-type tanks, to improve the R44 fuel system's resistance to a post-accident fuel leak. Recent post-crash fires in Australia have prompted CASA to mandate compliance with manufacturer's service bulletin to reduce the risk of further post-crash fires and increase survivability of such an event.

Aircraft which are maintained in accordance with the Manufacturer's Maintenance Schedule are already required to comply with all Robinson Service Bulletins by regulation 42A of the CAR.

[redacted]

29 April 2013

Page 1 of 1

Appendix E – Chronology of safety actions relating to R44 fuel tanks

A number of national safety investigation agencies and airworthiness authorities have taken, or considered, safety action in respect of the R44 fuel tank installation. Those actions are outlined in the following chronology:

26 June 2012: The Australian Civil Aviation Safety Authority (CASA) published Airworthiness Bulletin (AWB) 28-012 *Robinson R44 Fuel Tanks*. That AWB highlighted the improvement in the 'post-crash survivability' of R44 helicopters that had been fitted with bladder-type fuel tanks. It also ‘strongly’ recommended that operators of R44 helicopters incorporate Service Bulletin 78A (SB-78A) ‘at their earliest convenience’.

22 November 2012: The ATSB listed R44 fuel tanks as one of its Safety Watch priorities[42], and encouraged all owners and operators of R44 helicopters fitted with all-aluminium fuel tanks to ‘consider replacing these tanks with bladder-type fuel tanks as detailed in the manufacturer's Service Bulletin 78B as soon as possible’.[43]

19 December 2012: In response to an enquiry from the ATSB about the feasibility of mandating the SB-78B requirement, CASA advised:

> CASA has drafted a Notice of Proposed Rule Making (NPRM) relating to a unique Australian Airworthiness Directive (AD) that will mandate the Robinson Helicopters R 44 SB 78B Bladder Fuel Tank Retrofit. Release of this NPRM, expected in early in 2013, is subject to confirmation from the FAA [US Federal Aviation Administration] as to their intended actions, which will follow their current investigation.

CASA advised that it was liaising with the FAA regarding mandating SB-78B. In January 2013, the FAA advised CASA that, after analysis of accident data involving post-impact fires, the R44 fuel system crashworthiness did not appear inconsistent with that of other similar helicopters and that, as a result, the FAA would not be taking any corrective action.

Under Part 39 of the Australian Civil Aviation Safety Regulations, ADs issued by a foreign State of Design are automatically applicable to Australian aircraft. This does not prevent CASA, or national airworthiness authorities in other countries, from placing their own regulatory requirements on aircraft types if deemed necessary.

26 December 2012: The FAA issued Special Airworthiness Information Bulletin (SAIB) SW-13-11, *JASC*[44] *Code 2810 Fuel Storage Robinson Helicopter Company Bladder Fuel Tank Retrofit*. That document recommended owners and operators of Robinson helicopters incorporate SB-78B.

6 February 2013: CASA issued a revised version of AWB 28-012. It included the same recommendation to R44 operators to incorporate SB-78B at their earliest convenience. CASA also wrote to all R44 operators, advising that:

> Operators are reminded of their responsibility to ensure that aircraft are in a safe and airworthy state. This requires the operator to review manufacturer’s recommendations and associated data and, where appropriate, to incorporate those recommendations.
>
> Civil Aviation Regulation (CAR) 42A (4) 1988 states the following:
>
> (4) If a person has elected to use a manufacturer‘s maintenance schedule for an aircraft’s maintenance, all instructions issued by the manufacturer of components permanently, or from time to time, included in, or fitted to, the aircraft, being instructions for the continued airworthiness of the

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[42] The ATSB’s SafetyWatch highlights the broad safety concerns derived from its investigation findings and from the occurrence data reported by industry. The transport community is urged to give heightened attention to the identified risk areas in that watch list.

[43] See http://www.atsb.gov.au/safetywatch/r44-fuel-tanks.aspx.

[44] Joint Aircraft System Component.

> components, are to be taken to form part of the manufacturer's maintenance schedule and election has effect accordingly.
>
> At this time, CASA strongly recommends that all operators of R44 helicopters, which are subject to the Robinson SB (78B), incorporate the manufacturer's modified bladder tanks at the earliest opportunity.
>
> To enable CASA to determine the current and projected status of the R44 fleet, you are requested to advise CASA on the status of the fuel tank installation on your aircraft and whether the Service Bulletin modification has been installed. This can be achieved by completing the attached form and returning it by facsimile, mail or e-mail at the earliest opportunity.

21 March 2013: There were 484 R44 helicopters registered in Australia. SB-78B was applicable to 392 of these helicopters by serial number.

Soon after the accident involving VH-HWQ, the helicopter manufacturer advised that about 1,800 bladder-type tank retrofit kits had been factory installed or delivered worldwide to replace the all-aluminium tanks in the 4,000 affected R44 helicopters. The manufacturer advised that over 300 kits had been processed for Australia.

The helicopter manufacturer also advised that, in conjunction with the FAA, it was examining other methods to ensure greater compliance with the bladder-type fuel tank upgrade. Those methods did not include the development of an AD to mandate compliance with SB-78B.

25 March 2013: CASA advised the ATSB that it had received 142 responses to its letter of 6 February 2013. Those respondents indicated that 105 helicopters had incorporated the SB-78B requirements. For those helicopters involved in charter operations, a total of 70 had been modified and 26 had not. CASA also reported its assessment that approved maintenance organisations had the capacity to install about 35 bladder-type tank retrofit kits each month.

The ATSB contacted four maintenance organisations in Australia that were obtaining and supplying the R44 bladder-type tank retrofit kits in Australia. Those organisations advised that, as of 25 March 2013, about 247 kits had been either fitted or supplied by those organisations, with another 23 kits on order.

27 March 2013: CASA advised that compliance with SB-78B was dependent on an individual helicopter's maintenance program. If a specific helicopter utilised a maintenance schedule that included a requirement to carry out scheduled maintenance, overhauls and inspections in accordance with Page 1.1 of the manufacturer's maintenance schedule, then compliance with SB-78B by the due date was mandatory. CASA also advised that it was of the opinion that the vast majority of operators would be using the manufacturer's maintenance program.

However, CASA stated it was possible that not all owners or maintainers were aware of this indirect requirement to comply with service bulletins. If a helicopter was maintained using a system of maintenance, compliance with SB-78B was dependent on the specific wording of that system.

2 April 2013: In response to a request for clarification of the status of helicopter maintenance logbook statements in relation to compliance with manufacturer's service bulletins, including that applicable to VH-HWQ, CASA advised:

> [Civil Aviation Regulation] CAR 50A requires a log book to be kept in accordance with instructions issued by CASA. Those instructions are found in para 3.2 of [Civil Aviation Order] CAO 100.5. Paragraph 3.2 lists ten matters that must be included in a log book – including identifying the aircraft's maintenance program.
>
> In the case of the accident aircraft - the log book statement (LBS) identifies the program as the maintenance schedule – for a helicopter this can only be the manufacturer's schedule. Whilst the 6 things listed in the LBS does not include service bulletins, this does not mean that they do not have to be complied with. This is because the six things are the things that para 3.2 of CAO 100.5 requires to be included in the log book. One of those things is identification of approved variations or exemptions to the maintenance schedule – the LBS does not exclude service bulletins.

> In summary, the LBS does not describe in its entirety a maintenance schedule – CARs 41 and 42 requires compliance with the maintenance schedule and that is not qualified by what is in the LBS - the LBS simply describes the main aspects of it.

3 April 2013: CASA released AWB 02-044 advising all owners, operators and maintainers of Robinson R44 helicopters that they were required to comply with all service bulletins and that, in particular, SB-78B must be complied with by the due date. The background statement of that AWB stated in part:

> On 26 June 2012, the Civil Aviation Safety Authority (CASA) issued Airworthiness Bulletin (AWB) AWB 28-012 titled Robinson R44 Fuel Tanks ... That AWB highlights the improvement in the 'post-crash survivability' of R44 helicopters that had been fitted with bladder-type fuel tanks. The AWB refers to a Robinson Helicopter Company Service Bulletin SB-78 that, depending on the maintenance schedule affecting the individual helicopter, required the fitment of a bladder-type tank to all R44 and R44 II helicopters…

In the 'Recommendations' section of the AWB CASA stated:

> Registered operators of Robinson R44 helicopters that are maintained using the manufacturer's maintenance schedule are reminded that they must comply with Service Bulletins by their due date. The registered operator will be contravening regulation 41 of the CAR and the pilot and registered operator may also contravene regulation 47 of the CAR if they do not comply with Service Bulletins by their due date.
>
> If the helicopter is maintained to an approved SOM [System of Maintenance] then the SOM must have consideration for compliance with Robinson Helicopter Company Service Bulletins. With regards to Robinson Helicopter Company Service Bulletins mentioned in AWB 28-012, CASA would regard an SOM that does not include these Service Bulletins as deficient.

29 April 2013: CASA released AD/R44/023 *R44 Bladder Fuel Tank Retrofit* (appendix D), mandating that any all-aluminium fuel tanks Australian-registered R44 helicopters were to be replaced with bladder-type fuel tanks in accordance with SB-78B.

17 May 2013: The South African Civil Aviation Authority issued emergency AD 2013-001*re R44 Bladder Fuel Tanks*, which mandated compliance with SB-78B*.*

27 June 2013: The Civil Aviation Authority of New Zealand issued AD DCA/R44/30 *Bladder Fuel Tanks – Retrofit* requiring replacement of the all-aluminium fuel tanks by the next helicopter overhaul, or by 27 December 2013, whichever occurred first.

19 March 2014: The European Aviation Safety Agency (EASA) issued AD 2014-0070 *Fuel-Tank-Replacement*. That AD had an effective date of 2 April 2014 and mandated the incorporation of SB-78B into all affected R44 helicopters in the European Community, its Member States and any European third countries that participate in the activities of EASA under Article 66 of that Regulation.

15 January 2014: The NTSB made the following recommendation to the FAA:

> Require owners and operators of existing R44 helicopters to comply with the fuel tank retrofit advised in Robinson Helicopter Company Service Bulletin SB-78B to improve the helicopters' resistance to a postaccident fuel leak. (A-14-001)

9 April 2014: The FAA provided the following response to NTSB safety recommendation A-14-001:

> The Robinson Helicopter Company (RHC) Model R44 helicopter was originally certified on December 10, 1992, prior to the Federal Aviation Administration (FAA) final rule published on October 3, 1994, regarding fuel system crash resistant standards for new rotorcraft designs (Title 14, Code of Federal Regulations§ 27.952). Since the R44 helicopter had an earlier certification basis, it was not required to meet this regulation. The FAA does not mandate that later standards be retroactively applied unless an unsafe condition exists. The FAA initiated a review focused on the crashworthiness of the R44 helicopter fuel system using the Monitor Safety/ Analyze Data (MSAD) process. This review was to determine if an unsafe condition exists and if corrective action is necessary. The FAA reviewed the Board and MSAD accident databases to determine if the postcrash fire (PCF) rate for the R44 was

> significantly different from that of similar, small, reciprocating engine-powered multipurpose helicopters. Most of the records did not have specific data on the accident sequence of events (there is a helicopter crash. the crash is survivable, there is a PCF, and the fatalities are caused by the PCF alone and not the impact). Therefore, our analysis required certain assumptions to ensure a fully accurate comparison. Acknowledging the limitations and the assumptions associated with the review, the R44 fuel system crashworthiness does not appear significantly different from that of other similar helicopters. In order to further refine the assumptions associated with the overall review of the R44 fuel system crashworthiness, the FAA Rotorcraft Directorate and the Civil Aerospace Medical Institute analyzed 5 years of data involving U.S.-registered rotorcraft fatal accidents. This study explored the percentages of U.S. fatal rotorcraft accidents, with and without crashworthy fuel tanks, attributable to PCF versus blunt force trauma for parts 27 and 29 helicopters. The findings of this study suggested that there was not a statistical difference between the R44 and other part 27 rotorcraft without a crashworthy fuel system regarding:
>
> - The frequency of all fatal accidents where a PCF occurred;
> - The frequency of all fatal accidents where a PCF contributed to the fatalities; and
> - The frequency of all fatal accidents having a PCF, where the PCF contributed to the fatalities.
>
> The FAA plans to continue our analysis of this concern and will coordinate with the Australian Civil Aviation Safety Authority to discuss their findings. After the analysis of data is complete, we will determine if any further action is necessary. I will keep the Board informed of the FAA's progress on this safety recommendation and provide an updated response by March 2015.

3 June 2014: Having considered the FAA response to recommendation A-14-001, the NTSB responded:

> In order for you to require a retrofit with a more crashworthy fuel tank design, 14 Code of Federal Regulations Part 39, “Airworthiness Directives,” requires you to conduct a review to determine whether an unsafe condition exists and corrective action is therefore necessary. You described the extensive efforts you have made to comply with this requirement by analyzing NTSB data and using data and analyses associated with the FAA’s Monitor Safety/Analyze Data process. We note that you also analyzed 5 years of fatal accident data involving US-registered rotorcraft to evaluate the R44 fuel system’s crashworthiness but that, despite these extensive efforts, you were unable to find any increased death or injury risk from a postcrash fire for the R44 helicopter compared to the risks for other helicopters. As a result, you have been unable to identify the unsafe condition necessary for you to take the recommended action. We are pleased that, despite this, you plan to continue your analysis and coordinate with the Australian Civil Aviation Safety Authority to discuss its findings. We appreciate your extensive and in-depth analyses of the data associated with the risk of post-crash fires in R44 helicopters from fuel tank breaches. Pending completion of the recommended action, Safety Recommendation A-14-1 is classified OPEN—ACCEPTABLE RESPONSE.

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Australian Transport Safety Bureau

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Investigation

ATSB Transport Safety Report
Aviation Occurrence Investigation
Loss of control involving Robinson R44 helicopter, VH-HWQ
Bulli Tops, New South Wales, 21 March 2013

AO-2013-055
Final – 4 June 2015