VFR into dark night: Nothing to see but much to change

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Note: This paper is based on the ATSB's investigation AO-2011-102, Loss of control at night involving Aérospatiale Industries AS355F2, VH-NTV, 145 km north of Marree, South Australia, 18 August 2011. For further information including references, please obtain the report from www.atsb.gov.au.

Introduction

On 18 August 2011, an Aérospatiale AS355F2 helicopter was being operated on a charter flight under the visual flight rules (VFR) at night in an area east of Lake Eyre, South Australia. Two minutes after take-off, the helicopter impacted terrain, fatally injuring the pilot and the two film crew on board. Data from a portable global positioning system (GPS) unit showed that soon after take-off, the helicopter levelled at 1,500 ft, and shortly after it entered a gentle right turn and then began descending. Subsequent analysis indicated that the helicopter impacted terrain 38 seconds after the descent began.

Given the limited information available, the investigation initially had difficulty explaining the helicopter's flight path and the significant period of apparently undetected or uncorrected descent. Using a combination of techniques, the ATSB found that the pilot probably became spatially disoriented. A range of factors increased the risk of spatial disorientation.

The paper will discuss the process used to develop some of the ATSB's findings. It will also discuss the limitations of the risk controls and safety management processes in place associated with night operations.

Evidence from the accident site and initial investigations

The accident occurred in a remote area, and the helicopter was destroyed by impact forces and fire (Figure 1). The site examination found that:

- The impact occurred about 3 km east-north-east of the departure point.
- The helicopter impacted terrain at high speed with a right bank angle of about 90°.
- All of the helicopter's major components were identified at the accident site.
- There were no indications of fire prior to impact.

Other investigation activities found that:

- In the period leading up to the accident flight, the crew were visiting a tour group who were camping on a sand island in the Cooper Creek inlet.
- The helicopter departed at about 1900 local time, which was after nautical twilight (1850) and before moonrise (2158).
- Apart from the tour group's camp fire on the island, there were no other known sources of terrestrial lighting cues available in the vicinity of the helicopter's flight path.
- There was no cloud or rain in the vicinity at the time of the accident flight.
- Witnesses from the tour group observed the helicopter depart in an easterly then north-easterly direction. This was contrary to what they expected as they understood that the crew were returning to their accommodation at Muloorina Station, 96 km away to the south.
- Component examinations showed no pre-existing defects associated with the helicopter's flight control system, engines or airframe.

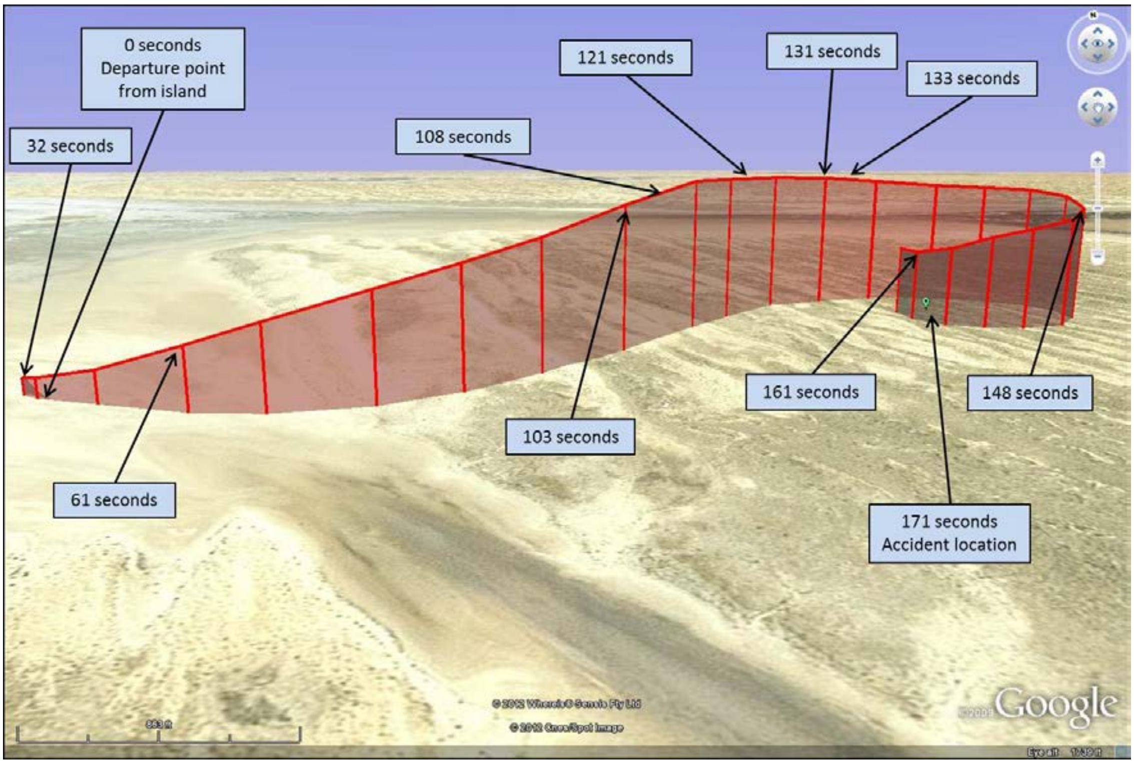
Figure 1: Helicopter wreckage

Source: ATSB

A Garmin GPSMAP 495 GPS unit was recovered from the accident site. Despite the unit being significantly damaged, the ATSB was able to download data from the accident flight. The unit provided data on the helicopter's position and altitude. Based on these parameters, the ATSB was able to estimate other flight path characteristics such as ground speed, track, rate of descent and bank angle.

The GPS data indicated that the helicopter took off at about 1859. About 103 seconds after take-off, the helicopter rolled out on a heading of 035°, and at 108 seconds it levelled off at an altitude of 1,500 ft above mean sea level. After 121 seconds, the helicopter commenced a gentle right turn. About 10 seconds later the helicopter was established at cruise speed (105 kt), and soon after (133 seconds) the helicopter started descending with the bank angle increasing. Based on the GPS data and flight path estimations, it was calculated that the helicopter impacted terrain about 171 seconds after take-off, or about 38 seconds after it started descending. Figure 2 provides an overview of the helicopter's flight path.

Figure 2: Flight path derived from recovered GPS data-elevation view



Source: Google Earth (modified by the ATSB)

Key questions and scenarios

There were two important and related questions to address regarding the sequence of events. Firstly, why did the helicopter initially head to the north-east rather than the south, before commencing a right turn? There were no known operational reasons such as weather, terrain avoidance, traffic avoidance or access to navigational aids for the helicopter to initially be heading to the north-east. Given the lighting conditions, there were no opportunities to conduct any filming.

The 035° outbound track can best be explained by the pilot having selected an incorrect destination on one or both of the helicopter's GPS units prior to departure. Analysis of the flight path indicated that the left turn onto a specific track after reaching 500 ft was consistent with the pilot using one or both of the GPS units for navigation and tracking to a destination selected prior to departure. In addition, one of the locations on the crew's itinerary, Cowarie Station, was on a bearing of 034° from the take-off point and about the same distance away as the intended destination. In summary, the investigation concluded that the right turn after reaching 1,500 ft was intentional, and it was initiated by the pilot in order to correct an unintended problem with the initial departure track to the north-east.

Secondly, and more importantly, why did the helicopter start descending and continue descending with an increasing bank angle until impact? Several potential explanations were considered very unlikely. For example, there was no adverse weather present at the time of the accident that could have influenced controllability of the helicopter, or required the pilot to vary the helicopter's flight path to remain in visual meteorological conditions (VMC). In addition, the physical and technical evidence showed no pre-existing defects with the helicopter's flight control system, engines or airframe.

The two main hypotheses considered to explain the descending turn were pilot incapacitation and spatial disorientation. However, the available information about the pilot did not indicate any relevant precursors or indicators for sudden pilot incapacitation. In addition, there was some concern about whether spatial disorientation could account for an experienced helicopter pilot not apparently detecting or attempting to correct a descent with increasing bank angle for 38 seconds in circumstances where there were no external visual cues and the pilot was required to use the flight instruments to maintain control. To help differentiate between these two hypotheses, the ATSB conducted simulation trials, reviewed related accidents, organised spatial orientation modelling and reviewed relevant human factors research.

Simulator trials

The ATSB conducted simulator trials in an AS350B, Cat B, FSD2 procedural fixed-base simulator to examine the control inputs required to replicate the flight path of the accident flight. A series of trials were carried out attempting to match speed, bank angle, rate of descent and turn rate. These trials were able to match the accident flight profile if the simulator pilot made continual control adjustments. A series of trials with the controls in a fixed position produced flight profiles that were significantly different to that of the accident flight, and none of them produced a sustained spiral descent.

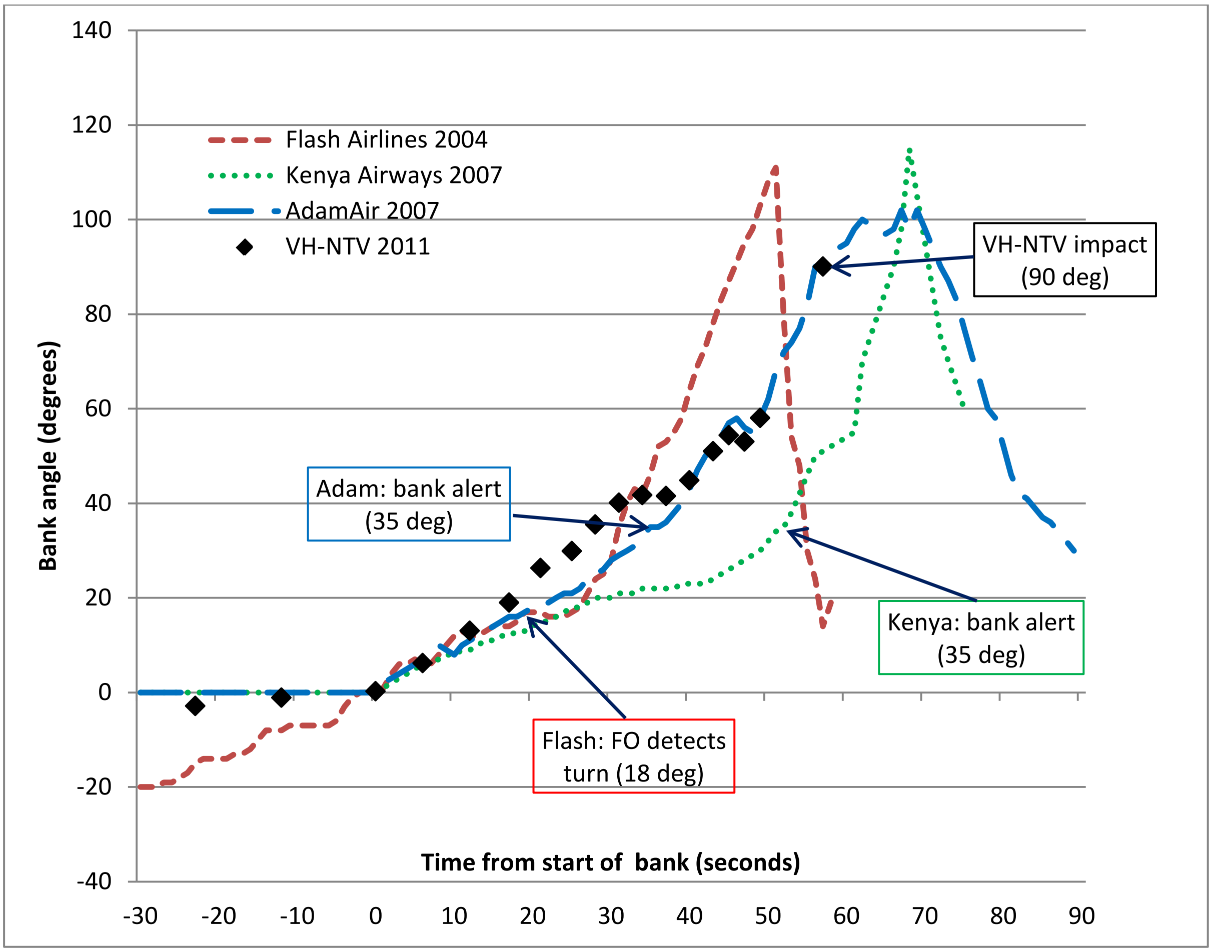
The ATSB also asked the helicopter manufacturer to conduct similar trials, which were done using the American Eurocopter's AS350B2/B3, Level B full-motion flight simulator. The manufacturer reported that its pilots could replicate the accident flight profile with continual control adjustments. The test pilots also commented on the difficulty of maintaining control of the helicopter when there were no external visual references.

Although there were some limitations with the simulators, the consistent result over both sets of trials was that continual control adjustments requiring pilot input were required to match the flight path. It was therefore considered very unlikely that the same flight path would have occurred if the pilot had become suddenly and significantly incapacitated.

Previous accidents

A significant number of aircraft accidents have been associated with a gradually increasing bank angle for an extended period. These have included several accidents involving civil air transport aeroplanes. In most cases the flight crew took a significant period of time (tens of seconds) to recognise the problem. Just as importantly, the bank often kept increasing for a significant period of time (tens of seconds) after it was detected. Common conditions in these types of accidents included the flights being conducted in instrument meteorological conditions (IMC) and/or dark night conditions, the crews not using the autopilot, and the crew's attention being diverted to other tasks. In all cases, there were two crew and both had instrument ratings. Figure 3 shows the bank angles of three aircraft involved in these types of accidents, as well as the estimated angles for VH-NTV.

Figure 3: Bank angles in some recent air transport accidents



Source: Data was derived from published information in the accident reports

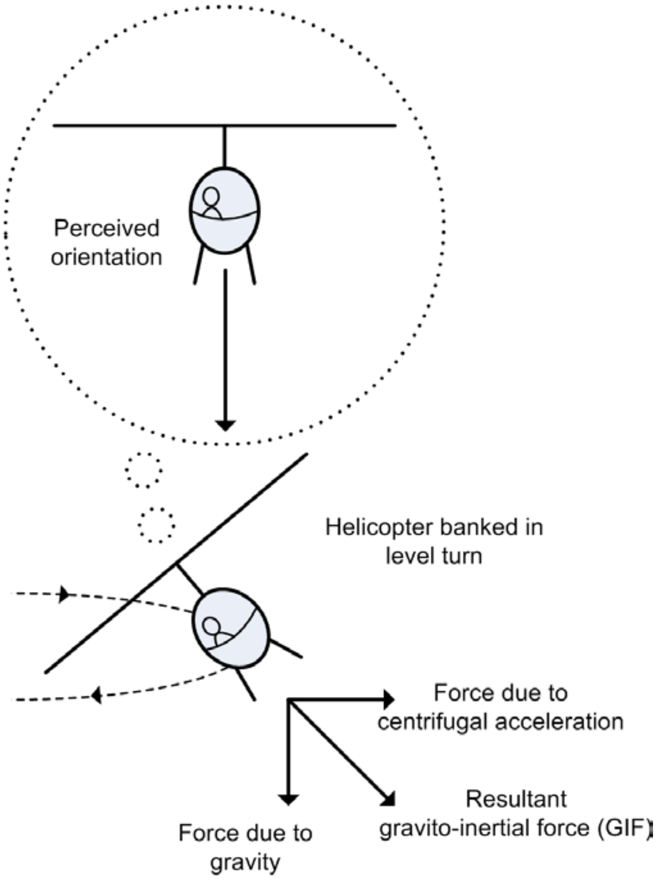
The ATSB did not identify any civil helicopter accidents in Australia that involved spatial disorientation and a gradually increasing bank angle over an extended time period. The ATSB contacted specialists in the United States Army Aeromedical Research Laboratory (USAARL) to determine if the United States military had experienced any such events. The USAARL advised that there had been many military helicopter accidents in which the crew had made no corrective control inputs and impacted terrain, including slow descent until impact, level flight into a rising terrain, or a slowly increasing turn until impact. These accidents generally occurred with two pilots, each with instrument ratings and usually wearing night vision goggles. The USAARL advised of several accidents that shared a similar flight profile to the accident involving VH-NTV. These accidents were generally attributed to spatial disorientation.

Spatial orientation modelling

Spatial disorientation (SD) occurs when a pilot does not correctly sense the position, motion and attitude of an aircraft relative the surface of the Earth. It has been involved in a significant proportion of aviation accidents, particularly those with more serious consequences. When SD is involved in accidents, it is generally 'unrecognised' or Type 1 SD rather than the more commonly occurring 'recognised' or Type 2 SD. Common factors associated with SD include limited or ambiguous visual cues outside the cockpit, not directing sufficient attention to the flight instruments due to workload or distraction, and not being proficient in instrument flying skills.

There are many misperceptions and illusions that can be associated with a gradually increasing bank angle. These include the roll being below the detection threshold, 'the leans', the somatogyral illusion and the somatogravic illusion. Although the latter is more commonly associated with false pitch perceptions during take-off, it also occurs in other situations where a pilot misinterprets the gravito-inertial force (GIF). For example, during a coordinated turn, the combined effects of the gravitational force and forces due to centrifugal acceleration can lead a pilot to perceive that they are upright rather than in a bank (see Figure 4).

Figure 4: Gravito-inertial force during turn and potential misperception

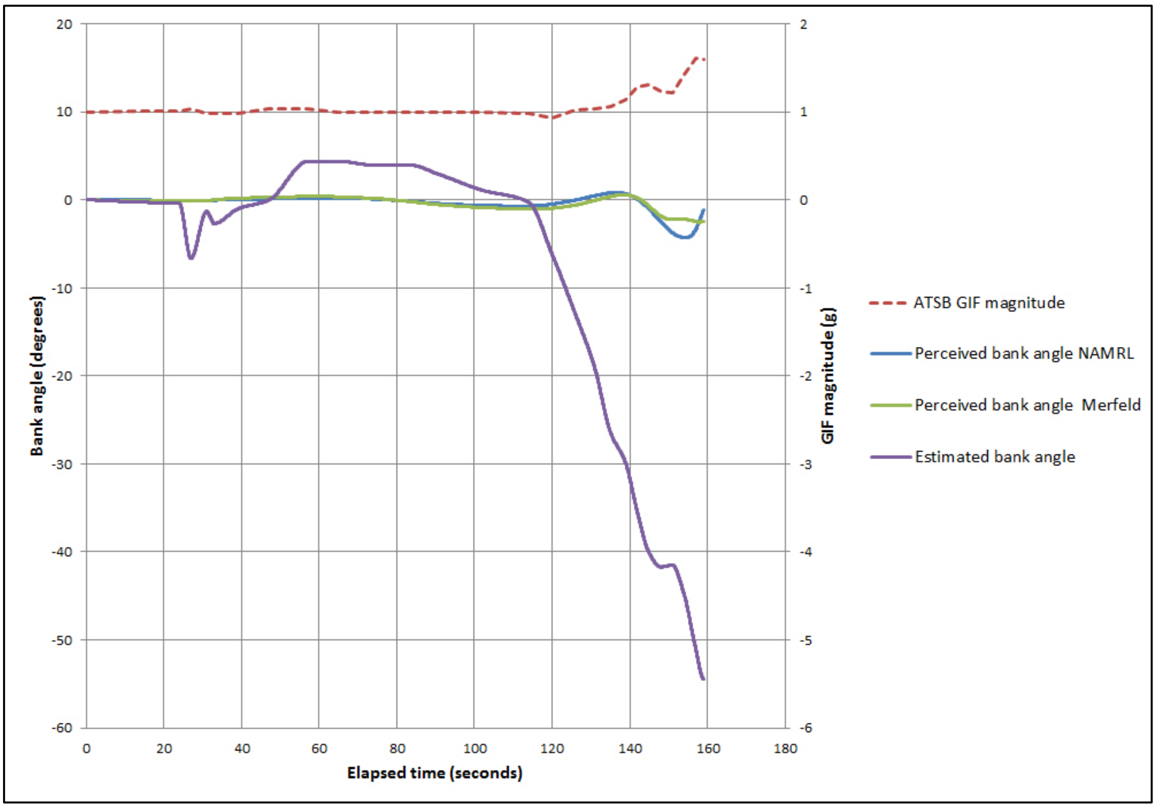


Source: ATSB

In recent years, researchers have developed models of human spatial orientation mechanisms, and such models have been used in several aircraft accident investigations. The ATSB asked the USAARL to conduct spatial orientation modelling work for the accident flight. The basic method was to use the GPS data, and estimated data for other parameters derived from the GPS data by the ATSB, as inputs into two spatial orientation models. The models then provided estimated values of how a pilot would perceive certain parameters.

Figure 5 provides details of the helicopter's bank angle estimated by the ATSB, and the two orientation models' estimates of the pilot's perceived roll. As indicated in the graph, the perceived roll during most of the right turn was very low in comparison with the actual roll. During the turn and descent, the magnitude of the GIF also only increased gradually. In summary, if it is assumed that the helicopter was in or close to coordinated flight, the orientation modelling shows that the pilot would have had very limited non-visual cues of the increasing bank angle and descent.

Figure 5: Estimated bank angle and perceived roll



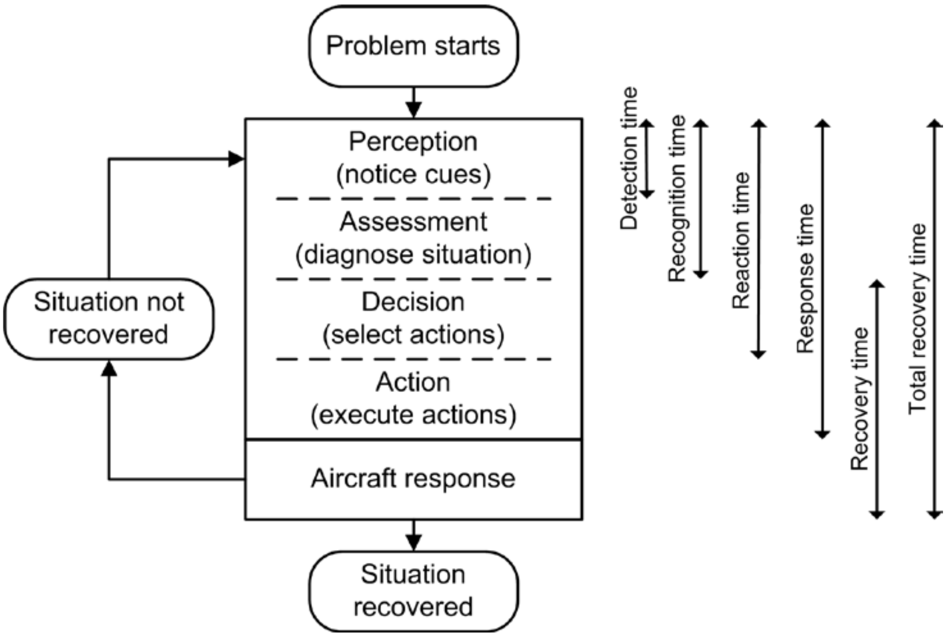
Source: ATSB

Human factors research

A common and significant challenge for the human factors discipline is to explain why a pilot does not appear to detect or correct a problem for a significant period of time, particularly when there are many who, with the power of hindsight, believe they would have been able to detect the problem quicker. Figure 6 provides a simplistic representation of the activities involved in recognising and recovering from a problem. Although each stage adds to the total recovery time, the more significant delays are usually the perception and assessment stages, and these delays are generally more to do with the focus of attention rather than the perception process.

Studies have found that pilots often recover from an unexpected or unusual attitude to straight and level flight within about 10 seconds. However, in these studies the pilots usually had recent practice in responding to an unusual attitude, know they will be presented with an unusual attitude, and know when it will be presented. Total recovery times in real situations will often be much longer.

Figure 6: Activities involved in recovering from a problem



Source: ATSB

In the case of the VH-NTV accident, a range of factors probably increased the time taken to detect and recognise the problem:

- There were no visual cues outside the cockpit to alert the pilot or passengers of the changing attitude or altitude.
- As demonstrated by the modelling, there were probably insufficient vestibular or somatosensory cues to indicate that the helicopter's attitude was different to what the pilot probably expected.
- Initially the flight instruments provided only limited deviations in altitude and airspeed and the difference between an intended gentle right turn and an increasing right bank would not have been that noticeable.
- After levelling off at 1,500 ft, it is likely that the pilot's attention was significantly diverted by the problem with the initial departure track. Reprogramming a GPS is a task that requires several keystrokes and a significant amount of visual attention, and people will often underestimate the time involved in doing such tasks.
- Performance will generally be slower when an abnormal event is not expected, and in this case the pilot probably had little reason to expect that he would be entering a spiral descent. Unusual attitudes are very rare events for an experienced pilot, and the pilot probably thought he was at a safe height, had sufficient time to attend to the GPS problem, and would be able to detect any deviations that occurred in sufficient time to recover.
- The pilot was very experienced, but almost all of his flying was under the VFR. Although he demonstrated instrument flying ability in the initial part of the flight, his last proficiency check was conducted 16 months before the accident. He had not held an instrument rating for over 30 years, and his proficiency checks in recent years were not as thorough as those required to maintain an instrument rating. A key area where instrument flying skill breaks down is the systematic scanning of the flight instruments.

- After detecting that an aircraft is at an unexpected or unusual attitude, a pilot needs to overcome their false perceptions and update their mental model of the aircraft's attitude and motion. This process can require some time, and can sometimes be complicated by a misinterpretation of the aircraft's attitude indicator (or artificial horizon) and roll reversals.

In summary, the pilot probably did not detect the descent and increasing bank angle for a significant time due to a range of factors. He may have detected a problem towards the end of the flight, but not fully recognised the nature of the problem in time to implement effective recovery actions. Although a period of 38 seconds may seem a long time for an experienced pilot to recognise and respond to a developing problem, such events with similar time intervals have happened many times before and the pilot's performance in this case during the right turn was well within the range of what could be expected given the circumstances.

Safety management aspects

Overall, the pattern of evidence was more than sufficient to conclude that spatial disorientation probably contributed to the accident. Key questions then remained regarding why the helicopter was being operated in the dark night conditions, given the inherent hazards of such operations, the pilot's limited recent night or instrument flying and the helicopter not being fitted with an autopilot. There was no indication that the pilot was concerned about the risk, or was under any pressure to conduct the flight.

The pilot of the accident flight was the owner, managing director, chief pilot and safety manager of the operator. He was one of two pilots who did the majority of flying for the operator's Sydney-based operations, with another permanent pilot based in Melbourne, and other pilots used as required on a casual basis. The chief pilot was fatally injured and some documentation associated with his management activities was destroyed in the accident. However, sufficient evidence was available to evaluate key aspects of the operator's risk controls and safety management processes through reviewing manuals and available documentation, as well as interviewing other personnel associated with the operator or who had travelled with the operator.

The operator did the majority of its flights during day time, and most of its night flights in areas with a significant amount of terrestrial lighting. However, it still occasionally conducted night flights in areas with minimal terrestrial or celestial lighting cues available. The operator had some risk controls in place for night operations that were in excess of the minimum regulatory requirements, and these mainly related to training. However, some of these risk controls were not always implemented as required.

The operator had no specific procedures that discussed the risk of dark night operations or required specific risk controls to be used for such operations. The operator had recently introduced a formal risk management process. Although this process had identified several hazards requiring management, it had not identified any aspect of night operations to be a hazard.

In summary, the investigation concluded that although some of the operator's risk controls for the conduct of night VFR flights were in excess of the regulatory requirements, the operator did not effectively manage the risk associated with conducting operations in dark night conditions. However, these problems were not considered to be unique to this operator, and the investigation also considered the fundamental requirements in place for VFR operations at night.

Requirements for dark night operations

Compared to situations at night where there is some ambient illumination and/or ground lighting available, there is a significant increase in risk in dark night conditions where no external visual cues are available. In dark night conditions, VMC is effectively the same as IMC. The only real difference is that, if there are lights on the ground, they can be seen in VMC. In remote areas where there are no lights or ambient illumination, there is no difference.

The definition of IMC is clearly and consistently specified in most countries, in terms of visibility and distance from cloud. There are also significant and consistent requirements for pilot qualifications, flying recency and aircraft equipment for operating in IMC. However, there is little consistency in how different countries deal with the minimum requirements for operating in dark night conditions. The only consistency is that the requirements are usually less onerous.

The ATSB has been concerned about the safety of VFR flights in dark night conditions for many years, and has previously issued recommendations on the issue. The Australian Civil Aviation Safety Authority (CASA) subsequently introduced Civil Aviation Advisory Publication (CAAP) 5.13-2(0), which provides a significant amount of guidance for operators and pilots conducting night operations. Although the CAAP strongly emphasises the importance of flying with reference to the flight instruments, and that pilots should maintain proficiency on flying on instruments, night VFR is still based on visual procedures. In dark night conditions, a pilot must fly with sole reference to the flight instruments, and should ideally have a demonstrated ability to fly to an instrument flight rules (IFR) standard to ensure an adequate level of safety, particularly for operations where passengers are being carried. In addition the CAAP discusses flight planning issues in depth, but does not discuss the importance of identifying the potential for dark night conditions, or provide guidance on how to identify and assess this potential.

The ATSB investigation concluded that the following safety issues existed (in Australia):

- Aerial work and private flights were permitted under the VFR in dark night conditions, which are effectively the same as instrument meteorological conditions, but without sufficient requirements for proficiency checks and recent experience to enable flight solely by reference to the flight instruments.
- Helicopter flights were permitted under the VFR in dark night conditions, which are effectively the same as instrument meteorological conditions, but without the same requirements for autopilots and similar systems that are in place for conducting flights under the instrument flight rules.

In response, CASA is taking a range of safety actions, including examining the definition of ‘visibility’ so that it is not restricted to illuminated objects at night.

Conclusions

The investigation posed many challenges. Of these, the most difficult and important challenge was explaining the helicopter's flight path, particularly the significant period of time that occurred with no apparent detection or correction of the descent with increasing bank angle. However, by using a range of different techniques the investigation team was able to provide a relatively detailed explanation of the accident flight, and based on this explanation raise a series of safety issues to facilitate safety action.

The post-on site phase of the investigation involved helicopter operations, engineering, flight data and human factors specialists. A key lesson of the investigation was the importance of the multi-disciplinary team working together throughout the analysis activities to identify, define and test hypotheses. Other key lessons included the fundamental importance of investigations conducting a detailed sequence of events analysis and a detailed review of potentially-related occurrences.