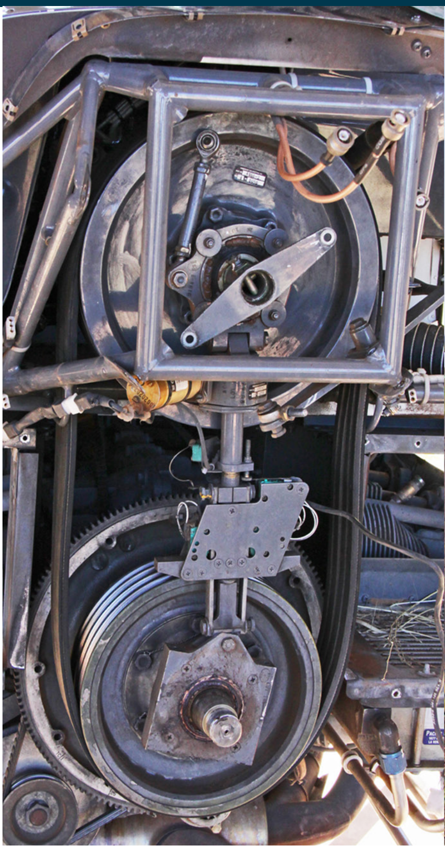
Australian Government

Australian Transport Safety Bureau

Reliability of the Robinson R22 helicopter belt drive system



Investigation

ATSB Transport Safety Report

Aviation Occurrence Investigation

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Safety summary

What happened

Following a number of accidents and serious incidents involving Robinson R22 helicopters where a failure of either one or both rotor drive v-belts has led to the occurrence event, the Australian Transport Safety Bureau (ATSB) initiated a S*afety Issues* investigation into the broader question of Robinson R22 v-belt operational reliability.

What the ATSB found

There were no systemic safety issues identified as a result of the ATSB investigation. However, drive belt reliability was found to be negatively influenced by a broad range of operational and maintenance-related factors, including:

- high gross or overweight operations
- high or excessive engine power settings (manifold pressures)
- sheave misalignment and/or poor drive system condition
- inadequate or infrequent inspections of the rotor drive system.

What's been done as a result

In July 2011, the ATSB issued safety advisory notice AO-2011-060-SAN-001, reinforcing the need for continued vigilance by operators and maintenance organisations regarding the routine inspection of the R22 drive system.

During the course of this investigation, the Robinson Helicopter Company released an updated 'Revision-Z' v-belt. Since that change, R22 industry feedback has indicated an overall improvement in the stability of the drive system and a reduction in failure rates.

Safety message

The Robinson R22 helicopter is the most popular light utility helicopter used in Australia and has a reputation for being an extremely reliable machine. Owners and operators should fully appreciate the nature and effects of the operational stresses placed on the helicopter, particularly if the machine is utilised in a dynamic and demanding manner such as required for cattle mustering operations.

Pilots, operators and maintainers should pay particular attention to the installation and condition of R22 drive belts and other components of the drive system, and should ensure that the manufacturer's requirements for inspection and maintenance of the drive system are adhered to at all times.

The continued safe flight of an R22 helicopter that has sustained a v-belt failure can be assisted by the pilot's awareness of the indications of a drive system malfunction, and the appropriate management of the emergency autorotation in accordance with published procedures.

Contents

Background to the report

In response to a fatal Robinson Helicopter Company (RHC) model R22 helicopter accident, and a number of other occurrences involving damaged or failed R22 helicopter v-belts, the Australian Transport Safety Bureau (ATSB) initiated a *Safety Issues* Investigation into the reliability of the R22 belt drive system.

Continued safe operation of the R22 helicopter is contingent on the reliability of all components within the main and tail rotor drive systems. The ATSB's experience, together with service reports and advice from RHC, has demonstrated that the drive belts have a greater overall likelihood of failure when compared with other components in the rotor drive system. Failures have been reported to occur suddenly and without obvious warning to the pilot.

Because of the frequent difficulty in establishing the specific mechanism/s that contribute to individual v-belt failures, the ATSB initiated this safety issues investigation to broadly identify the common factors in these events and to recommend appropriate measures to help prevent future occurrences.

Context

General description

The Robinson R22 helicopter is a two-seat, light utility helicopter powered by a horizontally mounted, rearward facing Lycoming four-cylinder reciprocating piston engine. The helicopter has design features that are common to other helicopters; however the drive system from the engine to the rotors is unique (Figures 1 and 2).

Power is transmitted from the engine to the main and tail rotors through vertically mounted sheaves (also commonly called drive pulleys) and a v-belt arrangement. The drive assembly carries two double banded v-belts. Each drive belt consists of two single v-belts that are bonded by a common rubber backing (tie-band). The lower drive sheave is bolted to the output flange of the engine crankshaft, while the upper sheave is located immediately above on the clutch shaft to the main rotor gearbox.

Before the engine is started, the clutch actuator is placed in the disengaged position, which leaves the v-belts slack and allows the engine to start and run freely without the load of the main and tail rotors. A pilot-operated, electrically-driven actuator is used to progressively tension the drive belts and enable power transfer from the engine to the rotor system.

The clutch actuator is vertically positioned between the upper and lower sheaves. When the actuator is engaged, the upper sheave and clutch shaft are moved upward, applying tension to the drive belts. A column spring arrangement within the clutch actuator senses the compressive load caused by increasing belt tension and stops the actuator motor when the tension reaches a pre-set value.

Figure 1: The Robinson R22 rotor drive system

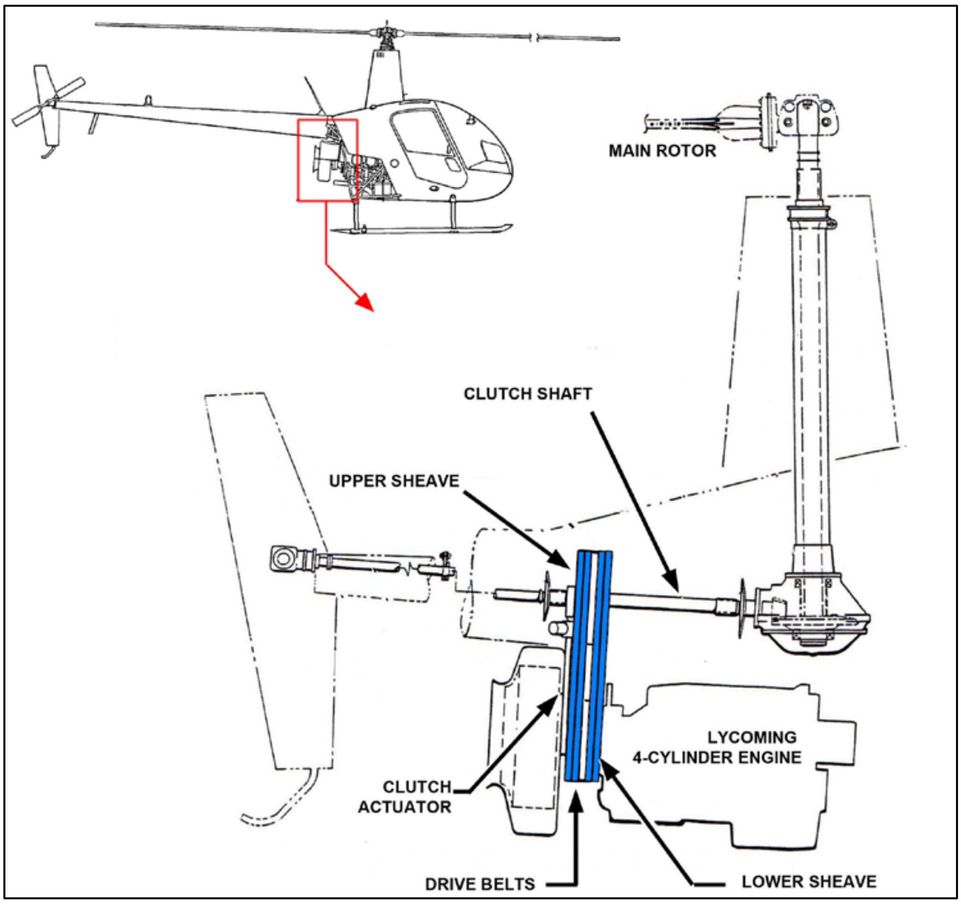
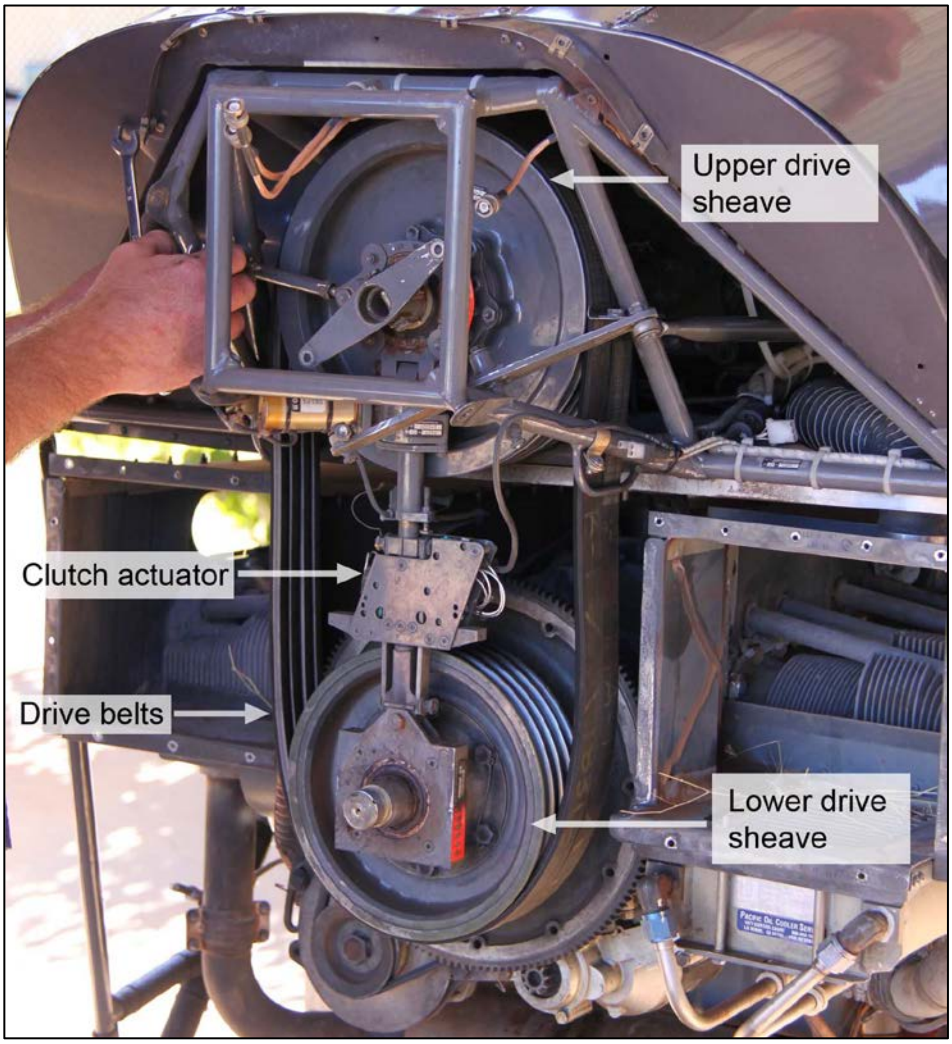


Figure 2: Mechanical arrangement of the R22 rotor drive system

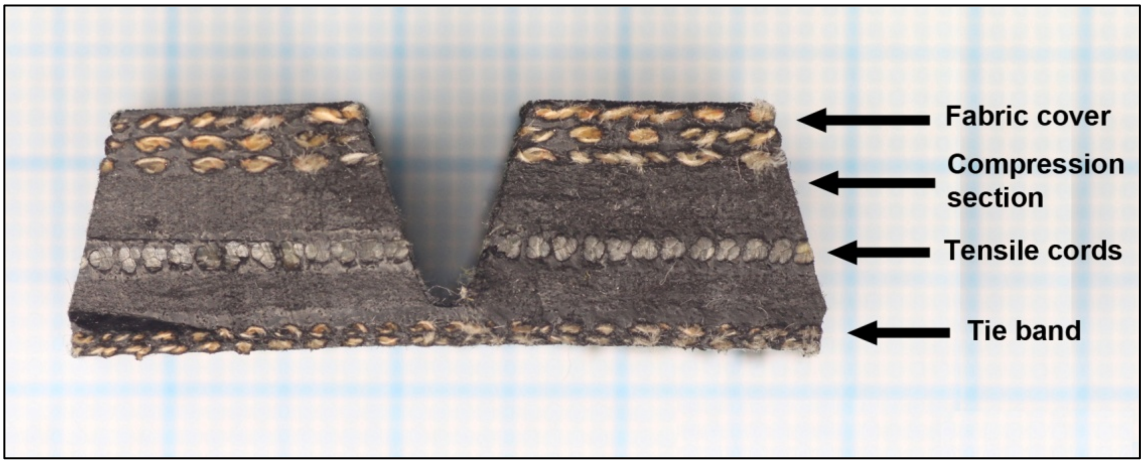


Drive belts from RHC

Each belt set is supplied from Robinson Helicopter Company (RHC) as a matched-length pair. This ensures that the belts seat evenly and share an equal portion of the load being transmitted. Belt quality control at the Robinson factory involves a full dimensional and visual inspection. The visual examination is aimed at detecting manufacturing defects such as splitting, delamination, cuts or voids, and if found, the belts are rejected and do not leave the factory.

During operation, the sidewalls of the belt grip the sheave groove sidewalls. Torque from the engine is transferred via shear stresses between the sheave and belts. Belt tensile strength is primarily achieved through the centre band of high-strength woven cords (tensile cords) that carry the power load and minimise axial stretching. A backing tie-band adds additional lateral stiffness to the belt structure; reducing the likelihood of belts rolling over or ‘walking’ out of their sheave grooves. The surrounding rubber matrix absorbs shock from any engine power or rotor load transients that are transmitted during flight. A cross-sectional view through the latest revision drive belt is shown at Figure 3.

Figure 3: Cross-section through a v-belt (Revision-Z)



V-belt revisions

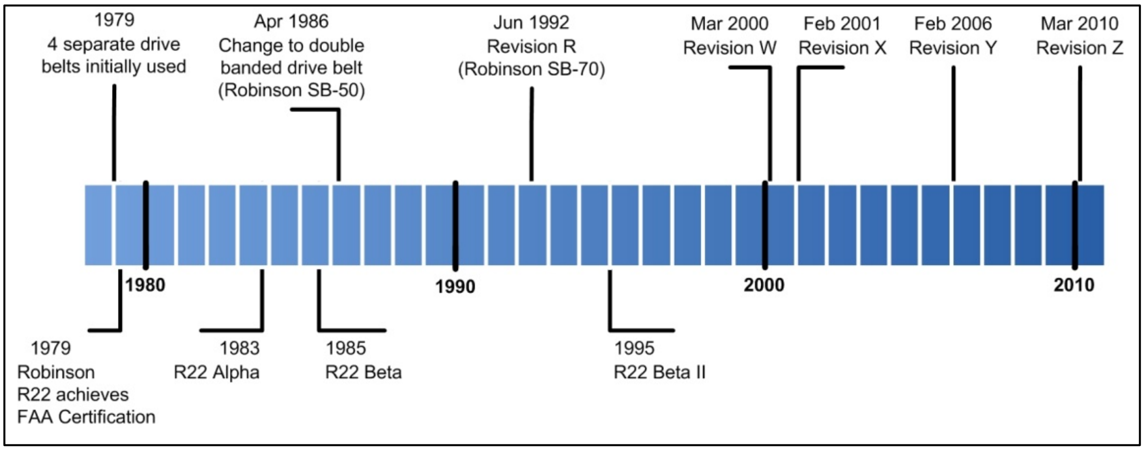
The R22 helicopter was initially certified in 1979. The helicopter's drive system at that time incorporated four individual v-belts. As illustrated in Figure 4, over the years, the R22 helicopter had numerous changes to the drive system. Each change was denoted by a successive belt revision, for example Revision-A, Revision-B and so on. In 1986, RHC introduced a new design in which the four separate belts were replaced by a double-banded design.

In 1986 and 1992, new belt design revisions were announced to R22 operators and maintenance centres through the release of service bulletins SB-50 and SB70 respectively. Other belt revisions were largely due to production variations that involved subtle changes to the belt formulation or belt geometry.

All belt designs up to and including Revision-Y were produced by the Gates Corporation in the USA. More recently, RHC changed drive belt suppliers to Mitsuboshi Belting Limited, and in 2010, the first of the new Mitsuboshi belts, denoted 'Revision Z', was released into service for the R22.

The Revision-Z belts are slightly shorter in circumference than the previous generations. Industry feedback has indicated that failures have been less frequent since the Revision-Z drive belt standard introduction. Once the initial break-in period is complete, the final stability of the belt system is reported to be much better than the earlier revision belts. The earlier Revision-Y belts were reportedly prone to progressive stretching that required increased vigilance and periodic adjustment of the drive system throughout the life of the belts.

Figure 4: History of R22 drive belt changes



The Australian R22 experience

As of June 2012 there were over 500 Robinson R22 helicopters on the Australian Civil Aircraft Register. It is the most popular helicopter in Australia and has a good safety record relative to other Australian-registered light piston-engine helicopters. That record has improved since the early 1990s.

The various models have been popular for flight training, private operations and aerial work applications. A previously released ATSB study of Australian R22 usage showed that the R22 was primarily used for aerial cattle mustering operations – a unique application that is conducted on a yearly basis in northern Australia during the dry season, between April and October.[1] A survey[2] of all owners and operators on the Australian register revealed that the Robinson R22 fleet conducted around 145,000 flying hours during the 2010 calendar year. Aerial work (cattle mustering) comprised the majority of those operations, totalling around 105,000 hours, with flying training, business and private flights making up the remainder of the Australian R22 fleet usage.

In 2004, the ATSB commissioned a study to examine the forces affecting an R22 during cattle mustering, and compared those operations to the R22 certification flight profile.[3] The study showed that aerial mustering involves considerable periods of low speed flight and abrupt manoeuvring. The study showed that mustering operations can involve large and sudden engine power changes that can apply very high loads on the helicopter's drive system. The report concluded that during low-speed mustering manoeuvres, pilots must employ good handling techniques and careful engine power management to avoid exceeding the helicopter's certification limits.

Australian v-belt failures

During the 8-year period between 2004 and 2012, there have been eight significant incidents or accidents reported to the ATSB, where failure or degradation of the v-belts has been central to the occurrence event. In most instances, belt failure has led to a successful landing or the occasional hard landing or rollover. However, there have been two fatal R22 accidents in which the pilot has been unable to successfully manage the emergency autorotation following v-belt failure.[4,5] The eight occurrences are shown in sequence at Figure 5, with the details summarised in Appendix A.

In addition to the ATSB's occurrence database, a search of the Australian Civil Aviation Safety Authority's (CASA's) service difficulty report (SDR) database was conducted to gauge the prevalence of v-belt problems reported by Australian operators. The SDR database contained a collection of reports from the Australian Robinson R22 flying and maintenance community. As plotted in Figure 6, the yearly number of reported v-belt failures rose and fell without any apparent pattern; however, a peak developed during the 2009 operating period. The failure rate has since declined since the introduction of the Revision-Z belts in March 2010.

The defect reports indicate the belt failure mechanism as:

- stretching to the manufacturer's specified limits
- tie-band debonding
- tie-band splitting

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1 Australian Transport Safety Bureau, Research Report BE04/73, *Light utility helicopter safety in Australia*, 2004

2 Bureau of Infrastructure, Transport and Regional Economics, *General Aviation Activity 2010*

3 Australian Transport Safety Bureau, Research Report B2004/292, *Robinson R22 helicopter aerial mustering usage investigation*, 2004

4 ATSB Aviation Safety Investigation AO-2011-060, Collision with terrain – Robinson R22 Beta II helicopter, VH-DSD, 85 km NW of Julia Creek, Qld - 9 May 2011

5 ATSB Aviation Safety Investigation AO-2007-046, Collision with terrain – Robinson R22 Beta II helicopter, VH-HCN, Doongan Station, WA - 25 September 2007

- edge cord failure
- excessive wear.

Figure 5: Timeline of occurrences reported to the ATSB that have related to v-belt failures (see also Appendix A)

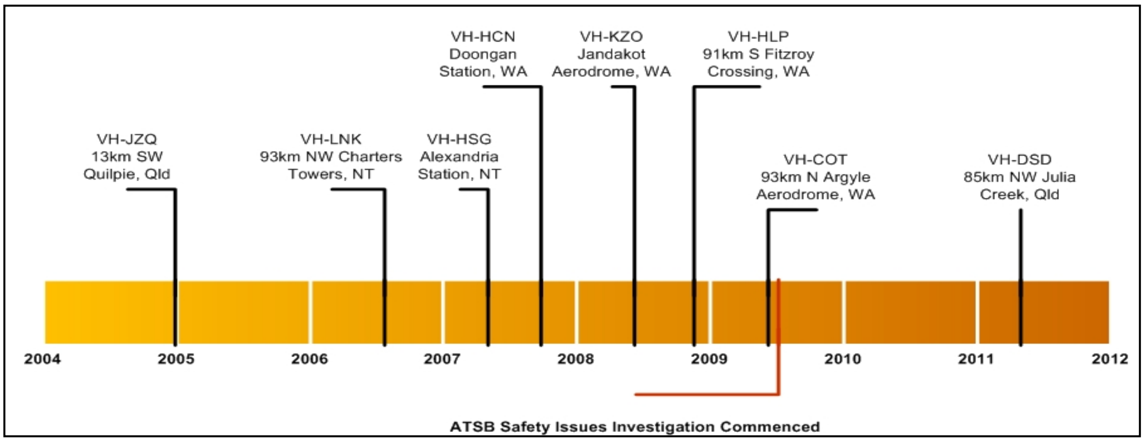
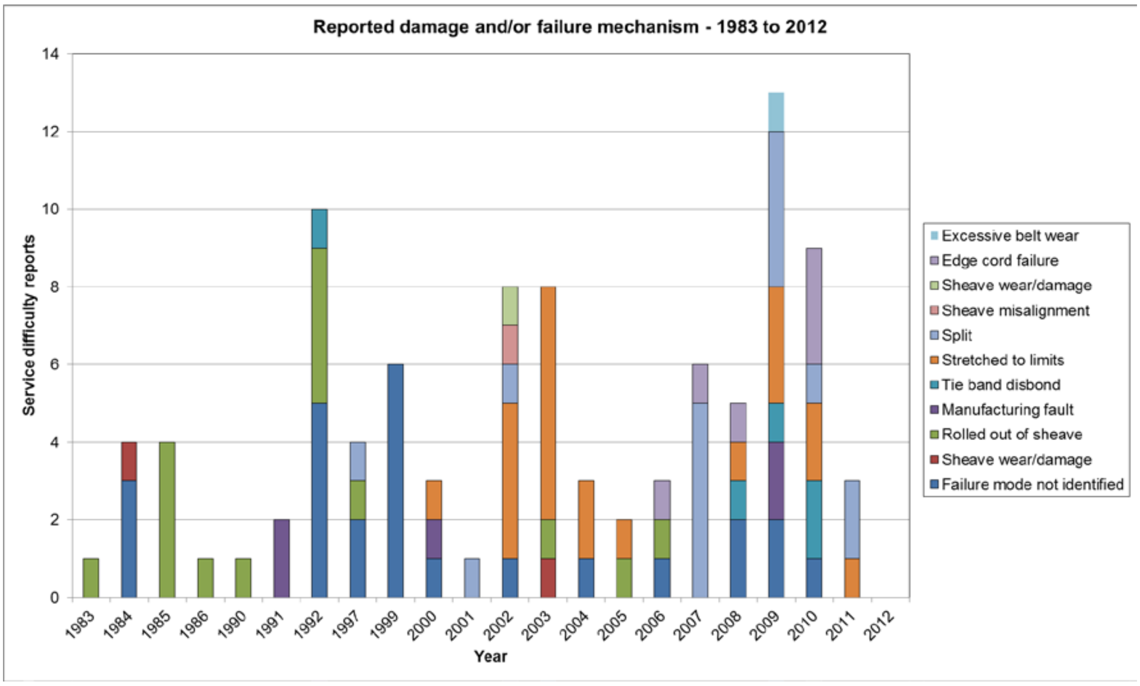


Figure 6: Australian record of reported v-belt serviceability problems from the CASA SDR database. The reports ranged from an identified belt condition (i.e. stretched beyond limits) to a belt defect (i.e. belt split)



International occurrences

In the 2005-period, the US Federal Aviation Administration's (FAA) Los Angeles Aircraft Certification Office (LAACO) reviewed relevant service difficulty reports involving R22 drive belt system problems. Drive belt failure modes associated with operation of the R22 included excessive stretch, splitting, clutch actuator serviceability problems, and belts slipping and rolling out of their sheaves. The findings from that study were published in an accident investigation report by the Transportation Safety Board (TSB) of Canada[6], and were also provided to the ATSB.

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6 Transportation Safety Board of Canada, Aviation Investigation Report 'Collision with water', Report Number A04P0314

On the basis of that study, the FAA noted that the current R22 drive system design, with accompanying advisory material for its safe operation, met the certification basis and was safe to operate. The report noted that in most cases, problems have occurred with relatively new belts and have been associated with some combination of the following factors:

- *Helicopter operation at high weight, or above gross weight conditions.*
- *Improper sheave alignment at installation, or alignment shifts caused by initial belt wear-in.*
- *Sheave surface condition with new belts mounted on worn or corroded sheaves.*
- *Actuator tension being out of specification.*
- *Excessive belt slack at initial engagement.*

A review of international accidents involving drive R22 drive system failures was also conducted as part of this safety issues investigation. Data from the United States[7], United Kingdom[8], New Zealand [9] and Canada[10] was examined and a total of 21 occurrences were identified between the period 1991 and 2012 where the failure of the v-belts was cited as contributing to accidents and incidents involving foreign registered Robinson R22 helicopters. A summary of each occurrence is contained in Appendix B.

Maintenance aspects - inspection requirements

Like all aircraft, the R22 helicopter must be inspected periodically to verify that it is airworthy. Guidelines for the inspection of the drive system and replacement of the drive belts are contained in the *Robinson R22 Maintenance Manual*. It is a requirement that the v-belts used in the R22 be replaced at the 2,200 hour major overhaul. Experience has shown, however, that it is very unlikely that a set of belts will last for a complete major overhaul cycle, with a set lasting typically for around 400 to 500 hours when utilised for mustering operations, and around 800 to 900 hours for flight training. Until the 2,200 hour replacement limit is reached, the required inspections that relate to the v-belts consist of the *daily and pre-flight*, and the *100-hourly* inspection.

Daily and pre-flight drive system inspection

It is an Australian regulatory requirement that the daily and pre-flight inspection of the helicopter be performed in accordance with the *R22 Pilot's Operating Handbook* (POH) by either a licensed aircraft maintenance engineer, a pilot endorsed on the aircraft type or an otherwise approved person. The daily and/or pre-flight inspections of the helicopter are intended to provide a regular opportunity to ensure the airworthiness and satisfactory general condition of the machine. Section-4 of the R22 POH provides a list of items that require direct inspection. With regard to the drive system, when inspecting the right side of the helicopter, the POH requires that the *condition* and *amount of v-belt slack* be checked.

Belt damage

Pre-flight inspections present an ideal opportunity for assessing whether a v-belt is serviceable or damaged and about to fail. Published literature suggests that the inspection should include examination of unusual damage such as excessive stretch, wear, cracking, delamination or splitting. All belts surfaces should be carefully inspected. The following section presents a summary of contemporary guidance material for the assessment of belt condition during pre-flight inspections.

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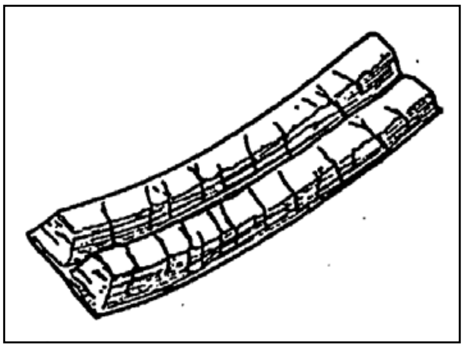
[7] US National Transportation Safety Board

[8] UK Air Accident Investigations Branch

[9] Civil Aviation Agency of New Zealand

[10] Transportation Safety Board of Canada

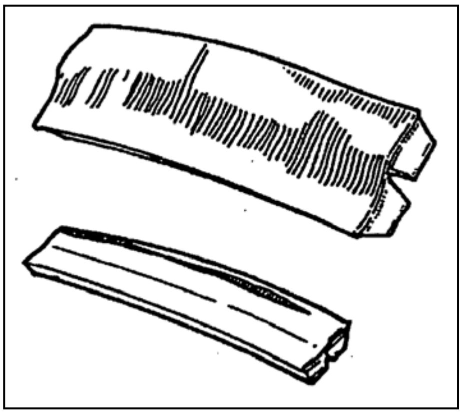
Symptom: belts cracking



Probable cause

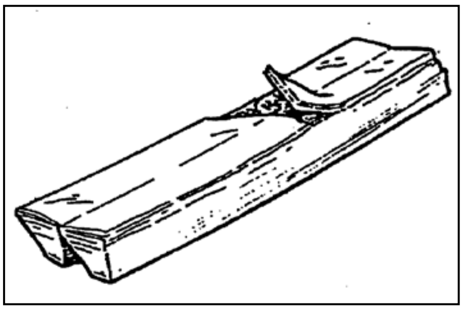
- Belts are old and have reached the end of their service life.
- Belts are slipping, causing heat build-up and gradual hardening of the tensile undercord.
- High belt temperatures from belt slippage may also glaze the belt side walls.

Symptom: tie-band frayed or damaged



- Belts have contacted an obstruction such as the belt guide plate.

Symptom: tie-band blistered or peeling



- Dirt or sand or a foreign object has contaminated the drive sheaves.

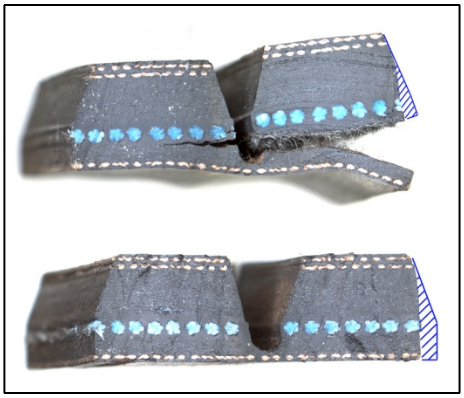
- V-belts have reached the end of their service life.

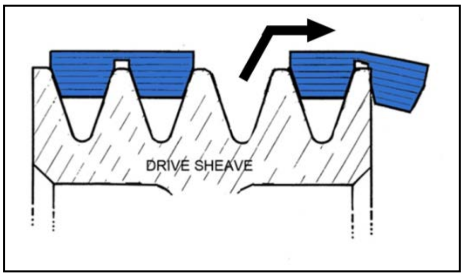
Symptom: tie-band splitting

- Excessive sheave wear may allow the v-belts to ride deeper into the grooves eventually damaging the tie-band.

- A belt that has rolled out of its sheaves can damage the tie-band in the manner shown.

Symptom: uneven wear

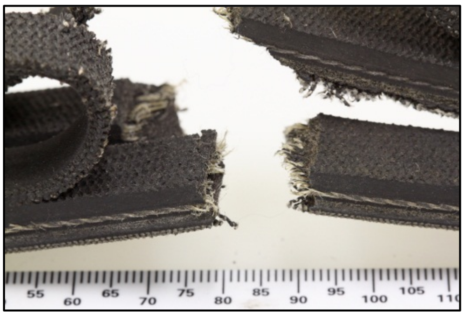




Probable cause

- The edges of the belts should be carefully examined for evidence of unusual or excessive wear which is indicative of a tracking or alignment issue between the upper and lower sheaves.
- Under these circumstances, any misalignment of the drive system will produce uneven wear to belt flanks, which may eventually allow the belts to dislodge and climb or roll out of their sheave grooves.

Complete belt failure



A tensile overstress failure can result from too much belt tension or excessive and continual shock loads to the drive. As outlined in the Robinson R22 POH, an amber caution 'clutch' light illuminates on the instrument panel whenever the clutch actuator is operating. If the belts stretch during flight, the clutch light will illuminate as the actuator adjusts the belt tension.

Heavy black dust deposits – belt failure imminent

During normal operation, light deposits of black dust can often be found in and around the R22 helicopter drive system as the v-belts wear against the upper and lower sheaves. Through the examination of a number of v-belt failures, the ATSB has observed a common indicator in these circumstances - being the presence of *significant quantities* (i.e. greater than normal) of black rubber dust over the drive system components around the belts.

Excessive black rubber dust is generated from an accelerated wear process, with the dust deposited onto the surrounding helicopter structure and drive system components. Abnormal deposits of rubber dust may therefore signal an impending belt problem or drive system alignment issue. Particular vigilance should therefore be applied when presented with these indications.

"If in doubt, change them out" (and check the alignment)

Upper and lower drive sheaves

Robinson helicopters provide two different types of upper drive sheave for the R22 rotor drive system; one is manufactured with a hardened anodized aluminium surface and the other with a metallized coating. Industry reports indicate that durability and wear behaviour of the metallized sheave is superior to that of the anodized sheave when exposed to dust and grit in harsh operating environments.

The condition of the drive sheaves strongly contributes to the reliability of the drive system. During the 100-hourly inspection, the grooved surfaces of the drive sheaves must be inspected for general damage or corrosion, excessive wear and sharp ridges. When replacing the v-belts the following warning is provided in the *R22 Maintenance Manual*:

> **CAUTION**
>
> Rough or corroded grooves in the upper or lower sheave grooves can cause v-belts to roll, break, or come off.

In a 1991 RHC service bulletin[11] to R22 operators, the incidence of v-belts rolling in the sheave grooves and breaking was related to belt and sheave compatibility. If the wear patterns are noticeably different from groove to groove, immediate replacement of the belts and an alignment check is required. As referenced in a RHC service letter[12], any wear of sheave grooves that produce ridges or steps greater than 0.006 in (0.15 mm) are cause for replacement of the sheaves.

Drive belt installation and replacement

Improper installation has been attributed as a common cause of premature drive belt failure. During start-up, before the clutch actuator is engaged, excessive belt slack can lead to a drive belt rolling or jumping out of its sheave groove. In this condition, the outermost belt rib can ride outside of its proper location without a supporting or aligning sheave groove. The belt can then separate from the common tie band across the joined strands.

Clutch actuator rigging

The manufacturer has advised that during the helicopter start-up procedure when the belts are initially tensioned, if the clutch light remains illuminated and the main rotor blades are not turning after 10 seconds, a problem with the drive system may exist. During such events the pilot should disengage the clutch actuator and de-tension the v-belts to enable an inspection of the rotor drive system. The manufacturer has also advised that in day-to-day operations if a step-wise change is noted for the time it takes for the clutch actuator to fully engage and tension the v-belts (i.e. from 5 seconds to 10 seconds, or 10 seconds to 20 seconds), that change may signify a problem with the rotor drive system has developed and further examination is warranted.

Glazed drive belt sidewalls indicate that the belt is slipping in the drive sheaves. This is a result of too little tension and may occur if the clutch actuator is damaged or no longer performing to the manufacturer's specifications. Slippage locally overheats the belt sidewalls and quickly reduces their tension and load carrying capacity. Heat generated from slippage can lead to cracking of the tensile undercords, chunking of the rubber flanks and loss of flexibility.

Prior to engine start-up when the clutch is fully disengaged, the *R22 Maintenance Manual* states that the down limit screw should be adjusted to ensure the correct drive belt deflection. Belt deflection is easily measured (Figure 7). If the belts stretch during service and that slack is not taken into account by readjustment of the down limit stop screw, the belts can droop and then jump outside their grooves on helicopter start-up, leading to a rapid drive system failure.

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[11] Robinson Helicopter Company, R22 Service Bulletin #66 'Vee Belt – Lower Sheave Inspection', dated 19 April 1991

[12] Robinson Helicopter Company, R22 Service Letter #20A 'Vee Belt Installation', dated 20 June 1984

Figure 7: Belt deflection measurements with clutch actuator disengaged

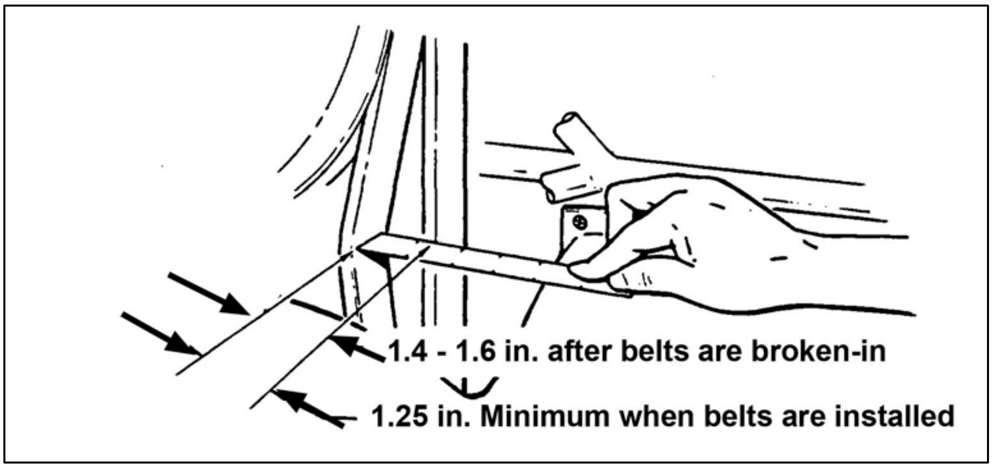

Image source: Robinson R22 maintenance manual

Drive system alignment

The overall alignment of the drive sheaves has been cited by the helicopter manufacturer as a primary contributor to v-belt reliability. Misalignment is also referenced in the literature by industrial belt manufacturers as being a strong factor leading to premature v-belt failures. As the nature and magnitude of the operational stresses carried by the v-belts is heavily influenced by belt and sheave alignment, it follows that any misalignment can have a significant detrimental effect on drive system reliability and the potential for belt failures.

It is a requirement within the *R22 Maintenance Manual* that the overall drive system alignment be checked during either the 12-month or the 100-hourly inspection. An alignment check must also be performed whenever the v-belts are changed.

Alignment checks are performed with the clutch actuator engaged and the v-belts under tension. The specific alignment procedures within the *Maintenance Manual* must be followed to ensure the drive sheaves are tracking in the same plane, direction and orientation. Correct alignment relies on each of the following:

- Engine height check as per Section 6.130 of the *R22 Maintenance Manual*
- Clutch shaft angle check as per Section 7.240 of the *R22 Maintenance Manual*
- Sheave alignment check as per Section 7.230 of the *R22 Maintenance Manual*

Operational aspects

Loss of drive to the main rotor system

The Robinson R22 helicopter main rotor system is a low-inertia design. As such, the main rotor will deplete its stored energy quickly once power is removed, associated with a rapid decay in rotor rpm and the subsequent blade aerodynamic stall. Consequently, the pilot has limited time to react to maintain the rotor rpm in the event of a sudden power loss.

In September 1986, the manufacturer issued Safety Notice SN-24, entitled *"Low RPM Rotor Stall Can Be Fatal"*. The notice warns that a very high percentage of accidents are caused by rotor stall due to low main-rotor RPM and explains the procedures that can be used to mitigate the risk.

Data from accident and incident reports indicates that symptoms of a drive belt failure can occur suddenly and may be initially confusing to the pilot. Pilots have reported the following symptoms during flight, before a complete drive system failure has occurred:

- a ‘rubber’ or ‘metallic’ burning smell
- intermittent or flickering clutch actuator light during flight
- sudden and continued illumination of the clutch actuator light during flight
- the onset of excessive vibration or a loud and unusual noise from the rear of the helicopter; such as a ‘bang’, ‘pop’ or ‘grinding’
- an abrupt rise in engine RPM and an associated decay in main rotor RPM.

In the case of a complete loss of rotor drive, a pilot is required to immediately enter autorotation by lowering the collective control to reduce the main rotor blade drag. Once established in autorotation, the main rotor is driven by the upward airflow generated by the descent and forward airspeed. Nearing the ground, a pilot will progressively flare the helicopter by applying rearward cyclic until the rate of descent and airspeed is sufficiently reduced and forward speed arrested. Upward movement of the collective follows to cushion the landing.

All single-engine helicopters such as the R22 have a range of heights and airspeeds within which it is not possible to safely conduct an autorotative landing. This region is usually depicted on a Height-Velocity (HV) diagram. The likelihood of completing a successful autorotation and landing is improved with the availability of sufficient altitude, airspeed and main rotor RPM.

Safety assurance – additional checks

The scheduled inspection and maintenance requirements as listed by the manufacturer provide a *minimum* basis for continued airworthiness of the R22 helicopter. Industry feedback to the draft of this report shows that certain Australian operators have recognised that the reliability of the v-belt and rotor drive system must be taken into account in their operations. In order to provide a further measure of safety assurance, extra vigilance and functional checks have been adopted by those operators to ensure the highest level of safety is maintained. For example:

- When operating in climates of significant temperature variation, it has been recognised that the clutch actuator light should briefly illuminate from time-to-time to indicate that tensioning of the belts is occurring. If the clutch light illumination is not observed during these periods, an operator has advised their pilots to land the helicopter and verify the proper operation of the clutch system.

The ATSB encourages operators to consider the risks of belt failure and the need for additional safety checks in the context of their own operations. The Robinson Helicopter Company has advised that they would welcome any opportunity to discuss additional safety measures that operators are considering or have found effective.

Effect on v-belts when gross weight limits are exceeded

With regard to the effect on the v-belts of exceeding the helicopter’s maximum gross weight, the helicopter manufacturer advised the ATSB that:

> *Exceeding the maximum gross weight is an issue for the drive belts in that it is likely to lead to a condition where power limitations will be exceeded. The Lycoming O-360-J2A engine is capable of producing as much as 180 BHP, compared to the maximum continuous rating of 124 BHP and 5 minute takeoff rating of 131 BHP for the helicopter.*
>
> *As torque is transmitted from the lower to upper sheave, there is a difference in belt tension between left and right sides. Exceeding manifold pressure limitations therefore leads to an excessive difference in tension. One half of the belt is subject to excessive slack in this condition and will be prone to vibrations and possible slippage that leads to belt damage and possibly causing one strand to move off the sheave, or splitting the strand from its backing to allow it to roll-over within the sheave groove. A misalignment of sheaves will exacerbate the tendency for one strand to move off the sheave.*

She'll be right mate….or will it?

Although the R22 rotor drive system is designed using a double-banded v-belt arrangement, the helicopter is not designed to fly using just a single v-belt. Industry feedback to the draft of this report indicated that in some instances, pilots have continued to fly the R22 helicopter with just a single v-belt in place.

If a problem is encountered with one of the belts, the helicopter should be considered unairworthy and no further flight should be undertaken until the serviceability of the drive system is restored. Failure to understand the risks associated with flying with damage to the v-belts has led to fatal outcomes (refer to the VH-HCN accident summary at Appendix A of this report).

Operating environment

Literature[13] from industrial belt manufacturers indicates that higher operating temperatures will shorten the v-belt service life. Excessive heat from any source will accelerate the progressive curing process, resulting in the rubber becoming hard and brittle. This in turn can result in cracks forming through the belt structure. When the v-belts are in motion, heat is generated both externally and internally. Internal heat is created by constant flexing of the structural components, while excessive slippage from inadequate tensioning can generate substantial heat from frictional effects – rapidly damaging the belt. As a general rule, the expected belt life is halved for every additional 20 °C increment of prolonged operation above 35 °C.

Investigations, research and additional guidance material

Australian Civil Aviation Safety Authority (CASA)

Following the September 2007 fatal R22 accident at Doongan Station, Western Australia (ATSB investigation number AO-2007-046), the Australian Civil Aviation Safety Authority (CASA) issued airworthiness bulletin AWB 63-006[14] *Issues related to the Robinson Helicopter Corporation (RHC) R22 main rotor drive system*, to all R22 operators and maintainers. The purpose of the bulletin was to:

- *Provide Operators and Maintainers' a consolidated summary of investigations carried out by CASA Airworthiness Specialists based on several information resources including CASA received SDRs.*
- *To remind maintainers and operators of the need to strictly adhere to the requirements of all current RHC approved data for the operation and maintenance of the R22.*
- *To provide a guide to the information available, including RHC data in relation to main rotor drive system with emphasis on the main rotor drive v-belts.*

The AWB provided a reminder of the need to strictly adhere to the requirements of all current Robinson data for the operation and maintenance of the R22 drive system and v-belts.

Civil Aviation Authority of New Zealand

The May/June 2011 edition of the New Zealand Civil Aviation Authority's 'Vector' magazine included an article that highlighted the criticality of the v-belts to the R22 drive system. The article, entitled *Two Belts, No Braces* provided an easily-read explanation of the drive belt installation in the R22 and highlighted the possibility of v-belt failures. Of interest to pilots and operators (and

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13 Carlisle Power Transmissions Products, 'Industrial v-belt drives design guide'
Gates Corporation, 'Hot and Cold Running Belts'

14 CASA Airworthiness Bulletin 63-006, 'Issues related to the Robinson Helicopter Corporation (RHC) R22 main rotor drive system', dated 14 August 2009

similar to the advice provided earlier by CASA in AWB 63-006), the article stressed the importance of the correct installation of the drive belts before commencing operations.

The Vector article also discussed the design of the belts, reinforcing that there is a limit to the belts' power transmission capabilities. Any time that power limit was exceeded, such as when carrying excessive weight, a reduction in belt life can be incurred. The article cautioned that, over time, any reduction in belt life could lead to a premature failure.

Australian Transport Safety Bureau

In July 2011, the ATSB issued a Safety Advisory Notice, AO-2011-060-SAN-001, reinforcing the need for continued vigilance by operators and maintenance organisations when routinely inspecting the R22 drive system. The advisory notice stressed the importance of attention to the following areas:

- *Drive belts. Check for defects or damage such as blistering, cracking or delamination.*
- *Drive sheaves. Check for incorrect alignment, poor sheave surface condition and/or uneven groove wear patterns.*
- *Clutch actuator. Check for incorrect tension, such as indicated by rotor engagement during engine start.*
- *Attention is also drawn to the detrimental effect on v-belt life of exceeding engine horsepower limits, as measured by manifold air pressure (MAP). To mitigate that risk, pilots should operate the helicopter within the flight manual limits; specifically, those related to MAP.*

Safety analysis

This ATSB investigation examined the issues surrounding the reliability and performance of the belt-driven rotor drive system as fitted to Robinson Helicopter Company model R22 light utility helicopters. The investigation drew upon information from a number of sources, including:

- ATSB safety investigations
- occurrence reports received by the ATSB
- international incident and accident reports
- service difficulty reports (SDRs) received by CASA
- maintenance documentation, service bulletins and alerts from the helicopter manufacturer.

From the collective information gathered, it was evident that the overall reliability and performance of the R22's v-belt drive system can be influenced by a range of operational, maintenance and environmental factors. The investigation did not identify any previously-unknown characteristics of the belt drive system that could be held as uniquely contributory to the reported reliability issues. Importantly also, the investigation found no specific or significant safety issues in the manufacture or design of the drive belts that might present an airworthiness issue for continued safe operation of the Robinson R22 helicopter fleet.

Industry feedback indicates that failures have been relatively infrequent since Robinson introduced the Revision-Z drive belt standard. Once the initial break-in period is complete, the final stability of the belt system is reported to be much improved over the earlier Revision-Y belts that were indicated as being prone to progressive stretching - requiring periodic adjustment of the drive system across the life of the belts if reliability was to be maintained.

By virtue of the system design and the general characteristics of reinforced rubber v-belts, it should be recognised that the belts represent a critical link in the main rotor drive system. Belt failures are often rapid and may be preceded by the onset of vibration or a burning smell. The ATSB reinforces the need for continued vigilance by operators and maintenance organisations during the routine inspection of the R22 drive system.

Some of the factors that can influence the reliability of the R22 drive system are:

Regular and detailed inspection

It is an Australian regulatory requirement that the daily inspection of the v-belts and sheaves must be performed in accordance with the R22 Aircraft Flight Manual by a licensed aircraft maintenance engineer, or a pilot endorsed on the helicopter type. Although the Robinson R22 helicopter has a reputation for being a reliable machine, particular vigilance should be applied during these inspections, as they represent a fundamental opportunity to detect the onset of drive system deterioration. Any form of drive belt damage such as blistering, cracking and tie band (webbing) separation is cause for belt replacement and further investigation.

Robinson Service Bulletin SB-66 highlights the importance of inspecting the sheaves. If the wear pattern is noticeably different from groove to groove, or from one side of the grooves to the other, it is recommended that the drive belts be immediately replaced and the sheave alignment checked.

Another prime inspection opportunity exists prior to installation of the belts. Careful inspection of the drive sheaves at this time may identify any surface abnormalities. The surface condition of the sheaves should be smooth and uniform and there should be no raised lips or sharp edges evident.

Operation

Pilots must monitor engine manifold pressure (MAP) and comply with placarded power limitations. Exceeding the drive system limitations may reduce belt life or result in sudden belt failure. Robinson Safety Notice SN-37 provides additional detail and guidance.

Environment

Operating the helicopter in environments where dust and grit can contaminate the drive system, or where the ambient temperature is high, can adversely influence the service life of the belts and sheaves. Helicopters operated in these environments may require additional periodic drive system inspections.

Sheave alignment

Correct sheave alignment after installation of the drive belts is critical in ensuring belt longevity. Any change to the dimensions of the belts, which may occur progressively during service, will cause a change to the operating position of the upper clutch shaft and an increased misalignment of the sheaves. As sheave misalignment has been identified as a contributing factor in a number of belt failure occurrences, operators and maintainers must ensure that alignments are periodically checked and corrected where necessary.

High gross weight operation

Pilots must ensure that the approved gross weight limits are not exceeded while operating the helicopter.

Clutch actuator

The electrically-driven clutch actuator automatically controls drive belt tension. A cockpit caution light will illuminate when the actuator is re-tensioning, engaging or disengaging the belts. Robinson Safety Notice SN-28 suggests that a problem with the drive belts may be imminent if, during flight, the clutch light flickers excessively or remains illuminated. Under these circumstances the pilot is advised to land immediately.

Findings

This investigation determined that the reliability of Robinson Helicopter Company model R22 v-belt drive system is dependent on numerous factors associated with the operation and maintenance of the system. The following key findings were identified:

Key findings

- The reliability of the v-belt based R22 drive system can be influenced by a broad range of operational and maintenance-related factors, including:
  - high or excessive engine power settings (manifold pressures)
  - sheave misalignment and/or condition
  - inadequate or infrequent inspections of the v-belt drive system.
- There was no individual factor or set of factors that were present across the range of failures examined, to the extent that would suggest the existence of a specific or systemic safety issue.
- Operators and maintainers can significantly enhance the reliability of the v-belt drive system and reduce the risk of in-flight failures, by ensuring that they explcitly follow the manufacturers' instructions and guidance material for the operation, maintenance and inspection of the helicopter rotor drive system.

Appendix A

Australian occurrences

A search of the ATSB aviation safety occurrence database identified a total of 8 events in the period between 2004 and 2011 where failure of the main rotor drive v-belts was cited as contributing to accidents and incidents involving Australian-registered Robinson R22 helicopters. Accidents and incidents recorded in the ATSB's safety database are categorised according to the type of event, and if known, the contributing factors. A summary of each occurrence follows:

VH-JZQ, 13km SW Quilpie, Queensland, Feb 2004

The helicopter was being flown to an adjacent station property, when approximately 15 minutes after departure and at 800 ft above ground level (AGL), the pilot observed a flickering clutch light. The pilot began to look for a suitable landing place; however, before one could be located, there was a loud 'bang' from the rear of the helicopter that prompted the pilot to conduct an autorotation. During the touchdown the helicopter struck small shrubs and was turned 180-degrees from the direction of flight. The helicopter remained upright.

Post-accident examination of the helicopter revealed that one of the v-belts had failed due to the belt tension actuator being driven past its lower stop position. During the last engine start and rotor engagement it was likely that the v-belts had slipped forward on the drive sheaves.

VH-LNK, 93km NW Charters Towers, Queensland, July 2006

During low-level mustering operations, the pilot reported to the ATSB that the clutch light illuminated and then immediately after, one of the v-belts from the main rotor drive system failed. At about 20 ft AGL, the pilot turned the helicopter towards more favourable terrain for landing however the second v-belt also failed. The pilot reported that the engine RPM increased rapidly while the helicopter yawed left before impacting terrain. There were no injuries.

VH-HSG, Alexandria Station, Northern Territory, May 2007

While on approach to land at about 200 ft AGL, the pilot smelled 'burning rubber' and then seconds later heard two loud 'bangs'. The pilot commenced an autorotation and the helicopter landed heavily resulting in bent cross tubes and a creased tail boom. Subsequent inspection of the drive system showed that both v-belts had failed. The belts were 'Revision-Y' and been fitted approximately 15 operating hours prior.

VH-HCN, Doongan Station, Western Australia, Sep 2007
ATSB investigation number: AO-2007-046

The pilot departed from Doongan Station to conduct a stock survey. On board the helicopter were the pilot and one passenger. About 5 to 10 minutes into the flight, the passenger detected a 'rubber' burning smell. The passenger informed the pilot who immediately landed the helicopter. The pilot visually inspected the helicopter with the engine and main rotor turning, and remarked that one of the v-belts appeared to be damaged. The pilot decided to return the helicopter to the station, while the passenger elected to remain at the landing site and await transport by motor vehicle. The passenger later began walking in the direction of the station and subsequently discovered the wreckage of the helicopter, which had been destroyed by impact forces and fire (Figure 8). The pilot had been fatally injured.

The investigation determined that the helicopter's main rotor v-belts probably failed or were dislodged, resulting in a loss of drive to the rotor system. The investigation also identified a *number of safety factors relating to unsafe decision making; including the operation of the helicopter beyond the allowable weight and centre of gravity limits.*

Figure 8: Burnt wreckage of VH-HCN

VH-KZO, Jandakot Aerodrome, Western Australia, June 2008

During a solo training flight, the student pilot noticed the clutch light illuminate. As only a few seconds remained before landing, the pilot completed the approach and hover-taxied the helicopter a short distance to a grassy landing area. During the taxi at about 5 ft AGL, a loud 'banging' noise was heard, which was followed by the smell of burning rubber. The pilot landed immediately and shutdown helicopter. Examination of the drive system revealed that the front v-drive belt had split and fragmented into multiple pieces. The rear belt remained intact. The helicopter was reported to be relatively new with only 6 hours of total operation. There were no injuries.

VH-COT, 93km N Argyle Aerodrome, Western Australia, June 2008

While cruising at around 500 ft AGL the pilot received a low rotor RPM warning. The pilot wound on the throttle with no effect before conducting an autorotation landing onto rocky ground. During the landing the skid struck rocks and the helicopter rolled onto its side resulting in serious damage. Neither of the occupants were injured. An inspection revealed that one of the v-belts had failed and the other belt had rolled off the drive sheaves.

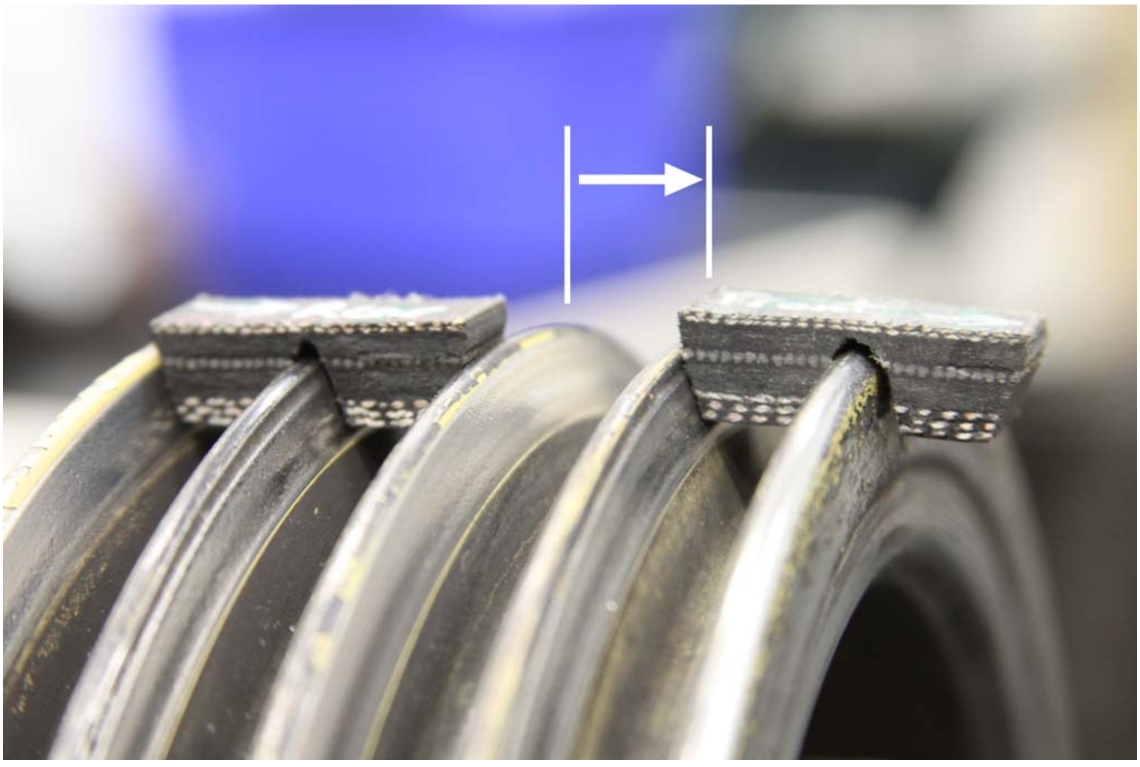
VH-DSD, 85km NW Julia Creek Aerodrome, Western Australia, May 2011
ATSB investigation number: AO-2011-060

A Robinson R22 helicopter was being utilised for cattle mustering operations when during the afternoon of the muster, the pilot issued a sudden radio transmission indicating that 'I'm going down'. Upon hearing the radio transmission, two other R22 pilots that had also been mustering in the local vicinity flew to the area and discovered that the helicopter had impacted terrain. The pilot of the accident helicopter had sustained fatal injuries. Examination of the wreckage revealed that a v-belt had broken. Two fragments of the front v-belt were found close to the main wreckage. The rear v-belt was found wrapped around the drive sheaves. Impact damage to the helicopter was consistent with a high rate of descent.

Recovery of data from the pilot's handheld GPS indicated that the belt failed which led to a rapid descent into terrain from about 120 ft AGL. The investigation determined that the forward v-belt had partially dislodged from the drive sheaves during the accident flight, resulting in consequential damage to the belt structure and its eventual failure. The sudden failure of the front v-belt also contributed to the failure of the rear belt and the subsequent complete loss of drive to the main rotor system (Figures 9 and 10).

Figure 9: Following an in-flight failure of the v-belts, the helicopter impacted terrain with a high rate of vertical descent

Figure 10: Examination of the drive system from VH-DSD showed that prior to the accident the front v-belt had shifted forward and off the sheave.



VH-HLP, 91km S Fitzroy Crossing, Western Australia, May 2008

The pilot was inspecting the condition of pastoral dams when on approach to land at about 80 ft AGL, the low RPM horn sounded and the engine RPM rapidly increased. The helicopter impacted the dam wall with a high rate of descent. The pilot survived the accident (though with severe injuries) and subsequently reported that earlier in the flight the clutch light had illuminated briefly for about 3 seconds. There were no other warnings of an impending issue.

Post-accident inspection of the helicopter revealed that both v-belts had dislodged forward from their drive sheaves. Although maintaining a continuous loop, one half of the rear v-belt had completely separated from the backing material. A detailed examination of the drive belts revealed considerable wear had occurred to the flanks of each belt. Wear of that nature was indicative that both belts had been operating with a degree of side load during service which indicated the failure was related to misalignment in the drive system (Figures 11 and 12).

Figure 11: The helicopter impacted terrain with a high rate of vertical descent

Figure 12: A cross-section through the rear v-belt from VH-HLP noting that one half of the belt had completely detached from the backing, with significant wear through the belt flanks found (shaded region)

Appendix B

International occurrences

A review of international accidents involving drive R22 drive system failures was also conducted as part of the investigation. Data from the United States[15], United Kingdom[16], New Zealand [17] and Canada[18] was examined. A total of 21 occurrences were identified between the period 1991 and 2012 where the failure of the v-belts was cited as contributing to accidents and incidents involving foreign registered Robinson R22 helicopters outside Australian territory.

Below is a summary of the narrative taken from each occurrence. For a detailed description of each event please refer to the relevant investigation report.

Riverside, California, United States, Mar 1991
NTSB occurrence report: LAX92LA034

> *While practising takeoffs and landings, the student pilot reported that the engine RPM indicator suddenly pegged at the top of the gauge and the rotor RPM began rapidly decreasing. The pilot initiated an autorotation and landed heavily. Examination of the helicopter revealed that the forward v-belt was split longitudinally and displaced from the transmission pulleys. The rear belt was found off the engine and transmission pulleys.*

Gurabo, Puerto Rico, Jan 1994
NTSB occurrence report: MIA94LA054

> *The pilot stated that during cruise flight over unsuitable terrain at 1,800 ft AGL, the clutch light flickered momentarily then remained illuminated. The pilot waited for 5 seconds then pulled the clutch circuit breaker and initiated an emergency descent for a forced landing. Examination of the helicopter revealed that one of the two v-belts had completely separated and half of the remaining belt had also completely separated. According to the maintenance records the drive belts had accumulated about 442 hours since new.*

Cambridge Airfield, United Kingdom, Nov 1998
AAIB occurrence: EW/G98/11/16

> *The helicopter was approaching the airfield at 75 kn in a cruising descent through 1,000 ft AGL when the pilot noted a 'scraping' noise, which reportedly lasted less than a second. Some 5 seconds later the transmission clutch light illuminated and did not extinguish. The clutch circuit breaker was then pulled, in accordance with the Emergency Procedures in the Flight Manual. As the helicopter approached the hover when the main rotor RPM decayed in response to raising the collective lever. A rapid descent was followed by a successful run-on landing onto the taxiway.*
>
> *Subsequent inspection found part of one transmission drive belt in the engine compartment, with the remainder being later recovered from the taxiway. The other belt was not found.*
>
> *A small 'nick' of damage was subsequently discovered on one of the upper sheave rims. As it did not appear that the damage could have been caused by anything within the engine compartment, it was considered that a foreign object may have damaged the rim which then led to failure of one belt. The helicopter (and drive belts) had accumulated some 500 hours since new, with 10 hours having elapsed since the last 100 hour inspection.*

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[15] US National Transportation Safety Board
[16] UK Air Accident Investigations Branch
[17] Civil Aviation Agency of New Zealand
[18] Transportation Safety Board of Canada

Wentworth Station, New Zealand, January 1999
CAA occurrence report: 99/23

While involved in a hunting operation, the pilot smelt something burning and decided to carry out a precautionary landing. As he was doing so, there was a bang and the engine 'revved up', but power to the main rotor was lost. The power loss to the main rotors was due to broken v-belts. The belts had been replaced approximately 50 hours earlier, at which time there was some indications of wear to the anodised coating in a groove on the upper sheave. Wear can rapidly accelerate, resulting in belts rolling, breaking or coming off.

Buffalo, Wyoming, United States, Mar 2001
NTSB occurrence report: DEN01LA067

Approximately 20 minutes after takeoff on a cross-country flight, the pilot noticed the clutch light was on and he smelled burning rubber. The pilot conducted a power on autorotation and at approximately 50 ft AGL a loud 'pop' was heard and the aircraft 'dropped' to the ground. Inspection revealed that the upper clutch bearing had failed. A Robinson Safety Notice (#28) requires the pilot to listen during start up and shut down for unusual noises in the upper and lower clutch actuator bearings. According to the safety notice a failed bearing will produce a whine, rumble, growl or siren sound.

The probable cause of the accident was determined as the failure of the rotor drive system clutch assembly which rendered the aircraft uncontrollable.

Henderson, Nevada, United States, June 2002
NTSB occurrence report: LAX02LA189

The pilot felt a jolt and observed the clutch light illuminate in the cockpit. The subsequent wreckage examination revealed one of the two rotor system v-belts had broken. The second belt was intact, however the upper section of drive belt had shifted forward one groove on the pulley.

Kent, Texas, United States, February 2003
NTSB occurrence report: FTW03LA099

The pilot reported that the helicopter was in level cruise at an altitude of 700 to 900 ft AGL at an indicated airspeed of 70 to 75 kn, when a loud 'thump' was heard from behind the cabin, immediately followed by the activation of the clutch light and a change in engine and rotor noise.

One of the two v-belts was later found missing and the remaining belt was off of the upper sheave and showed considerable damage. Apart from impact-related damage, no other discrepancies in the assembly or installation or alignment of the engine, clutch assembly, or actuator assembly were noted during examination of the wreckage. The belt had separated between the vees with only a 5-inch section still intact.

Hertfordshire, United Kingdom, Apr 2003
AAIB occurrence: EW/C2003/04/04

At around 500 ft AGL as the helicopter approached for landing, the pilot heard a loud 'grumbling' noise and felt a 'twitch' to the left. Assuming the engine had failed, the pilot lowered the collective and entered autorotation. The helicopter rolled over on its right hand side after landing. The passenger commented that the clutch light had illuminated periodically during the flight.

Post-accident examination of the helicopter revealed that one of the v-belts was missing, and there was evidence of rubber deposits around the transmission compartment suggesting that the belt had flailed around after it had failed. The remaining belt was still intact and appeared undamaged. No damage was observed on the sheave rims. The actuator was found at a mid-position.

Winsted, Minnesota, United States, May 2004
NTSB occurrence report: CHI04LA119

The pilot reported that he had heard a loud bang, smelled burning rubber, received a clutch warning light, and conducted an autorotation into a recently planted corn field. One of the belts was centrally split for approximately half of the circumference of the belt. The second belt was found shredded.

The investigation determined the probable cause of the accident as the failure of the main rotor v-belts for an undetermined reason, and the pilot's management of the flare during the autorotation.

McIvor Lake, British Columbia, Canada, Aug 2004
TSB occurrence report: A04P0314

The helicopter was being used on a short flight from Campbell River to a private airstrip. As the helicopter approached McIvor Lake, the engine RPM increased and the helicopter pitched up then entered a steep descent. As the helicopter descended toward the lake, witnesses reported 'popping' or 'banging' noises. In the latter stages of the descent, the forward motion of the helicopter slowed and the vertical descent rate increased. The helicopter was observed to strike the lake surface with high vertical velocity and low rotor rpm. The helicopter sank in about 30 ft of water. The pilot was fatally injured. Examination of the wreckage indicated that both v- belts had dislodged from their drive sheaves before water impact.

The investigation found that at some point after installation, both drive belts were subjected to changes in dimension, probably as a result of shrinkage due to excess heat. Any changes to belt length would increase the risk of the belts coming off the sheaves and disconnecting the engine from the rotor system. The investigation also found that the use of a 10-amp fuse in place of the required 1.5 amp fuse in the electrical circuit to the belt tensioning actuator could have allowed the actuator to over-tension and damage the belts.

Prescott, Arizona, United States, Mar 2005
NTSB occurrence report: LAX05LA122

While cruising about 60 kn at 300 ft AGL, the helicopter's nose yawed left and then right. Concurrently the helicopter shook, and the clutch light illuminated. Upon landing, it was observed that the v-belts were shredded. A company mechanic had performed a 100-hourly inspection about 4.3 hours prior to the accident flight. During the inspection, he had adjusted the belt actuator down limit screw self-locking nut, but had forgotten to reposition the stop-crew at the conclusion of the inspection.

Crete, Illinois, United States, July 2005
NTSB occurrence report: CHI05LA173

A Robinson R22 Beta helicopter sustained substantial damage following an in-flight fire, hard landing and subsequent ground fire. The pilot reported that while flying the helicopter he noticed the clutch light illuminate for longer than 7 seconds. A decision was made to pull the clutch actuator circuit breaker and the pilot conducted an emergency landing. Upon exiting the helicopter flames about three feet high were observed above the v-belts. A section of drive belt about a foot in length was recovered from the accident site.

The investigation found that the separation of the v-belts during cruise had led to the puncturing of the oil cooler and a subsequent fire.

Whangarei Harbour, New Zealand, February 2007
CAA occurrence report: 07/324

The helicopter was being utilised for training and had just turned crosswind out of the climb from the active runway when a jolt was felt, followed immediately by a reduction in main rotor RPM.

The instructor initiated an autorotation into the surrounding harbour, from which both instructor and student managing to escape without injury. CAA investigation of the accident found that the transmission v-belts had failed. Tests were conducted on the one recovered section of belt, and the drive belt clutch actuator assembly, but no reason for the belt failure could be determined.

Plant City, Florida, United States, December 2007
NTSB occurrence report: NYC08LA060

While cruising at 700 ft AGL, the pilot noted a strong odour of burning rubber, a loss of power, illumination of the clutch light, and yawing of the helicopter. The pilot entered autorotation and descended into trees. In a follow-up interview, the pilot stated that during engine start, 10 to 15 seconds transpired between the times that clutch switch was engaged and the main rotor blades turned. According to the pilot's operating handbook starting engine checklist, the rotor blades should start turning less than 5 seconds after engagement of the clutch switch. According to a note in the manufacturer's maintenance manual, V-Belt Installation, 'A delay of more than 5 seconds between clutch switch engagement and rotor turning indicates excessive slack.'

The investigation determined that a loss of rotor drive occurred due to excessive slack and breakage of the drive belts. Contributing to the accident was the pilot departing in the helicopter after the rotor engagement time during engine start exceeded the time outlined in the pilot's operating handbook.

El Monte, California, United States, Jan 2008
NTSB occurrence report: LAX07LA274

While in cruise flight at about 1,700 ft AGL, the pilot heard a loud 'bang' from the back of the helicopter. The alternator warning light illuminated and the pilot initiated the alternator emergency procedure. The pilot conducted an emergency autorotation on uneven terrain; the main rotor struck the tail boom and the helicopter rolled onto its left side. Subsequent inspection of the helicopter revealed that the two main v-belts had dislodged from the drive pulleys. The alternator belt was missing and not recovered.

The investigation determined that the failure of the main rotor drive belts was due to damage sustained when the alternator drive belt failed.

Suffolk, Virginia, United States, Jan 2008
NTSB occurrence report: NYC08LA043

While circling the helicopter at about 600 ft AGL, the pilot noticed that the clutch light was illuminated. About five seconds later, he pulled the clutch circuit breaker. At the same time, the engine's RPM sharply increased and the main rotor RPM alarm sounded. Post-accident examination of the helicopter drive system revealed that the v-belts had rolled off the sheaves; however the investigation was unable to determine why the belt failure had occurred.

Fort Stockton, Texas, United States, Sept 2008
NTSB occurrence report: N993KC

The helicopter experienced a hard landing after a malfunction of the main rotor drive system. The pilot had just taken off from a trailer and transitioned to low level cruise when he heard a loud 'bang'. The pilot cross-checked his engine instruments and observed the *engine RPM was excessively high, the rotor RPM was below 80 percent and the low rotor RPM warning horn was sounding. The on-scene investigation noted that one of the v-belts to the main rotor drive system had separated, which caused the other belt to slip off the upper spindle. The reason for the belt failure could not be determined.*

Del Ray Beach, Florida, United States, June 2009
NTSB occurrence report: N2306T

During a training flight at about 3,000 ft AGL and while cruising at 65 – 70 kn, both the student pilot and flight instructor felt a vibration through the airframe. On transition to an altitude of 4,000 ft, additional airframe vibration was felt. The vibration increased in intensity to a point where the instrument panel could not be read. Both the clutch and rotor brake light illuminated. The flight instructor took control of the helicopter and initiated an emergency autorotation.

Subsequent examination of the drive system showed that both main v-belts had dislodged from their sheaves; the rear belt had broken and contained multiple tears along the belt centreline. There was no evidence that the belts had been damaged prior to that flight. A review of the helicopter logbooks found no entries regarding the last belt replacement.

Banks Peninsular, New Zealand, October 2010
CAA occurrence report: 10/3925

It was reported that the helicopter had a v-belt failure, landing heavily on a forestry track. The aircraft was written off.

West Melbourne, Florida, United States, July 2010
NTSB occurrence report: ERA10LA361

During takeoff, while the helicopter was about 80 to 100 ft AGL, the clutch caution light briefly illuminated. The clutch light illuminated once again, and the pilot felt the helicopter vibrate. The pilot initiated a descent and heard a loud 'pop and grinding noise' from the rear of the helicopter. A post-accident examination of the drive system found that the grooves in the upper sheave were worn beyond serviceable limits. An entry in the logbook states that the drive belts were replaced 22.9 hours prior to the accident. The investigation determined that given the level of wear in the upper sheave grooves, it was unlikely that maintenance personnel had properly inspected the sheave prior to drive belt installation.

Sources and submissions

Sources of information

The sources of information for this investigation included:

- Robinson Helicopter Company
- ATSB Aviation Research and Analysis Report B2004/0292, 'Robinson R22 helicopter aerial mustering usage investigation'
- ATSB Aviation Research and Analysis Report BE04/73, 'Light Utility Helicopter Safety in Australia'
- US Federal Aviation Administration
- Transportation Safety Board of Canada
- US National Transportation Safety Board
- UK Air Accidents Investigations Branch
- NZ Civil Aviation Agency
- Australian Civil Aviation Safety Authority
- Gates Corporation
- Mitsuboshi Belting Ltd

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003*, 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 organisations tabled below.

Aviation Specialists	Bankstown Helicopters Pty Ltd
Barkly Helicopters Pty Ltd	Black Helicopters
Cloncurry Mustering Company Pty Ltd	Civil Aviation Safety Authority
Central Queensland Aviation	Channel Country Heliwork Pty Ltd
Derby Air Maintenance	Davidson Heliworks Pty Ltd
Fitzroy Crossing Helicopter Maintenance	Fairlight Station
Heli Engineering	Heli Centre Australia Pty Ltd
Helibits Pty Ltd	Helibiz Gold coast
Helicopter Rebuilds	Helidoc Pty Ltd
Heliflite Pty Ltd	Helimuster NT
Heliwest Group Pty Ltd	Hillside Station
Howard Helicopters Pty Ltd	Kalala Station
Kestrel Aviation	Lone Eagle Aviation Services
Melbourne Helicopters Pty Ltd	Mengel's Heli Services
North Australian Helicopters Pty Ltd	Nimvale Pty Ltd
North Queensland Aviation Services	Robinson Helicopter Company
Southwest Aviation	Tadgell Aviation Services

Submissions were received from Robinson Helicopter Company, Mengel's Heli Services, Hillside Station, South West Aviation, Barkly Helicopters, Howard Helicopters, Helidoc and the Australian Civil Aviation Safety Authority. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau 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 safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

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.

Terminology used in this report

Occurrence**:** accident or incident.

Safety factor**:** an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor**:** a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor**:** a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding**:** any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue**:** a safety factor that (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 operational environment at a specific point in time.

Risk level**:** The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of z taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical safety issue:** associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant safety issue:** associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor safety issue:** associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action**:** the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

Australian Transport Safety Bureau

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Investigation

ATSB Transport Safety Report
Aviation Occurrence Investigation
Reliability of the Robinson R22 helicopter belt drive system
AI-2009-038
Final – 30 April 2013