Robinson R22 Beta, G-BYHE

AAIB Bulletin No: 3/2001

Ref: EW/C2000/9/3 - Category: 2.3

Aircraft Type and Registration:	Robinson R22 Beta, G-BYHE
No & Type of Engines:	1 Lycoming O-320-B2C piston engine
Year of Manufacture:	1991
Date & Time (UTC):	13 September 2000 at 1423 hrs
Location:	Wycombe Air Park (Booker) Buckinghamshire
Type of Flight:	Aerial Work (Training)
Persons on Board:	Crew - 1 - Passengers - None
Injuries:	Crew - None - Passengers - None
Nature of Damage:	Substantial to helicopter tail structure
Commander's Licence:	Commercial Pilot's Licence, Aeroplanes
Commander's Age:	59 years
Commander's Flying Experience:	2,128 hours (of which 13.9 hours were on type)
	Last 90 days - 13.9 hours
	Last 28 days - 13.9 hours
Information Source:	AAIB Field Investigation

History of the flight

An experienced aeroplane pilot was undertaking training to gain his Private Pilot's Licence (Helicopters). On the day of the accident the Chief Flying Instructor (CFI) briefed him for a pre solo check flight. The weather at the time was fine with a light wind and no low cloud.

The pilot carried out a pre flight inspection of the helicopter and seated himself at the controls in preparation for engine/rotor start, putting on a headset, which was fitted with Active Noise Reduction. The CFI joined the student who had started the helicopter using the checklist. Following clearance from ATC, the student hover taxied to the helicopter operating area 'November', on the north side of the airfield. Two dual circuits were flown to the satisfaction of the CFI and he declared the pilot competent to carry out a solo circuit. Having delivered a short briefing, the instructor exited the helicopter, secured his seat belt and walked away in the 10 o'clock position from the nose of the helicopter. He had noted before leaving the helicopter that the engine RPM

(ERPM) was set at 104% and the governor was engaged with the governor warning light extinguished.

Having walked some 10 metres away the CFI heard the engine note increase and turned around to see the aft section of the tail boom had detached and was hanging down with the tail rotor resting on the ground. The student was still seated in the helicopter with the engine running and the CFI, concerned that the student might attempt to take off motioned him to stay on the ground. The CFI then entered the helicopter and shut down the engine.

Collective pitch control lever

The collective pitch control lever is positioned to the left of the pilot and is a 38 cm long, 2.5 cm diameter metal tube hinged at the aft end. On the forward end of the tube is a motorcycle type twist grip throttle. The throttle is held in the pilot's left hand and is opened by twisting the grip clockwise when viewed from the front. The collective pitch control lever is connected to the main rotor blade pitch change mechanism by a system of control rods. Raising the forward end of the collective control lever about the rear hinge causes the main rotor blades to increase pitch collectively. A mechanical linkage correlates the rotor blade pitch angle to the engine carburettor butterfly. As blade pitch angle is increased more engine power is required and the throttle is opened by the mechanism. An electro mechanical governor is located in the collective/throttle mechanism to maintain a constant ERPM. It is selected on or off by a conventional metal switch located on the forward end of the collective lever orientated left/right. Moving the switch to the left selects the governor off.

When the collective lever is raised the governor adjusts the throttle in order to maintain 104% ERPM. Initially this requires a slight closing of the throttle. Tests established that with ERPM set at 80% and Manifold Air pressure (MAP) indicating 12.5 inches, raising the collective lever and not permitting the throttle to back off until the ERPM indicated 104% occurred at 17 inches. An increase of 4.5 inches MAP produced an increase in ERPM of 24%. With the collective control lever fully down governor selected off and ERPM set to 80% only a very small movement of the twist grip throttle was required to increase ERPM to 104%.

Tail rotor drive and tail boom structure

The tail-rotor drive of a Robinson R22 consists of a long shaft of approximately 1 inch diameter, extending from a flexible coupling in the rear of the fuselage just aft of the drive pulley to another flexible coupling just forward of the tail-rotor gearbox. The shaft is situated within a tapering tail boom, which is a circular section sheet alloy structure made in six sections. Adjacent sections are joined in the planes of supporting frames by riveted lap joints. Each row of rivets joins two skin panels and the flange of the supporting frame.

A single bearing is mounted flexibly at a point approximately one third of the length back from the forward coupling and is attached to the third frame by means of a bracket and a thin gauge strap. The strap is attached to the bracket by a single bolt and at its other end it is attached to the plate carrying the bearing by a similar bolt. Each of these bolts uses a friction washer system enabling the bearing to damp local lateral or vertical oscillation of the shaft.

Examination of the helicopter

When first examined, the forward section of the helicopter showed no abnormal features. The tail boom, however, was found in three portions, the first portion, consisting of three bays, remaining attached to the helicopter. The second portion consisted of the next two bays whilst failure had also occurred at the penultimate frame station leaving the last portion, consisting of the final bay, attached to the tail rotor gearbox. Thus two total separations of the boom structure had occurred, leaving the drive shaft as the only component uniting the failed sections.

The shaft was complete but the forward coupling exhibited a torsional failure. The drive through the tail rotor gearbox was intact and free to turn. The damper bearing support bracket had been pulled from its mounting on the frame and had broken away from the strap, probably as a result of the bracket striking the interior of the forward section of the boom whilst rotating at speed during the break-up of the boom. The bearing cage was damaged as a result of being twisted out of alignment with the shaft, but the bearing surfaces were undamaged.

Examination of the rivet failures in the boom revealed that no fractured rivets remained in the rivet holes, which was unlike the normal situation when overload failure occurs in a similar structure. Some degree of elongation of the holes was noted and some polishing of the mating faces of the skin lap joints was evident. No predominant direction of failure loading could be determined. The frames coincident with these two failed joints were reduced to small fragments. Other frames in the boom structure were much less damaged.

Tail rotor drive shaft whirl modes

Information supplied by the manufacturer indicated that the tail rotor drive shaft design featured whirl modes, which occur at 15%, 40%, 60% and 132% RPM respectively. The shaft fundamental (at 15%) is normally damped by the presence of the damper bearing, which is positioned reasonably close to the anti-node for this whirl mode. The mode at 40% is a fundamental whirling of the section between the damper bearing and the rear coupling. The second order whirl of the whole shaft length occurs at 60% RPM and should again be effectively damped by the bearing which falls close to an anti-node under these conditions.

However, since the drive is normally engaged when the engine is operating above these rpm figures, the shaft both accelerates and decelerates rapidly through these speeds leaving insufficient time for significant amplitude of vibration to develop even if the damping at 15% and 60% rpm proves ineffective.

Should the shaft reach a speed of 132% however, a further whirl mode will be encountered. In this instance, the damper bearing has no effect since its position coincides with a node of the shaft. The shaft deflects to form three anti-nodes, the two rearmost of which fall close to the planes of two frames, whilst the intervening node falls almost in the plane of another frame. The third and most forward anti-node coincides approximately with the plane of a frame of large internal diameter towards the forward end of the tail boom.

The two frames that were very close to the planes of the rearmost pair of anti-nodes were both highly fragmented and co-incident with the failed riveted joints. The frame/joint nearly coincident with the node between the two rearmost anti-nodes was a lightly damaged junction, the frame forming part of the undamaged riveted joint situated between the two failed joints. Thus the two most damaged areas appeared to have suffered damage as a result of local orbiting of the shaft close to its anti-nodes, whilst the lightly damaged frame/joint between them had survived as a result of the limited orbital deflection of the shaft close to the node. The frame falling closest to the most forward anti-node was of large internal diameter and hence unlikely to have been fouled, even by a whirling shaft.

It was therefore concluded that the structural damage to the boom was consistent with the effects to be expected of the shaft whirling in the harmonic mode that occurs at 132% RPM. No other explanation for the highly unusual distribution of damage could be postulated.

Further confirmation of excessive rotor speed was found when the standard R22 overspeed inspection was carried out in accordance with the maintenance manual. Amongst other items, this calls for examination/testing of the main blade root bearings for smoothness of operation. When these were tested, severe 'notchiness' was found on both units. The engine was removed and subjected to strip examination. Evidence of valve bounce, an indicator of overspeed, was seen on the piston crowns, together with damage to the cylinder bores.

The governor system

The three main components of the engine governor were inspected and tested by the helicopter manufacturer in the presence of an AAIB Inspector. The principal of operation takes an electrical signal from an additional set of contact breaker points in the right hand magneto. The signals are passed through the helicopter wiring to the Governor control box. The controller box measures the signal strength against a datum set at between 102.5 to 105.5% ERPM. If the signal is lower or greater than the datum then the controller commands the throttle actuator to open or close at a rate consistent with the degree of variance from the datum in order to maintain the rotor RPM (RRPM) within the correct operating band.

The three components were tested individually for their compliance with the standards required for fitting to a new helicopter. The only area of relevance to the investigation which was outside the tolerance related to the friction brake torque loading of the governor actuator. The friction brake is designed to prevent the throttle twist grip from being moved inadvertently by the pilot both with and without the governor selected. The pilot can over ride the system provided enough force is exerted on the throttle. The brake is pre-loaded to obtain 11 to 12 inch pounds of friction at manufacture, which must be overcome before the throttle operating mechanism can move. The setting on the actuator removed from G-BYHE was set to 15.5 inch pounds. As a result, the pilot would have had to exert a slightly higher force to open the throttle against the friction brake or resist the closing of the throttle as the collective pitch lever was raised than normal. The actuator electric motor is required to use only 20% of available power output to overcome the friction brake but due to the increased friction loading, 30% was required to start the movement but once moving 20% was sufficient to continue the movement.

The individual components when assembled as a system on a bench test rig functioned normally. The magneto signal output was varied by increasing or decreasing the magneto RPM throughout the governor operating range of 80% to 115% ERPM. Either side of the 102.5 to 105.5 ERPM datum the actuator moved in the correct sense and with the appropriate degree of movement consistent with the magneto RPM selected. The possibility that the governor had received a false signal just above the 80% minimum operating ERPM and commanded the actuator to open the throttle thus causing the engine to over speed was eliminated due to the proven integrity of the governor system.

Active noise reduction (ANR) headset

The Defence Evaluation and Research Agency (DERA) were asked to provide data on the levels of noise reduction achieved when using the type of headset which was worn by the student pilot. They concluded that in the frequency range 70.5 Hz (80% ERPM) to 111 Hz (130% ERPM) the peak noise level in the cabin without a headset was 98 dB. The noise level measured inside the headset without ANR on and using only the passive ear defender quality of the headset was 91 dB. With ANR switched on the noise level measured inside the headset was 82 dB. This gave a total noise level reduction over the frequency range where the over speed would have been heard occurring as 16 dB. Although this was a significant reduction in noise level, a person with normal hearing should have been able to hear the ERPM increasing.

Discussion

After the CFI had exited the helicopter the pilot had carried out the pre-take-off checks, which included checking that the ERPM were normal and the governor light was out. He raised the collective control lever, noting the increase in MAP but could not recall what the ERPM gauge was indicating. He continued to raise the collective gently, the power indicated a normal controlled increase through 18 to 19 inches MAP. On reaching 20 inches MAP, with the helicopter still on the ground, he felt a violent judder and promptly lowered the collective lever. He thought that when the lever was fully down, he might have inadvertently opened the throttle instead of closing it. The duty ATCO, who was watching the helicopter but could not hear it due to the sound proofing in the tower, saw no yawing of the helicopter on the ground prior to the tail boom 'falling down'. This was also as described by another witness who was a Flying Instructor in another R22 on final approach to area 'November'.

In order to have achieved an ERPM of 132% the pilot would have had to either open the throttle at flat main rotor blade pitch with the collective lever fully down or, when raising the collective lever, prevented the throttle from winding back under the influence of the governor. As established in the post accident tests, very little movement was required to increase the ERPM by 24%. By opening the throttle and preventing it from backing off, an increase of 4.5 inches of MAP delivered the same increase as when the collective lever was raised.

Whilst the pilot was described by the instructor as relaxed and confident with no previous history within his helicopter training of being tense on the controls, the pilot confirmed he was very focused on ensuring he maintained the MAP within the safe limits. The effect of the ANR is to reduce the noise level outside the headset, radio and intercom levels are unaffected. The general sensation is one of the noise being softened with the sound of the engine and rotors still audible but much less intrusive. With the pilot concentrating on a specific aspect, in this case the MAP gauge, it is probable that the rise in ERPM went unnoticed and only the violent juddering alerted him to an abnormal condition having arisen. The fact that the pilot could not recall what actions had created the situation was in itself indicative of the level of concentration he was applying at the time.

Whilst no conclusive sequence of events could be identified despite the open and frank evidence provided by the pilot, the incorrect management of the throttle was identified as the most likely cause of the rotor over speeding. The combination of becoming focused on the MAP gauge and the effects previously described of the ANR headset reducing the audio cues meant that the sound of the increasing ERPM was not detected.