Robinson R44 Clipper, G-KAZZ

AAIB Bulletin No: 1/2004	**Ref: EW/C2003/07/02**	**Category: 2.3**
INCIDENT		
Aircraft Type and Registration:	Robinson R44 Clipper, G-KAZZ	
No & Type of Engines:	1 Lycoming O-540-F1B5 piston engine	
Year of Manufacture:	2001	
Date & Time (UTC):	9 July 2003 at 0926 hrs	
Location:	Sywell Airfield, Northamptonshire	
Type of Flight:	Engineering Test Flight	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Tail rotor drive shaft failure. Tail cone, tail cone support frame, drive shaft flexible plate and engine clutch assembly damaged	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	49 years	
Commander's Flying Experience:	1,100 hours (of which 74 were on type)	
	Last 90 days - 25 hours	
	Last 28 days - 10 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The helicopter was being flown to Sywell for a 50 hour maintenance inspection when it developed a lateral vibration with a frequency coincident with main rotor rotation. It was able to land successfully at Sywell where the main rotor drive system was examined. As no apparent problems were identified an engineering test flight was carried out to see if the vibration event could be replicated. Normal handling failed to reproduce the event so a towering climb from the hover was initiated. This produced worsening vibration levels, an increase in engine manifold pressure, and difficulties in yaw control necessitating an immediate descent and landing. After landing it was discovered that the tail rotor was not rotating. An inspection of the tail rotor drive system revealed a failure of the tail rotor drive shaft aft of the whirl mode damper bearing. The subsequent AAIB investigation could not find any evidence to explain the cause of the failure.

History of the previous flight

On the day before the incident G-KAZZ, flown by the owner, and accompanied by a passenger, was en-route from Lichfield to Sywell for a 50 hour maintenance inspection at a maintenance facility. The weather was good with the wind estimated to be approximately 270°/10kt. The takeoff, hover, transition and cruise were initially flown without incident. When the helicopter was approximately 3 nm north-west of Sywell however, in a level attitude at an altitude of 850 feet and a speed of about 90kt, the pilot/owner and passenger experienced a side to side oscillatory vibration with a frequency coincident with main rotor rotation (1R). The pilot decided to enter auto-rotation by closing the throttle and reducing the collective pitch. As the helicopter descended through 500 feet the vibration ceased. All indications in the cockpit were normal and, as Sywell was visible in the near distance, the pilot decided to abort the auto-rotation, resume normal flight and cautiously continue to land at Sywell.

The pilot made an approach into wind on Runway 25 and then hover taxied along the runway to the apron in the front of the maintenance hangar. As he entered the hover the vibration and oscillations recurred but more violently than before. The throttle was closed rapidly and the helicopter made a positive, but not heavy, landing. The vibration had ceased during the landing and was not evident during the shut down procedure. Engineers at the maintenance facility who witnessed the helicopter landing described the motion as being similar to over controlling.

History of the incident flight

The following morning engineers from the maintenance facility carried out a full and detailed visual inspection of the helicopter. The vibration was thought to have originated from the main rotor system and this was given the most attention. Panels to the side of the engine were removed, the main rotor head, blades, teeter and coning bearings, swashplate and the control systems were thoroughly checked. The only defect discovered was slight 'notchiness' on the collective lever. This was traced to the carburettor heat control. The tail rotor system was not inspected and the engineer could not recall if there was any damage to the tail boom support frame. As these inspections did not reveal any problems that could have explained the vibration it was decided that a test flight should be carried out in an attempt to replicate the event.

The flight was conducted by a test pilot for the maintenance organisation. He was also a qualified licensed aircraft engineer (LAE) on the R44. The engineer who had carried out the aforementioned inspections accompanied him. The test pilot carried out his pre-flight inspections, including a check of the engine drive belts, and did not notice any damage in the area including the tail boom support frame. The engine start, warm up and runs were all normal. The helicopter was then lifted into the hover with no repeat of the vibrations. After the completion of a couple of spot turns it was decided to fly to a disused airfield approximately 6 miles to the north of Sywell. The flight was without incident and on arrival at the disused airfield several manoeuvres were carried out which included steep turns to the left and right, steep approaches and autorotations at various airspeeds. In addition, the pilot specifically sought areas of turbulence. Throughout all of these manoeuvres there was no sign of the vibrations experienced by the owner so the helicopter was flown back to Sywell.

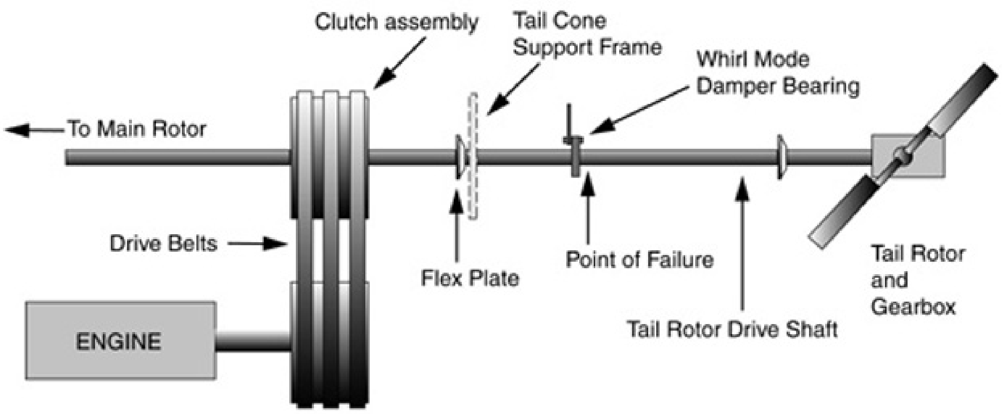
On arrival the test pilot brought G-KAZZ to the hover in the 'helicopter operating area' and carried out several more spot turns and backward manoeuvres without incident. The surface wind at the time was reported as 030°/5 kt. The test pilot was about to hover taxi to the maintenance facility when the accompanying engineer suggested that a vertical climb should be carried out to expose the drive system to a high load. The test pilot agreed, full power was applied to approximately 23 inches manifold pressure (MP) and the collective raised. The heading was maintained with the application of left pedal to counter the torque reaction. Having reached about 30-35 feet agl a vibration was felt which was similar to a main rotor imbalance with a frequency of about twice the main rotor rotation (2R). The test pilot commented that this vibration must be the same as that described by the owner. The vibration steadily worsened and after a couple of seconds the test pilot elected to land and lowered the collective. This however, seemed to have no effect and there was no indication of a descent. The passenger then noticed that the engine MP was increasing toward its maximum 'red line' value. Instinctively the test pilot overrode the engine governor and closed the throttle. As he did so the helicopter yawed to the left and this was countered by the application of right yaw pedal. After 90° of left yaw the motion reversed and a slow yaw to the right developed. The test pilot applied forward cyclic control, in an attempt to fly the helicopter onto the ground, and just before touchdown applied rear cyclic control and collective to reduce the forward momentum and cushion the landing. Although the helicopter had completed approximately two full rotations before touchdown the landing was normal and there were no injuries to the occupants. ATC were informed of the emergency and the fire service personnel were dispatched to attend.

With the rotor blades still turning the passenger exited the helicopter and inspected the rotor head. He did not notice anything abnormal so the pilot ran the engine up to 102% RPM and back to idle. As there were no abnormal indications in the cockpit a hover taxi back to the maintenance facility was contemplated. Fortunately it was pointed out to them by the attending fire service that the tail rotor was not turning. The helicopter was subsequently shut down and towed back to the maintenance facility for further investigation.

Helicopter description

Engine and clutch drive system (see Figure 1).

Figure 1: Simplified Robinson R44 drive system



Simplified Robinson R44 drive system

Figure 1

The engine on the Robinson R44 is a six-cylinder piston engine driving the main and tail rotors through a lower pulley to v-belts which connect to an upper pulley, containing a clutch assembly. The clutch assembly has attachments fore and aft to shafts driving the main and tail rotor gearboxes. The clutch assembly consists of an actuator that raises the upper pulley to tension the v-belts and engage drive transferring rotational energy to the main and tail rotor drive shafts. A safety system is installed, to protect the drive shafts and the engine from over torque during start up, such that if the clutch is engaged the engine cannot be started and a warning horn sounds in the cockpit. Once the engine has started the clutch can be safely engaged by the pilot. When the clutch is in operation a warning light is illuminated in the cockpit.

A governor, that manipulates the throttle, is installed to maintain engine RPM when it is over 80%. When the RPM drops the throttle is increased and vice versa. The pilot is able to override the governor or it can be switched off by a switch at the end of the collective lever.

Drive Shaft

Shafts are employed to provide drive from the upper pulley to the tail rotor and main rotors. The tail rotor drive shaft runs aft of the pulley. It is connected via a flexible coupling, and is then supported at about a third of its length by a whirl mode damper bearing and its supporting hanger. A second flexible coupling then connects the shaft to the tail rotor gearbox.

Whirl Modes

As with many long shafts, at certain drive shaft RPMs a 'whirl' mode can be induced. This can result in whipping of the shaft and can lead to possible shaft distortion and subsequent physical damage. A damper bearing is installed on the R44 tail rotor drive shaft to damp out the first and second 'whirl' modes. It does not, however, prevent whipping in the third 'whirl' mode. The 'whirl' modes on the R44 occur at the following engine RPMs:

1st - 15.2 % main rotor RPM

2nd - 60.6% main rotor RPM

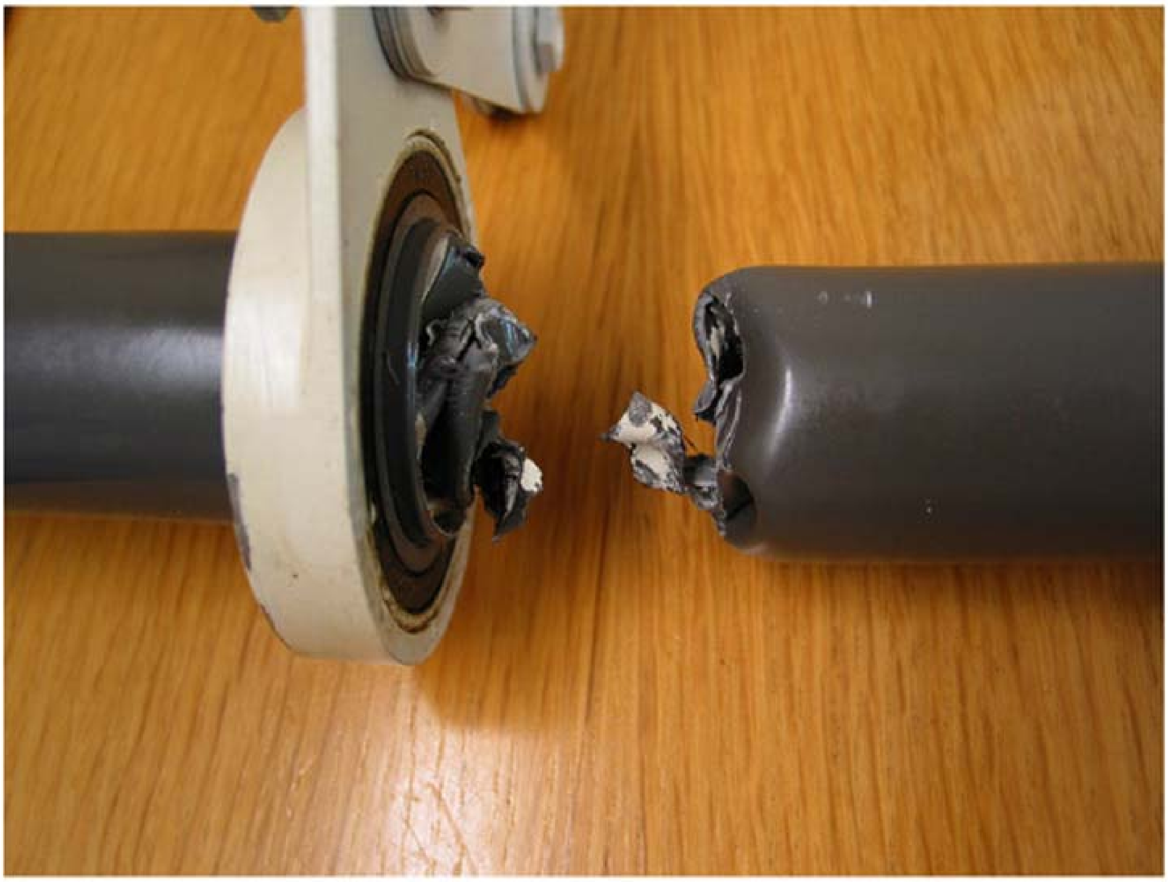
3rd - 136.4 % main rotor RPM

The first two whirl modes do not occur in flight as they are below the normal main rotor RPM operating range. The third whirl mode will only occur if an over speed occurs (maximum operating main rotor RPM is normally 102%).

Engineering Examination

Inspection revealed that the tail rotor drive shaft had completely fractured at a point just aft of the damper bearing (see Figure 2 and Figure 3).

Figure 2: Tail rotor drive shaft failure

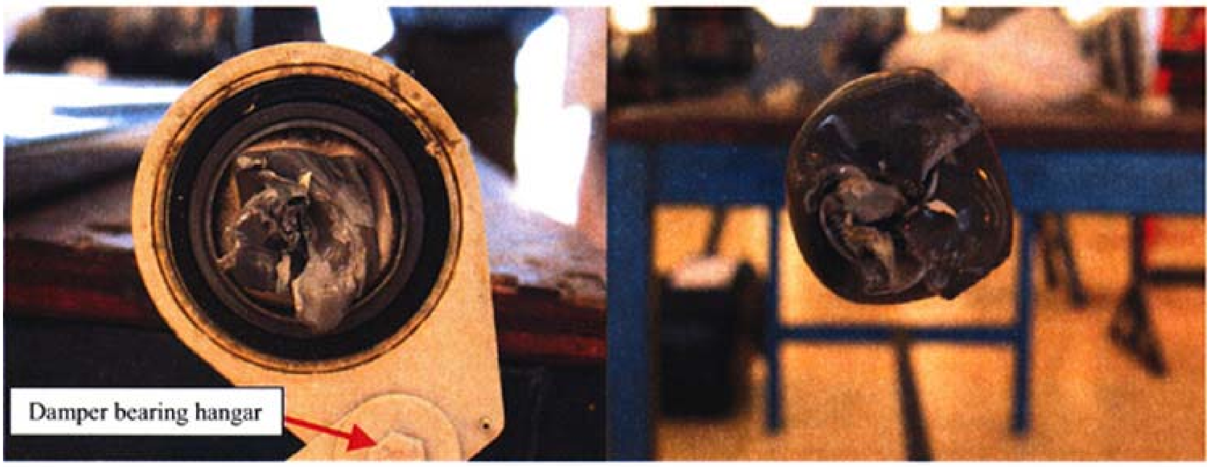


Tail rotor drive shaft failure

Figure 2

Following the failure the rear portion of the tail rotor drive shaft was unsupported and had flailed around causing contact damage to the frames of the tail cone and the drive shaft. The forward portion remained supported by the damper bearing.

Figure 3: Drive shaft fracture faces



View Forward

View Rearward

Drive shaft fracture faces

Figure 3

Additional damage was evident on the tail cone support frame where the flexible plate connecting the main engine drive shaft to the tail rotor drive shaft had come into contact with it on it's lower section (see Figure 4).

Figure 4: Tail cone support frame damage

Figure 4

This was also evidenced by damage to the attaching nuts on the flexible plate. As the tail rotor shaft separated the flexible plate assembly had returned to its usual position with a clearance of approximately 0.4 inch. This was later confirmed to be similar to other Robinson R44 helicopters. Also the clutch actuator assembly had contacted the inner rim of the drum of the engine clutch and drive belt assembly. There was no other damage to the external tail cone assembly, vertical fins or the stinger. The tail rotor blades were also scanned for the presence of contact with organic material such as birds or grass, using UV light, but none was found.

The tail rotor drive shaft, tail rotor gear box and rotors were removed from the helicopter, under AAIB supervision. There was no damage on the tail rotor blades to indicate any kind of hard tail rotor strike. The tail rotor gearbox was also free to turn and the magnetic chip detector was clean. The gearbox, subjected to a detailed strip examination at the manufacturers overhaul facility, revealed no abnormalities.

A full examination of the main rotor drive system did not reveal any defects. A test of the engine clutch drive system and the safety system that prevents the engine from being started with the clutch engaged, was satisfactory.

Metallurgy

Metallurgic examination of the tail rotor drive shaft revealed that the fracture, just aft of the 'whirl mode' bearing, was due to a torsional overload, consistent with stoppage of the aft section of the drive shaft while the forward section was still rotating. The fracture surfaces had 'shear type' failures consistent with overload in thin walled material.

The physical dimensions and material properties of the drive shaft were measured and met the manufacturer specification. Examination of the drive shaft surface did not reveal any signs of distress. The run out of the drive shaft was checked and found to be <0.0005 inches; well within the manufacturer's specification. The whirl mode damper bearing hangar arm and link frictions were checked and were found to be very low compared to the ranges specified in the Robinson R44 maintenance manual (MM). The arm was measured as 1.74 lb, with the MM range being 2.5 to 4.25 lb. The link was measured as 1.33 lb, with the MM range being 2.14 to 3.5 lb.

History of Helicopter

G-KAZZ, built in 2001, had completed 270.8 hours in service with the last maintenance check completed in May 2003 at 219.9 hours. A review of the maintenance records revealed a problem with a tail rotor restriction in January 2003 (139.4 hours) that was rectified with the cleaning of the pitch change mechanism and output shaft of the gearbox. There was no recurrence reported after the work was carried out. The last check of the tail rotor drive shaft was completed in May 2003 and was well within the MM limits. There is no requirement in the R44 MM to test the whirl mode damper bearing hangar for friction, although there are instructions for accomplishing the adjustments. The damper bearing hangar friction, on G-KAZZ, had therefore never been checked.

A check of the original build list of components in the tail rotor system, against those found on G-KAZZ following the accident, indicated that none of these components had been replaced since the helicopter was constructed. The records did not show any overspeed events and this was confirmed by the owner.

The only significant event was an attempted overweight takeoff approximately six weeks prior to the incident. The helicopter was too heavy for a normal take off so a running takeoff was carried out with the low rotor RPM warning horn sounding during the takeoff run.

After discussion with the manufacturer and a review of the various incident databases, no other occurrences of this type of failure could be found. Previous failures of the tail rotor drive shaft have occurred however, due to overspeed with the shaft entering the third whirl mode (137% RPM). This usually produces severe distortion of the drive shaft and extensive contact damage and disruption of the tail cone assembly (see AAIB report on G-BYHE in Bulletin 3/2001).

Discussion

Physical damage

The physical evidence points to an 'over-torque' in the aft section of the tail rotor drive shaft. The failure, very localised in an area just aft of the whirl mode damper bearing, indicates that the rotation of the rear of the shaft had been stopped while the engine had still been driving the forward section.

This had caused the drive shaft to twist, plastically deform and shorten. The shortening of the shaft had been taken up by the flex plate of the flexible coupling situated near to the tail cone support frame. The coupling had been pulled rearwards bringing it into contact with the frame. When the shaft failed the flex plate returned to its pre-failure position suffering minimal plastic deformation.

Engine indications

When the shaft started to shorten, coming into contact with the frame, restrictions in the system caused the engine to work harder. In an attempt to maintain engine RPM the governor opened the throttle resulting in a rise in engine MP. The pilot's observation of the MP increasing towards the red line therefore probably indicates the point at which the tail rotor shaft began to fail.

Yawing moments

The main rotor blades of the R44 rotate anti-clockwise when viewed from above. The torque reaction will yaw the helicopter to the right unless left yaw pedal is applied. During the progressive failure of the tail rotor drive shaft however, the helicopter initially yawed to the left. This was probably due to the fact that left yaw pedal was still fully applied as the throttle was rolled off and the tail rotor was still under power as the drive shaft had at that time had not completely failed. The eventual yaw to the right would then have been due to the torque reaction of the main rotor blades as the tail rotor drive slowed down and eventually failed.

Drive system restrictions

The over-torque failure of the tail rotor drive shaft is difficult to explain. The failure would tend to point to a restriction in the rear drive of the tail rotor, or a stoppage of the tail rotor itself. Physical examination of the tail rotor blades did not reveal any kind of hard tail rotor strike nor was their any damage to the tail cone or the vertical stabiliser. A soft tail rotor strike was considered but there was no evidence that such an event took place although this scenario cannot be discounted. Indeed an object, such as a plastic bag, could have temporarily come in contact with the tail rotor producing enough torque to initiate the failure.

A restriction within the tail rotor gearbox was another possibility. However, the gearbox was free to rotate immediately following the incident and no defects were reported during a full strip examination. Additionally, in over-torque situations, such as an over speed or an engine start with the clutch engaged, the gearbox can exhibit signs of gear slippage. This again was not evident during the examination. Furthermore the clutch safety engagement system was found to be working satisfactorily therefore an over torque at engine start with the clutch engaged can be eliminated.

Tail rotor stall

Another consideration was the possibility of a tail rotor stall inducing a high torque in the tail rotor drive shaft. According to the manufacturer, tail rotor stalls in the R44 may occur when a rapid left yaw pedal input is made during high speed cruise flight or during a right turn at the hover with a high yaw rate. Both of these situations are outside the certification criteria for the helicopter and, given the recollection of the event by the pilot, are unlikely to have occurred.

'Whirl mode' damper bearing

The only anomaly discovered during the investigation was low friction on the 'whirl mode' damper bearing hangar. It was initially thought that such a low friction could allow whipping of the drive shaft at certain engine RPM, but testing by the manufacturer at frictions similar to those found on G-KAZZ showed that the 'whirl' was still suitably damped. Over speed can induce whirling in the drive shaft but, as has been discovered in previous investigations (AAIB report G-BYHE Bulletin 3/2001), over speed would normally result in distortion of the drive shaft and damage to the tail boom. This was not evidenced on G-KAZZ. Firstly, neither the owner nor the pilot reported over speeding the helicopter and secondly the drive shaft was still 'true' and there was no paint damage; an indication of distortion.

Vibration / oscillation

There appears no explanation for the vibration reported by both the test pilot and the owner. The vibration was described as being a side to side movement and at a frequency relating to the main rotor. Despite a thorough examination of the main rotor drive system, nothing was found that would cause such a vibration. One scenario, that was explored but could not be fully investigated due to lack of evidence, was whether the vibration, coupled with the low damper bearing frictions, allowed a resonance to build up in the drive shaft. This could have produced a concentration of high stresses in the area just aft of the damper bearing. These high stresses may have weakened the drive shaft sufficiently such that the high torque loading imposed during the towering manoeuvre eventually caused the shaft to fail.

Inspections and testing

A full inspection of the main rotor drive system was carried out after the owner reported the initial vibration. No examination however, was made of the tail rotor system. The tail cone is equipped with inspection holes that allow a certain amount of visual inspection of the tail rotor drive shaft. It is possible that if such an examination had taken place, and if there had been evidence of the impending failure, it could have been identified, the failure avoided and rectification could have been carried out before the test flight was accomplished. The decision to carry out a test flight however, given the circumstances, was considered to be the normal course of action to take when troubleshooting a defect of this kind. The engineers had already undertaken a full inspection and testing on the ground of the main rotor system, with no defect detected. They continued testing the helicopter in a logical manner and were fully aware of the implications of undertaking a test flight. The quick reaction of the test pilot following the onset of the failure kept the situation under control, no one was injured and the helicopter suffered only minor damage. Furthermore the progressive nature of the failure of the tail rotor drive shaft was such that the resulting yaw was more controllable than would have been the case had the drive failed under full power conditions.