No: 9/91 **Ref: EW/C91/5/5** **Category: 2c**

Aircraft Type and Registration:	Bell 47G-5, G-BMDV
No & Type of Engines:	1 Lycoming VO-435-B1A piston engine
Year of Manufacture:	1969
Date & Time (UTC):	22 May 1991 at 0800 hrs
Location:	1 nm northwest of Cranfield airfield, Bedfordshire
Type of Flight:	Training
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - 1 (serious) Passengers - N/A
Nature of Damage:	Substantial; damaged beyond repair
Commander's Licence:	Airline Transport Pilot's Licence (Helicopters) with Instructor rating
Commander's Age:	51 years
Commander's Flying Experience:	7,500 hours (of which approximately 400 were on type)
Information Source:	AAIB Field Investigation

History of the flight

The aircraft was engaged on a familiarisation flight with the instructor handling the controls and a student pilot, who had not previously flown in the aircraft, in the left-hand seat. In a position about 5 nm north-west of Cranfield at 2000 feet the instructor demonstrated an autorotative descent. As the aircraft was descending through about 1500 feet, with the rotor freewheeling and the engine running at 2200 rpm, a light metallic clatter was heard. This clatter was not accompanied by vibration and sounded like a baffle or piece of ducting flapping in the slipstream. The instructor immediately restored power to the rotor and headed back towards Cranfield at an airspeed of approximately 70 kt. The clatter continued with no detectable change but the aircraft appeared to handle normally and the engine instruments gave no indication of unserviceability. He joined the Cranfield circuit at 1000 feet to land parallel to runway 22, in a surface wind reported to have been 300° to 330° at about 15 kt. Just after he turned on to right base leg and began to descend he heard a bang, which was felt through the flying controls. He lowered the collective lever, turned the aircraft away from a built-up area and sought a suitable field for an emergency landing. The nose dropped, speed increased to about 80 kt and he found that the fore and aft cyclic control was jammed. He switched off the hydraulic boost but this made no difference. He then pulled hard on the cyclic stick with both hands and was able to raise the nose very slightly. This movement caused a slow reduction of speed but was not enough to check the descent. The aircraft touched down heavily in a field at a speed of about 50 kt and on a heading of 231°. The pilot had the impression that the aircraft was still nose-down on impact.

Engineering examination

Examination of the initial impact point showed that the aircraft had touched down with negligible yaw and almost level in pitch attitude. It had then 'skipped' momentarily into the air again before sliding to a halt approximately 65 yards further on. The initial impact marks showed that the skids had splayed outwards due to overload failure of the cross-tubes. This had allowed the underside of the cabin and the lower engine mount to contact the ground, the resulting distortion to the cabin structure causing the perspex canopy to shatter. Other damage included compression wrinkles on the underside of one of the main rotor blades, rotor mast distortion and inertial failure (in a downwards direction) of the tail boom. The tail rotor itself was undamaged, however, and the lack of a discernible tail rotor strike on the ground at the initial impact point confirmed the lack of significant nose-up attitude at impact. A fuel leak was found to have originated from the breakaway, self-sealing, coupling at the outlet of the right hand fuel tank. Movement of the tank within its cradle had caused a partial separation of the coupling, allowing fuel to leak into the protective sleeve covering the fuel line that connects the two tanks.

The engine cooling fan assembly, which is normally attached to the front of the crankcase of the vertically installed engine, was found lying propped between the engine and the flying control rods which are located on the rear of the cabin bulkhead. The fan was badly damaged, with six blades having broken-off at their roots and the remaining blades bent against the direction of rotation. As found, however, the cyclic and collective controls could be moved normally. (In fact only the yaw controls were found jammed; this was later discovered to be due to the belly panel being deflected onto a yaw control cable quadrant during the ground impact, thereby jamming the control pedals close to the full left yaw position.) The fabric shroud, which ducts the cooling air around the engine, was still in position as was the shroud support ring which is normally attached to the fan assembly by means of four radial spokes. The latter had broken and the remains of these, in addition to some fan blade fragments, were found in the bottom of the shroud. Other debris included the broken-off portions of the three studs which normally attach the fan assembly to the engine, via an alloy casting with 3 mounting-feet. One of the two fan belts was found looped over the forward flange of the driving pulley on the main rotor gearbox mounted above the engine. It had suffered numerous cuts and abrasions that may well have been caused by fan blades. The other belt had been completely severed and was found on the ground shortly after the initial impact point. A photograph of the damaged fan assembly, together with an intact unit, is shown at Fig.1.

The aircraft was taken to the operator's maintenance organisation where the engine was removed in order to improve access to the flying controls and to further investigate the reported restriction. It was clear that the fore-and-aft cyclic servo had suffered a number of light impacts, most probably from fan blades. Heavier damage had occurred on the alloy blocks at the lower end of the servo and it appeared that some of this may have been caused by the fan pulley flange. Reasonable correlation between witness marks on the fan and servo was achieved with the fan positioned as shown in Fig. 2, and it is considered that this represents the best estimate of the position at which the fan assembly may have come to rest, i.e. jammed between the engine and the servo. The observed distortion on the pulley flange was most likely caused by the pilot pulling back on the cyclic control in his attempt to flare the aircraft prior to landing.

The fan assembly and associated debris were examined by the Materials and Structures Department at the Royal Aerospace Establishment, Farnborough. This revealed the presence of 'high strain' fatigue on all three fan assembly mounting studs, i.e. indicative of failure having occurred as a result of high stresses over a relatively low number of cycles. The examination also confirmed that the fan blade and shroud ring support spoke failures were all as a result of overload. The break in the failed fan belt bore no evidence of being associated with a fan blade impact. Additionally, it was apparent that the belt had been through the fan, as there were rubber deposits on the leading edge of one of the fan blades, together with smear marks of a width similar to that of the belt on some of the other blades. A diagram of the fan assembly is shown at Fig. 3.

The bearing assembly upon which the fan rotates comprises two bearings located on a central shaft. It was apparent these had been destroyed and it was therefore necessary to establish through examination whether break-up had occurred before the incident or was as a result of out-of-balance forces following the fan blade damage. Disassembly revealed the presence of metal debris and a small amount of blackened grease which was heavily contaminated with metal particles. The raceways of the dual race front bearing bore evidence of heavy wear, with some spalling on the inner race. The outer race had to be drifted out of the hub and emerged in three pieces. This was found to be due to the presence of axial cracks that had turned in a circumferential direction under the action of removing the bearing. The relative lack of discolouration on the fracture surfaces suggested that these cracks had occurred very late in the break-up process. A small amount of 'blueing' around the cracks and on the inside of the washer located at the front of the bearing (item 4 in Fig. 3) indicated that high temperatures had been generated locally. Additionally the washer surface exhibited considerable circumferential scoring from contact with front bearing components. The inner race of the rear bearing was heavily spalled over approximately 100° of arc. The race had not rotated on the shaft, thus the orientation of the spalled area relative to the engine was preserved. This showed that the spalled area represented the loaded portion of the circumference, the load being due to the fan belt tension. This in turn suggested that the spalling had occurred over a long period, as a random distribution around the circumference would be the expected result had it occurred during the short period in which the fan was running in its damaged state. Two of the bearing cages had been reduced to fragments, some of which were found in the grease deposits. The rear cage of the front bearing had survived intact, although raised 'lips' were noted on the edges of the ball cut-outs. The balls themselves exhibited somewhat pitted surfaces.

Examination of the aircraft's technical records showed that the aircraft had been subjected to a 100 hour inspection only 7 flying hours earlier and this had included lubrication of the fan bearings. It was also apparent that the bearings had achieved 1,121 hours out of their 1,200 hour life. There was only a small amount of grease found within the bearing and a total absence of 'old' grease in the shaft connecting the nipple to the bearing area. A sample of the bearing grease was spectrometrically analysed and apart from the contamination due to metallic debris, showed no significant difference from a sample of new grease. A further test revealed that the viscosity decreased sharply at temperatures above 132°C. Although the absence of grease at first suggested that the last lubrication may have been omitted, the evidence of heat on some of the components gave rise to the possibility of the grease having flowed away due to the loss of viscosity. Moreover it was considered that the last 7 hours running was so short a period that it would have been unlikely to have led to the failure of the bearing. Finally it was established that the bearing had been installed correctly on the shaft. (The presence of a side shield on one side of the bearing would have inhibited the flow of lubricant into the rolling elements in the event of reverse installation).

Consideration of all the evidence indicated that the sequence of events was precipitated by failure of the front bearing. The resultant play in the bearing would have allowed upwards movement of the fan assembly under the action of the fan belt tension. The fan would also have tended to tilt rearwards, out of plane, due to the pulley being located several inches forward of the bearing. Further examination of the shroud support ring confirmed that blade rub had been confined to an area close to the 12 o'clock position, and that one of the support ring spokes, also at the 12 o'clock position, had received multiple blade strikes due to tilting of the fan. The reduced fan belt tension then probably allowed one of the belts to jump out of its channel so that it was running on the edge of a pulley flange. This in turn would have increased the tension to the extent that it broke and became entrained into the fan assembly. The subsequent damage to the fan would have produced out-of-balance forces causing rapid fatigue of the fan mounting studs, followed by fan assembly detachment.

The operator provided paperwork that included the release note for the bearings used at the last fan overhaul. This showed that they had been sourced from the aircraft manufacturer.

Premature fan bearing wear is not an unknown occurrence although the unusual noise that accompanies it normally allows detection before a failure condition is reached. However, in this instance failure, in the form of a bearing cage break-up, had apparently occurred without any preceding audible warning even though the bearing was suffering from wear, as evidenced by the spalled condition of some of the raceways. Spalling, sometimes called rolling contact fatigue, is typically observed on high time bearings, and can be exacerbated by inadequate lubrication and/or excessive bearing stresses.

1. Grease Fitting
2. Shaft
3. Retaining Nut
4. Washer
5. Pulley
6. Belts
7. Rings (3)
8. Fan
9. Shroud Support
10. Spacer
11. Hub
12. Index Plate
13. Fan Support
14. Retainer
15. Locking Pin Handle
16. Locking Pin and Spring
17. Bearing (Shield Aft)
18. Spacer
19. Bushing
20. Bearing (Shield Fwd.)
21. Nut (Lockwired)

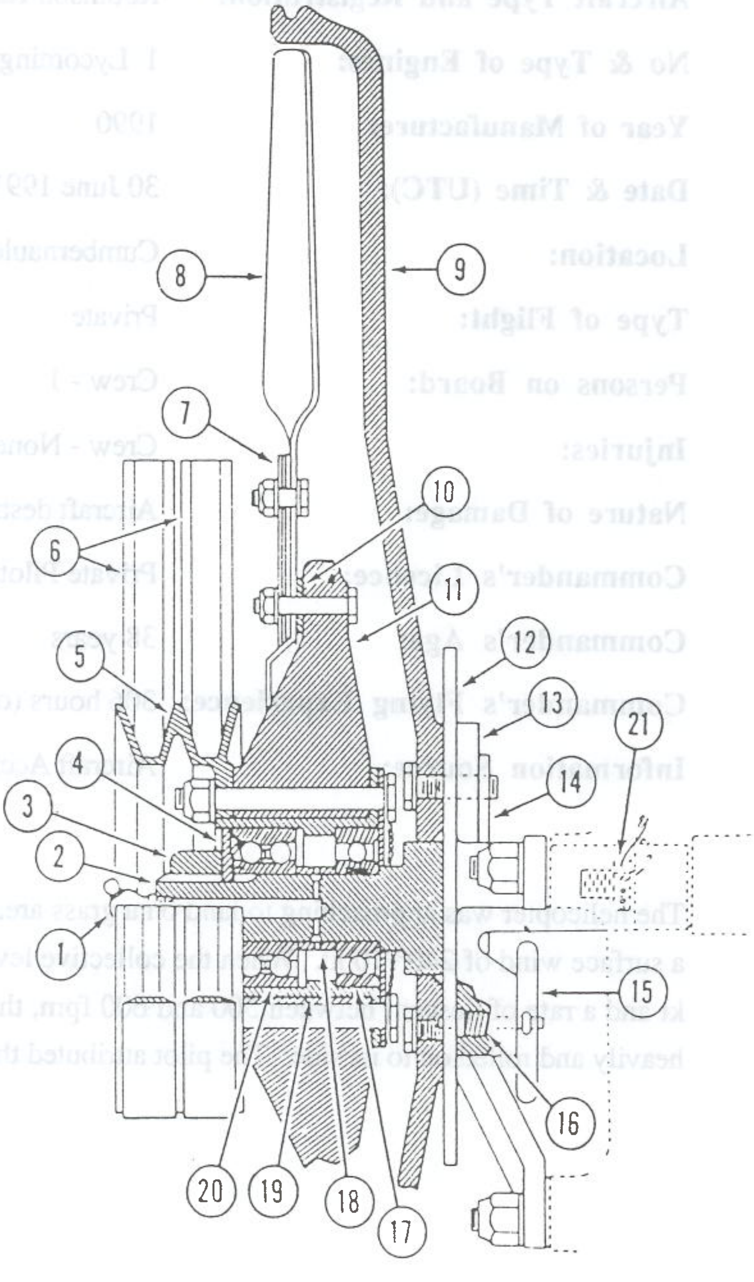

FIGURE 3 Diagram of Cooling Fan Assembly