Aircraft Type and Registration:	Bell 206B JetRanger, G-BODW
No & Type of Engines:	1 Allison 250-C20 turboshaft engine
Year of Manufacture:	1972
Date & Time (UTC):	15 January 1994 at 0849 hrs
Location:	Luton Airport, Bedfordshire
Type of Flight:	Private (Pleasure)
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 Fatal Passengers - N/A
Nature of Damage:	Aircraft damaged beyond economical repair
Commander's Licence:	Private Pilot's Licence (Helicopters)
Commander's Age:	45 years
Commander's Flying Experience:	50 hours (of which 9 hours were on type) Last 90 days - 40 hours Last 28 days - 9 hours
Information Source:	AAIB Field Investigation

History of Flight

The aircraft was parked on a grass area to the west of the cargo apron and in front of the operator's portacabin office. It had been parked there since the previous Sunday and the ground was wet from recent rain. The sequence of events was determined, in the main, from the observations of two witnesses, one in the portacabin and one in the open to the west of it, and from marks on the ground; both witnesses were specifically watching the aircraft.

The pilot booked out for a local flight; his intention was to carry out some training at the 'helicopter square', to be followed by some visual circuits. Shortly afterwards the helicopter was seen on the ground with the rotor turning; the engine was reported to have sounded normal; the aircraft remained in this position for an estimated 8 minutes. At 0848:25 hrs the pilot called Luton tower and requested permission to 'LIFT OFF FOR THE SQUARE'; this was given and the controller passed the surface wind as southerly at less than 5 kt. Apart from a short duration transmitter switch pulse at 0849:10 hrs, there were no further relevant recorded transmissions.

The helicopter was seen to 'go light on the skids' and then to lift into a low hover, estimated to be at a height of between 6 inches and 1 ft above the ground. It then yawed left through about 70° and remained in that attitude for 2 to 3 seconds. This was followed by a yaw and slight bank to the right; the left skid remained clear of the ground but the right one moved down and rearwards, and tunnelled into the soft earth. The angle of bank increased rapidly and one rotor blade struck the ground. It is believed that the mast broke at this stage; subsequently, the trailing edge of one of the blades sliced into the cockpit and killed the pilot. The aircraft came to rest on its right side and the engine was heard to wind down rapidly and stop. There was no fire although small flames were observed emanating from the engine exhaust for a few seconds.

The aircraft operator saw the accident and immediately telephoned ATC; the area where it occurred was not visible from the control tower. The aerodrome controller pressed the crash alarm and declared an aircraft ground incident at 0850 hrs; the emergency services went immediately to the scene. At 0852 hrs, on the advice of the ATC watch manager, the occurrence was upgraded to an aircraft accident . At 0853 hrs, CRASH 1, at the scene, transmitted a situation report to the aerodrome controller.

Weather

The special meteorological observation for the time of the accident contained the following:

Surface wind	170°/7 kt
Visibility	5 Km
Weather	Rain
Cloud	Broken, base 3,000 feet
Temperature/Dewpoint	+3°/+3°C

Pilots experience

The pilot started flying training, at Luton Airport, on 30 September 1993; the initial training was done on a Robinson R22 and a Private Pilot's Licence (Helicopters) was issued on 7 December 1993. On 15 December 1993 he started a conversion course onto the Bell 206; 6.6 hours were flown in G-BODW to obtain a rating on 23 December 1993. He flew another 2.7 hours as P1 in G-BODW on 31 December 1993 and 1 January 1994.

The pilot's progress through both the initial training course and his conversion to the Bell 206 had been very good; there was good continuity both of aircraft and instructor. No major problems were identified, however, his instructor had, on one occasion, remarked on a tendency to be slightly 'heavy' on the yaw pedals. He had also been told that leather soled shoes were not advisable as these may cause the feet to slip off the yaw pedals; on the accident flight the pilot wore footwear of a type described as a 'deck shoe' the soles of which are designed to be non-slip.

Weight and balance

The maximum authorised weight for G-BODW was 3,200 lb; the permitted longitudinal centre of gravity (CG) range was from 106.0 inches to 114.2 inches aft of the datum; above a weight of 2,350 lb the aft limit reduced linearly to 111.4 inches. The aircraft weight at lift-off was estimated to have been 2,608 lb and the CG was 111.9 inches aft of the datum; the aft limit at this weight was about 113.2 inches.

The accident flight was the first the pilot had made in a Bell 206 as the only occupant of the aircraft. The CG would have been about 3 inches further aft than he had previously experienced; a significant variation when the total range was, typically, only 6 to 7 inches. The lateral CG position would have been biased to the right. Consequently, once airborne, the helicopter would have adopted a higher nose attitude than the pilot was used to, and there would have been a tendency for it to bank to the right.

Pathology

Post-mortem examination of the pilot revealed no pre-existing medical condition which could have contributed to the accident. The injuries sustained in the accident were to the head, right side of the chest and the right arm, which was severed; these injuries were all attributed to a single blow from the rotor blade. The cockpit area was largely intact and the full upper torso restraint harness held; it was the opinion of the pathologist that the accident would have been survivable had the rotor blade not impinged on the cockpit.

Accident site details

The helicopter had come to rest on its right side on a heading of 123° M, which was close to the heading before lift-off. The imprint of the left skid at the original parked position was visible in the grass parallel to, and to the left of the right skid. It was clear that the rear of the right skid had penetrated the ground as a result of the aircraft moving rearwards by approximately 1 ft. The turf had

been broken in an upwards direction as the skid came out of the ground after the aircraft fell on its side. To the right of the aircraft were two main rotor strikes, the first having entered the ground at an angle of 40° to the horizontal. The other strike was orientated in a way which suggested that the rotor had become detached from the aircraft. One of the blades had rotated 180° on its spindle so that it penetrated the cabin trailing edge first. In attempting to react the forces generated by the rotor strike on the ground, the rotor mast and transmission had tilted rearwards prior to the mast breaking; this had resulted in the disconnection of the drive between the engine and the main rotor gearbox.
The rotor blade had also struck the instrument binnacle such that it remained attached only by electrical cables. This had additionally resulted in the main battery supply lead being ripped away from the battery contactor in the nose of the aircraft, thereby disconnecting electrical power.

There was no fuel spillage, although a quantity of hydraulic fluid had escaped from the reservoir which supplied the hydraulic flying control system.

Following the on-site examination, the aircraft was recovered to the upright attitude prior to removal to Farnborough for a detailed examination. The only piece of wreckage not recovered was the tip portion of one of the main rotor blades. Prior to transportation, approximately 74 imperial gallons of fuel were drained from the aircraft.

Detailed examination of wreckage

a) Flying controls

Examination of the flying control system revealed no evidence of pre-impact failure or disconnection of any of the linkages. Apart from the fluid spillage from the reservoir, the hydraulic system was intact, and was able to be functioned after being connected to a hydraulic rig. The yaw and cyclic actuators appeared to function normally: however, movement of the collective lever appeared to be slow in the down direction in comparison to the rate at which it could be moved upwards. Neither the actuators, nor the cradle in which they were mounted, had suffered any impact damage that could have accounted for this anomaly. Accordingly, all four actuators were removed from the airframe and taken to an overhaul agent for test and strip examination. No faults were found with the yaw and cyclic actuators. However, the fault on the collective actuator was confirmed in that the unit was comparatively slow in the ram extending, ie down collective direction. Examination revealed that the problem was due to the pilot valve input link not being centralised within the 'sloppy link' that was attached to the airframe flying controls (see Figure 1). This resulted in the pilot valve link bottoming out at one end of the sloppy link before it had achieved the full valve open position. The fact that the full orifice area was not available produced the sluggish movement in one direction. The valve input link, which is adjustable, had been secured with a tab washer which was still in position. In addition, a 'tell-tale' paint mark was still intact, suggesting that the valve had not moved in service since its last overhaul in the US, approximately 1,865 aircraft hours prior to the accident. It was found that the pilot valve input link needed to be adjusted 0.013 inch to produce satisfactory operation of the actuator.

The examination of the actuator also revealed that the internal leak rate, ie the amount of fluid that leaks across from 'pressure' to 'return' with the valve in the null position, was 50% more than the limit permitted by the manufacturer. The overhaul agents that conducted the test stated that it was rare to see an actuator that was anywhere near the leak rate limit even on a unit that had achieved its 3,600 hour overhaul life. Disassembly of the valve components revealed no significant damage other than what appeared to be normal wear patterns.

Subsequent to this investigation, the aircraft manufacturer indicated that, following accidents, they had encountered instances of apparently mis-rigged pilot control valves on actuators. This is thought to originate from slight yielding in the valve linkage arising from high reaction loads being generated in the flying control linkages.

b) Engine

The engine was removed and examined by the overhaul agents for Allison engines. It was not possible to run the engine in a test cell in the as-received condition and guidance from the manufacturer cautions against running an engine that has been involved in an impact, due to the possibility of undetectable internal damage causing a catastrophic failure on test. Accordingly it was decided to subject it to a strip examination which revealed that it had sustained only very minor damage as a result of the impact. Small dents on one blade on each of the axial compressor stages was indicative of a small piece of debris being ingested into the engine. The centrifugal impeller had suffered a minor contact with its housing, causing some abrasion of the aluminium coating on the latter. This was thought to be responsible for a small amount of solidified aluminium spatter that was visible on the first stage turbine nozzles, and which provided confirmation that the engine was alight at the time of the impact. The engine examination also extended to the gearbox and the freewheel unit; no defects were found.

c) Fuel system

The engine was equipped with a Chandler Evans (CECO) fuel control system, comprising the fuel pump, power turbine (PT) governor and fuel control unit (FCU); the majority of Allison 250 engines are Bendix equipped. The components were removed from the engine and, because it is not possible to test them together as a system, individually rig-tested. When the components were removed, it was noted that they were primed with fuel, with no evidence of any water contamination. The tests revealed no problems with the units, although the FCU was typical of a unit part way through its overhaul life in that it was running rich throughout its operating range. The fuel nozzle was also tested, and although heavily carbonised, was found to produce a satisfactory spray pattern. The high pressure fuel filter was examined and found to be clear.

The airframe part of the fuel system was also examined. This included confirming that the electrically operated fuel valve was in the open position, and checking the integrity of the two electrically operated boost pumps at the bottom of the tank, and the fuel feed line. The airframe mounted filter was found to be clear, and the filter bowl was full to the brim with fuel, ie there was no bubble of air in this part of the fuel system.

d) Compressor delivery pressure (P_C) sensing line

Before engine disassembly began, it was found that a pipe running between the compressor diffuser scroll and PT governor was slightly loose. This was traced to a loose nut (of a type known as a 'B' nut), at the union of the pipe with the diffuser scroll. The purpose of the pipe is to supply a reference compressor pressure, P_C, to the fuel control components. In the event that the pipe becomes disconnected, there will be a complete loss of engine power; the gas generator will run down to sub-idle and even flame out. The nut could be turned under firm finger pressure, although the engine manufacturer specifies an assembly torque of 80 to 120 lb ins for this and similar unions on the engine. It was established that the union was leaking by disconnecting the P_C pipe at the PT governor and blowing air into it; bubbles appeared after soap solution was applied to the union (see Figure 2). Most of the 'B' nuts on the engine had no 'torque paint' applied to provide an indication of loss of torque during inspections, although a white, crumbling residue was visible on a few. Such residue was found on the loose union, and the two halves of the mark were misaligned by approximately 1/16 inch, ie only a small rotational movement. It was later noted that the application of 80 lb ins of torque caused realignment of the marks and also eliminated the leak. The P_C pipe is normally disconnected at the compressor scroll whenever a compressor wash is carried out. The aircraft records indicated that this was last accomplished on 2 October 1993, approximately 30 operating hours before the accident.

When a new tube is fitted, the collar within the nut pushes the bellmouth area of the tube onto the olive. This results in the tube material being cold-worked such that it is permanently deformed; subsequent assembly of the same union therefore requires less nut rotation.

An attempt to quantify this was made by performing tests on a new piece of tubing. The amount of rotation required to torque the nut to 100 lb ins from finger tight was noted to be 60°. This value almost halved on the next assembly, and the downward trend continued to the extent that approximately 24° of nut rotation was needed on the tenth application. The effect of a moderate overtorque (142 lb ins) caused an additional reduction in the nut rotation needed to apply 100 lb ins.

The tested and untested ends of the tube were then subjected to microhardness tests in the bellmouth areas where the collars impinged on the outside of the tube. The results were compared with those of similar tests conducted on both ends of the tube removed from G-BODW. The average increase in hardness for the tested end was around 10%. The work-hardened area of the compressor end of the pipe removed from G-BODW showed an increase of around 15% over the surrounding area.

e) Subsequent engine tests

During the testing of the FCU and PT governor, it was possible to loosen the unions of the pipes on the rig supplying the P_C pressure to the point where significant air leakage occurred. This resulted in only small reductions in the values of P_C measured at the units, and correspondingly small reductions in fuel flow. However, it was considered that these results did not necessarily reflect the effect of a leaking P_C line on the engine and fuel system operating together. It was therefore decided to conduct a test, witnessed by the AAIB, whereby an engine was assembled with the fuel control equipment from the accident aircraft and run in a test cell.

The engine was run at ground idle for five minutes before the union of the P_C line with the scroll fitting was loosened. It was noted that considerably more rotation, approximately two flats, had to be applied to the 'B' nut in order to obtain a leak. However, apart from a tiny increase in turbine outlet temperature, and a similar decrease in gas generator RPM (N1), the engine operated normally, and continued to do so when it was accelerated to take-off power.

The engine was run to cruise power, and the nut was backed off a long way, giving a considerable air leakage. Once again, there was virtually no effect on the operation of the engine. It was also found that the engine could be slam accelerated to take-off power from ground idle with the nut in this position. Only when the pipe was physically disconnected did the N1 stabilise at a sub-idle RPM and could not subsequently be accelerated.

Another test was conducted (not witnessed by AAIB), using an engine fitted with Bendix fuel control equipment. The principle of operation is similar to that of the CECO components, although there are considerable detail differences. Loosening the 'B' nut at same union resulted in a similar lack of effect on the engine. However, when the pipe was completely disconnected, the N1 decayed to the point where the engine flamed out.

Maintenance aspects

As noted earlier, the P_C line is disconnected at the union with the compressor diffuser scroll whenever a compressor wash is carried out. The remaining unions are not routinely disturbed. The Allison-250-C20 Series Operation and Maintenance Manual Checklist calls requires a check of the entire engine for security of connections at the 100 hour inspection. However, Section 3-20, 'Rigid Tube Installation', and subsequent paragraphs, detail the proper torque tightening procedures for the 'B' nuts together with the necessity to apply slippage marks (torque paint) across the fittings. Paragraph 3-26B specifically calls for an inspection of the 'B' nuts for indications of slippage at 100 hour intervals.

Allison is in the process of revising the Checklist part of the Operation and Maintenance Manual to include reference to slippage marks, together with the necessary cross reference to the 'Rigid Tube Installation' and subsequent paragraphs in the manual.

Earlier incidents resulted in the CAA issuing an Additional Airworthiness Directive, Allison 010-12-92, calling for the inspection of the fuel control system lines in accordance with the appropriate Allison Alert Commercial Service Letters. This has now been revised (from 28 April 1994) to include the requirement for condition and proper assembly of the 'B' nut fittings, including the correct torque values and slippage marks.

Discussion

The possibility of an engine failure was exhaustively investigated, as such an event could have accounted for the left yaw before the aircraft rolled over. Initial suspicions appeared to be confirmed on discovering the loose 'B' nut on the P_C line. However, subsequent engine tests indicated that there was no significant effect on engine operation until the pipe was completely disconnected. The fact that the engine stopped after the accident could not therefore be explained. Although the boost pumps would have stopped following the disconnection of electrical power that occurred as a result of the rotor strike, the engine mounted fuel pump would have been capable of supplying the engine once the N1 exceeded the self-sustaining RPM. One possible explanation is that a bubble of air entered the fuel feed line at the bottom of the tank as the aircraft rolled over.

Safety Recommendations

The AAIB have reported on four previous accidents, one involving a fatality, in which the same nut on the P_C line has come loose in flight, causing engine power failure. These reports appeared in Bulletins 10/84, 3/90, 2/91 and 12/92. The CAA's SDAU database has a further four incidents which did not result in reportable accidents. Two years ago, the following safety recommendation was made as a result of an accident to a Bell 206B, G-SHCC (see Bulletin 12/92):

92-85 That the CAA, in conjunction with the FAA, take action with the engine manufacturer, to introduce some form of positive locking of the 'B' nuts on the compressor delivery pressure (P_C) sensing line on all Allison 250 Series engines, to prevent the loosening of such nuts and consequent sudden loss of engine power.

The CAA accepted this safety recommendation, and liaised with the FAA and Allison; however, the response from these two organisations has not resulted in any action. Notwithstanding this, the AAIB remains committed to the spirit of the recommendation and it is therefore re-issued for action by the FAA.

94-26 It is recommended that the FAA take action to require some form of positive locking of the 'B' nuts on the compressor delivery pressure (P_C) sensing line on all Allison 250 Series engines, to prevent the loosening of such nuts and consequent sudden loss of engine power.

A partial solution to the problem already exists in the form of a safety valve that can be installed in the P_C line close to the union with the compressor diffuser. This device is a Supplemental Type Certificate (STC) modification and is already fitted to a number of aircraft equipped with Allison 250 engines. The valve can be manually moved to the 'closed' position whenever a compressor wash is carried out, and afterwards is returned the normal 'open' position, thereby eliminating the need to disturb the 'B' nut on the compressor diffuser for compressor washes.

94-27 It is recommended that the CAA and the FAA consider a requirement for the fitting of safety valves to the P_C sensing lines on all aircraft equipped with Allison 250 Series engines, in order to eliminate the need to remove and reattach the P_C line to the compressor diffuser during compressor washes.

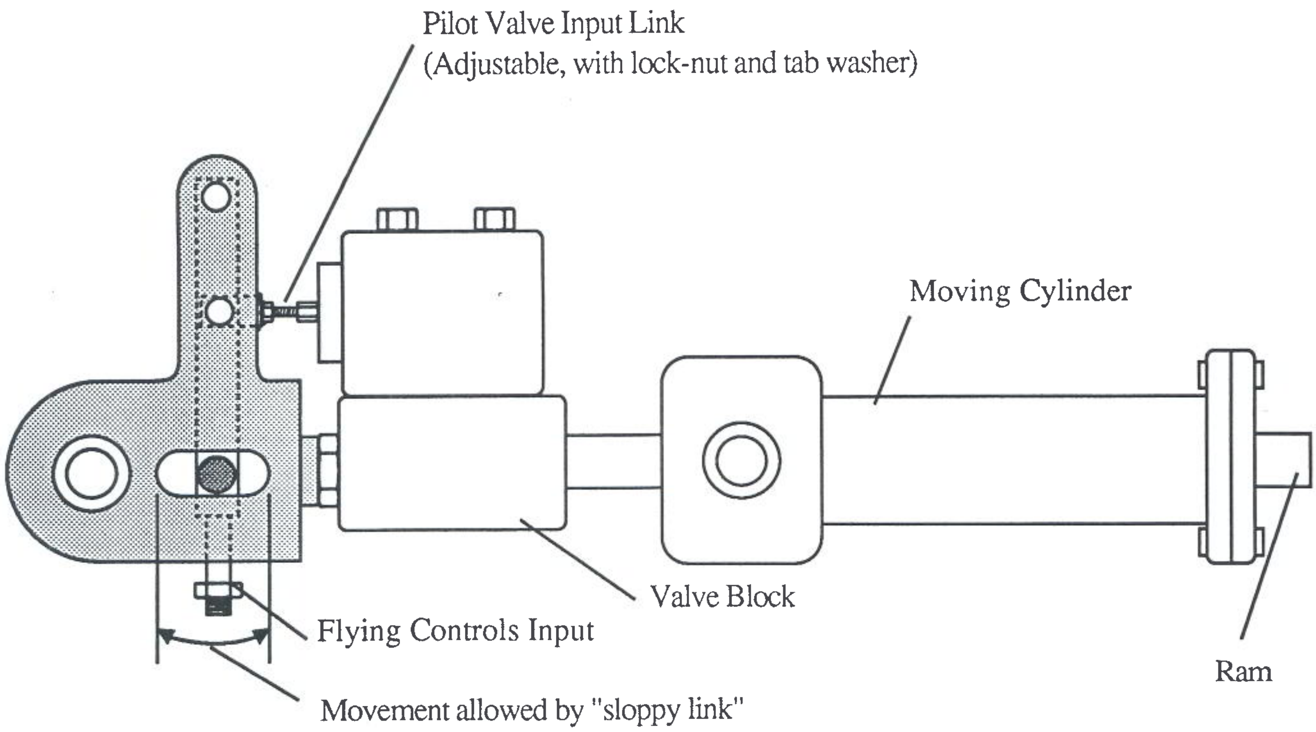

FIGURE 1 **Diagramatic representation of collective actuator, showing principle of sloppy link**

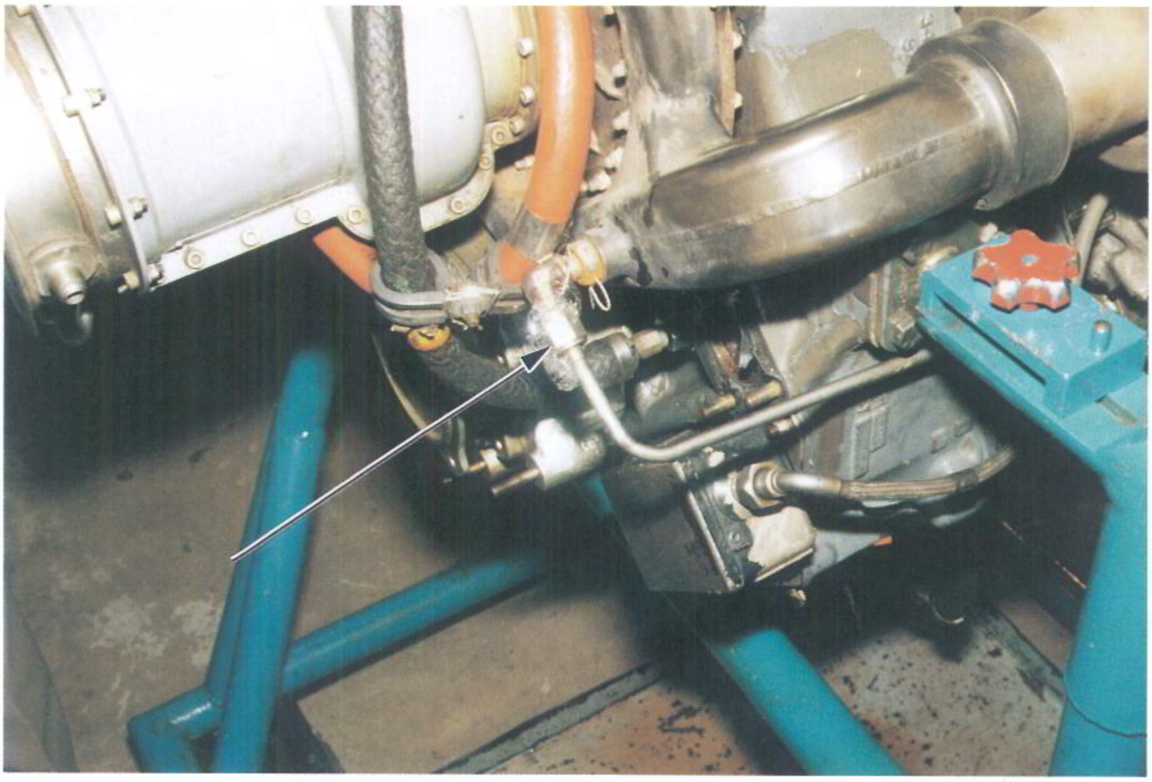

FIGURE 2 **Location of B nut on compressor diffuser scroll, showing soap bubbles from leaking air**