Agusta Bell Jet Ranger III, G-SHRR, 11 August 1997 at 1537 hrs

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Aircraft Type and Registration:	Agusta Bell Jet Ranger III, G-SHRR
No & Type of Engines:	1 Allison 250-C20 turboshaft engine
Year of Manufacture:	1968
Date & Time (UTC):	11 August 1997 at 1537 hrs
Location:	Adjacent to M6 motorway at Nether Kellet, Lancashire
Type of Flight:	Aerial work
Persons on Board:	Crew - 2 - Passengers - None
Injuries:	Crew - 2 (fatal) - Passengers - N/A
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Airline Transport Pilot's Licence (Helicopters)
Commander's Age:	53 years
Commander's Flying Experience:	3,412 hours (of which 3,060 hours were on type)
	Last 90 days - 69 hours
	Last 28 days - 42 hours
Information Source:	AAIB Field Investigation

Purpose of the flight

The helicopter was engaged on a gas pipeline inspection. The pilot, who flew for the operator on a freelance basis, was accompanied by an observer whose task was to inspect the route of the pipeline visually according to a pre-arranged, computer produced route schedule. The pilot flew the route according to directions given to him by his observer to allow inspection for activities such as farm drainage schemes and other workings in the vicinity of the pipeline. The normal flight profile was to cruise at approximately 600 feet agl at a speed of 80 kt the pilot would land to allow closer inspection should the need arise.

History of the flight

The helicopter left its base at Swinton, near Mexborough in Yorkshire at 0830 hrs on the day of the accident. It then flew by way of Catshaw to Holmfirth on the Yorkshire Moors where, due to poor visibility, it landed and remained until 1002 hrs. After taking off from Holmfirth it was then flown on a route that circled Greater Manchester in an anti-clockwise direction and took it over or near Oldham, Bolton and Stockport. The crew landed at Manchester Airport at 1204 hrs for a lunch break. While at Manchester the helicopter was refuelled with 210 litres of fuel.

At 1320 hrs, the helicopter took off from Manchester Airport and departed on a northerly track that roughly followed the M6 motorway. A landing had been planned at Blackpool but this was cancelled due to the time lost while waiting at Holmfirth for the weather to improve. At 1533 hrs the helicopter passed Torrisholme, a village immediately north of Lancaster; this was the last position timing that was entered on the flight log by the observer. Shortly afterwards the helicopter crashed into a field close to the M6 motorway. The first emergency telephone call was received at 1537 hrs.

The helicopter was recorded on radar, with no height information, flying north along the route of the M6 converging with it from the west. The radar information indicates that it was probably flying at a ground speed of about 90 kt and eye-witnesses describe it as being a few hundred feet above the ground. It crossed to the east side of the motorway abeam the village of Nether Kellet at a point where a road bridge crosses the motorway. From this point northwards the gas pipeline follows the motorway on its eastern side. For the observer to look diagonally downwards on to the pipeline it would be appropriate for the helicopter to be flown parallel with the motorway on its eastern side. The first untoward event noticed by eye-witnesses at or about the time that the helicopter crossed the motorway was an abrupt turn to the right which was described as flat or only slightly banked. For a brief period of time it appeared to fly level but in a way which was described as unstable. It then rolled rapidly to the left and pitched down and tumbled. One main rotor blade was seen to strike the nose and the aircraft fell to the ground. The attention of some witnesses was drawn to the machine by unusual noises. Some described an increased main rotor noise similar to that heard when a helicopter comes to the hover to land, then there was a rapid series of loud cracks, a loud explosive sound and a high frequency screeching noise. The main rotor was seen to detach and fall onto the motorway, one blade breaking into two as it did so. The fuselage fell inverted into a field some 100 yards from the motorway. The pilot remained strapped into the helicopter during its descent while the observer was flung clear. Both the pilot and observer died instantly of multiple injuries received on impact.

Meteorological aspects

The weather forecast for the route to be flown included 15 km visibility, nil weather, and cloud cover of 3/8 to 7/8 altocumulus with a base of between 12,000 and 18,000 feet. In addition, the north of the country was forecast to have isolated areas of 7 km visibility with haze, and cloud cover of up to 3/8 stratocumulus with a base of between 2,000 feet and 3,000 feet. There was also a warning of the possibility of isolated thunderstorms and heavy showers with low cloud on the hills. At the time of the accident the local weather consisted of 6 km visibility in light rain or drizzle with a broken cloud base at 9,000 feet. The wind on the surface was variable at 5 kt or less but was probably from between the east and south-east.

Engineering investigation

Wreckage Distribution

Aircraft debris fell to the ground to the east of the M6 motorway with the major part of the main rotor falling on to the motorway itself (Figure 1). One complete blade, coded red, was still attached to the main rotor hub with about two thirds of the other blade, coded white. The fuselage descended inverted into a small field about 100 metres east of the main rotor's position on the motorway. It was severely crushed by the impact and a fire developed around the engine. Immediately to the south of the fuselage within the same field there was a large number of small pieces of wreckage from the nose, the instrument panel and the windscreen of the helicopter. Most items in this area were of low density and would have fallen almost vertically once they became detached, being affected only by some light wind-drift. Therefore, the break-up of the helicopter is considered to have occurred directly above this field with the fuselage, as it fell, continuing for a short distance in a north or north-easterly direction, the original direction of flight. The aircraft's battery, weighing 40 lb, and a ballast weight, weighing 26 lb, lay about 100 yards east of the fuselage. These items came from the nose of the aircraft. The outer five feet of one of the main rotor blades lay to the south of this area in an adjacent field.

Separation of Main Rotor

The main rotor had separated from the fuselage through failure of the mast immediately below the flapping stops. After the separation, one of the main rotor blades (coded white) had cut through the aircraft's nose in front of the cockpit (Figure 2). This blade had itself broken when it contacted the heavy battery and ballast weight within the nose and its outer section was thrown to the southern edge of the wreckage area. Given the direction of flight of the helicopter, the normal direction of rotation of the rotor (anti-clockwise from above) and the direction in which the heavy objects had been thrown it appears that the helicopter had yawed through 180û or had inverted when this occurred. As the eye-witnesses described an initial yaw which was not a complete reversal of heading but which was followed by a violent roll and pitching motion it appears that the helicopter was most probably inverted when this occurred.

Mast Failure

The fracturing of the mast was due to severe bending loads being applied in the spanwise plane of the blades and, therefore, also in the plane of the flapping stops. The aluminium flapping stops were not grossly damaged or crushed; only at the lower corners of the contact surface, which is a circular arc to match the enlarged local circumference of the mast, was there some crushing and it was not certain that this damage had occurred during the accident sequence. Simple stress calculations suggest that a stop could sustain a contact load distributed over its surface which would break the mast but not exceed the stop material's yield stress. The contact area on the mast showed little more than damage to the painted surface around the edges of the contact area. In one small area the cadmium plating had been removed possibly as a result of heavy contact. Metallurgical examination showed that there was no pre-existing material or mechanical defect in the mast which had led to its failure. The fracture, which was predominantly in bending, had not been completely instantaneous. The fracture surface showed that the initial cracking from the outer, tensile surface had grown in a series of steps before complete rupture. Thus the mast had broken under a rapid series of bending overloads, a minimum of ten, in the direction consistent with impacts on the 'white' flapping stop. The main rotor rotates at 390 revolutions per minute and at one-per-revolution ten load cycles emanating from the rotor could occur in under two seconds. The investigation mostly consisted of efforts to identify the source and cause of such overloads.

Mast Bumping

The design of the Model 206 rotor requires that it is operated under positive 'g' loading. The fuselage is suspended on the mast on a 'teetering hinge' set, within the rotor hub, slightly above the feathering axes of the blades. If the level of G reduces towards zero then the stable pendulum relationship between the fuselage and the rotor is lost. If correct action is not taken within a few seconds then uncontrolled motion of the fuselage (and mast) relative to the rotor can result in contact on the flapping stops (mast bumping) which can be violent and repetitive and commonly breaks the mast just below the stops in the manner seen in G-SHRR. Though both stops are hit in this situation, subjecting the mast to reverse bending, if cracking initiates on one side then the sudden reduction in strength on that side may be rapidly exploited before cracking starts on the other side. The overall failure can, therefore, be unidirectional. Consideration was given to circumstances which could have resulted in mast bumping and other mechanisms by which the mast could have been over-stressed in bending were also examined.

Pitch Change Rods

Initially, the condition of the two pitch change rods attracted attention. One of these, coded white, had suffered distortion from being twisted around the mast and it was evident that it had still been attached to its rotor blade and to the rotating swashplate when the rotor had separated from the mast and had begun to slow down relative to it. That control rod had clearly not been a primary failure. The other rod, coded red, was found separated from but close to the main rotor at the edge of the motorway. This rod (Part No 206-010-330-7) exhibited some minor bending and impact damage but was virtually straight and its condition therefore raised the possibility that it had failed before the main rotor had separated. The fitting at the lower end of the red rod which contains the spherical bearing and screws into the aluminium tube section was missing along with the threaded end of the rod and was not found, despite ground searches with metal detectors and publicity in the local village and local newspapers. However, at the end of the technical investigation of this control rod the conclusion was reached that there was nothing to show that its failure had been the primary cause. The rod conformed to design in its material and dimensions and the initial fracture at its lower end in the swaged section of the tube at the run out of the thread for the lower end fitting, which led to its separation, was in tensile overload with no pre-existing defect. This area is subject to scheduled inspection for cracking which can result from corrosion between the rod and the end fitting's threaded insert. The fracture in the rod did not correspond to the type of failure which has been seen to develop from corrosion damage; there was no corrosion present, it was at the end of the threaded section not within it and it was circumferential not axial. The broken rod had remained attached at its top end to the main rotor until the rotor hit the ground beside the motorway. The damage which the rod had sustained was consistent with it being slightly crushed as it was broken off from the pitch change horn at ground impact.

On the inner surface of the transmission fairing an impact mark was found which contained an impression from a threaded component. This was consistent with having been made by the pitch change rod lower end fitting. After the rod separated from the fitting, the fitting, still attached to the rotating swashplate, swung outwards on its spherical bearing under centrifugal load and fouled the transmission fairing. Under this impact the lug on the rotating swashplate which houses the spherical bearing broke in bending and the rod end fitting was released. This evidence also suggests that the spherical bearing was free and had not seized; a seized bearing could result in failure of the pitch change rod. It was considered most probable that the rod had failed during the separation of the main rotor but at an earlier stage than the white rod which had been twisted around the mast however, during the investigation, consideration was given to any defects or circumstances which could have introduced an overload into the rod.

If a pitch change rod had broken in flight then the released blade, restrained in pitch only by the twisting of the torsion strap, would probably adopt a lower (oscillating) pitch angle and the helicopter would suffer a heavy vertical vibration. Similar machines which have suffered heavy vertical vibration have afterwards shown circumferential crippling at the forward end of the tailboom due to the cantilevered mass of the tail rotor and gearbox. There was no sign of this effect on G-SHRR which suggests that violent vertical vibration, and therefore severe blade loading asymmetry, did not occur in this case.

The Main Rotor Hub

The main rotor hub was dismantled. The pitch change bearings were in good condition, apart from some slight corrosion staining on the inner race of the white bearing. There was no surface damage that could have caused a restriction in their rotation and a consequent overload in their respective pitch change rods. The assembly had been secure but did contain some irregularities. A washer was missing from under one of the latch bolts and there were no shims present under the flapping stops. The stops are shimmed to give a slight interference with the orientating flat on the blade retention fitting; lack of shims would increase the interference. Because of the damaged state of the stops it could not be determined what the fitting interference had been but this was not seen as relevant to the accident. From information in the Illustrated Parts Breakdown (IPB) and from the aircraft manufacturer it appeared that the yoke which formed part of the main rotor hub assembly (Part No 206-010-101-125) was an incorrect part for the assembly and for the aircraft serial number (from the IPB 'usable on' code). The major difference from the correct part was an increase of 25 minutes in precone angle. The opinion of the manufacturer was that this difference would, in fact, decrease loads in the yoke and would have little effect on the flight characteristics of the helicopter. The records showed that this component had been originally incorporated into the assembly in 1980 by a maintenance organisation on behalf of the then operator.

A more striking anomaly was the difference between the two blade grips which were fitted. The red grip was of Part No 206-010-102-9 and the white Part No 206-010-102-121. These are of the same mechanical fit and function but are made of different alloys, have different external dimensions and are significantly different in weight. It was not intended by the manufacturers that the two types should be mixed but the information in the IPB implied that the -121 grip could replace the -9 grip and there was no **note** to say that they could not be mixed. In column (4) of the IPB listing, "Unit per assy", the quantity called out for each standard of grip was 2 and the manufacturer has stated that this signifies that the two grips fitted should be of the same standard. However, in the cases of some other components there were specific notes declaring that certain standards should not be mixed and this could be taken to imply that where mixing was not prohibited then it was permissible. The IPB has since been modified to make clear the non-interchangeability of the two grip types. The weight difference was measured as 0.81 Kg and no balance weights were found in the hollow blade retention bolts to compensate for this. The aircraft had operated for 121 flying hours since the main rotor had been last aligned and balanced and no unusual vibration indicating a main rotor out-of-balance condition had been noted.

Pillow Blocks and Trunnion Bearings

One of the pillow blocks (supporting the main rotor trunnion) had broken from its attachment flanges but the failures were in overload and appeared to be the result of ground impact. A ring spacer was missing from inside each pillow block and so the outer race with the caged needle rollers in each trunnion bearing was able to move axially. This movement would have been over good bearing surfaces on the inner races and would not have affected the operation of the bearings. The bearing inner race surfaces showed some damage which was in the form of equally spaced indentations caused by the needle rollers. One set equally spaced around the circumference conformed to the full set of the needle rollers and there were other partial sets. Some of this damage may have been caused by ground impact but some of it appeared to have been pre-existing. Associated with some of the indentations there was some fatigue spalling and smearing of the surface material. This was microscopic in scale but would have been pre-existing. Both the manufacturing company, Agusta Bell, and Bell Helicopter Textron, producer of the original 206 model advised that post service wear or damage in these bearings is not unusual, that this was within what could normally be seen after a full service life of the component and such wear was not known previously to have caused any deleterious effect on other components. From design considerations this damage could not have caused unusual loads in the pitch change rods but it could have produced some bending load into the mast itself. Estimates of these loads by a bearing specialist, however, showed them to be very small and they were calculated to cause an increase in mast stress about 1/4% of ultimate stress in 1g flight.

Flying Controls

There were numerous failures in the mechanical linkages of the flying control system but these all exhibited the characteristics of overload and distortion consistent with impact. None of the failures were characteristic of any pre-existing failure condition. The flying control hydraulic servo-actuators were stripped for examination; they were too badly damaged to test. No defect was found which could have caused a malfunction in their operation, in particular, on each actuator the flexible 'wire drive' between the input lever and the pilot valve was intact.

This aircraft was fitted with a stability augmentation system. This is uncommon in this model of helicopter and the system was introduced as a CAA approved modification in 1968 when the machine had been newly imported into the U.K (Flight Manual ATEL Supplement No 2 refers). Responding to rate gyro signals the system made small corrective control inputs in series with pilot inputs through electrically driven actuators incorporated into control rods in the cyclic system and the yaw system. The authority of the system was limited to 10% of rod total movement and a disengage switch (press-button) was fitted to the cyclic stick. The gyro amplifiers had suffered high impact loads in the crash but, on bench test, they were found to be functional though out of tolerance on some parameters. The left cyclic actuator was found damaged and seized in the nulled position. It was also found to have internal corrosion and the motor would not rotate. The corroded condition of this actuator was found late in the investigation and though the actuator had been stored in dry conditions it could not be certain that this had been its condition before the accident. The right cyclic actuator was trapped by impact damage in the fully retracted position and the yaw actuator was fully extended and severely damaged by fire. Neither of these two actuators had any internal corrosion and in the cyclic actuator the motor operated and the gearbox was free to rotate.

That two of the actuators, in separate channels, were at extreme positions could mean that they had both suffered a 'runaway' or 'hardover' co-incidentally but this is unlikely. It could also mean that they had been reacting to aircraft motion, probably of an extreme kind, when power was removed from the system and this could imply that the system was engaged at the time of the accident. The nulled position of the third actuator could be fortuitous if it also was active when power was removed but if its position was the result of seizure due to corrosion then this would more likely happen when the system was at rest between flights and be discovered on take off. (The Flight Manual supplement describes only a procedure for engaging the system before flight.) The system had operated, apparently normally, during recent flights. If the system had been in use and had been disengaged by the pilot because of a fault at any time before the crash, perhaps at the previous take off, then the aircraft would be flyable even with non-nulled actuator extensions though there would be a datum displacement of the cyclic and yaw controls. For the system to precipitate a pitching down motion, to produce a low 'g' condition, both cyclic actuators would have to extend together and there is no evidence to show that this unlikely co-incidence occurred. The condition of the autostabilisation actuators is, therefore, anomalous but it is not possible to identify the anomalies positively as having occurred at the time of the accident or implicate them in the sequence.

On G-SHRR the left hand set of pilot's flying controls had been removed to allow a passenger to be carried in this seat when operating under public transport rules. The left set of controls did not have 'quick release' fittings and the installation was intended for 'permanent dual' use. However, it was not possible to see any way in which this could have led to a loss of control in this case.

Engine and Transmission

The main rotor gearbox and tail rotor gearbox were intact and the freewheel unit operated correctly. The main engine to gearbox driveshaft was intact and its flexible couplings, though fragmented, showed no sign of pre-existing failure. The tail rotor showed some signs of rotation at impact and its drive shaft contained one failure which had some torsional characteristics. The output shaft to the tail rotor from the freewheel unit also exhibited a torsional shear failure; this probably occurred when the cooling fan was crushed and trapped at impact and indicates that power was being transmitted through the shaft at that time. The failure in the main rotor mast itself and the direction in which one pitch change rod was dragged around the mast after separation also indicates that the main rotor was being driven at the time of separation (ie the rotor slowed down relative to the mast) and, therefore, that engine power was available. Damage to the engine was consistent with it delivering low power at impact with some ingestion of material and counter-rotational damage to compressor blades. Some of the witnesses reported a very high frequency screeching noise. This is likely to have been the engine overspeeding after the main rotor detached. The engine's overspeed governor would have immediately reduced fuel flow to reduce engine speed to idle, and the evidence above is consistent with this being the condition at impact.

Landing Skids

The landing skids were of a type that houses inflatable flotation bags which can be used in emergency landings on water. The approved installation is with the bags installed in the skid housings and a pressure bottle fitted on the aircraft to inflate them when necessary. The Flight Manual contained an appendix covering operation with flotation bags and it was stated that, "The floats and covers must be installed for all flight operations." The skids were still fitted but the bags and bottle had been removed. It was recorded in the maintenance documentation that the bags were removed in November 1994 and the aircraft had operated for 325 flying hours since then. It is likely that the absence of this equipment had only minimal effect on the flying behaviour of the helicopter

Conclusion

The investigation did not identify a clear technical reason for the in-flight break-up of this aircraft. Much of the evidence was consistent with the aircraft having suffered a 'mast bumping' incident of such severity as to break the mast but from the witness evidence there was no indication that this helicopter was being manoeuvred in a way which could have brought it into the hazardous flight regime which might bring this about. The weather was benign and the radar record shows the helicopter following a virtually straight course up until the final moments. A number of anomalies were identified in the mechanical condition of the helicopter but none could be associated with its break-up in the air.