AIRCRAFT ACCIDENT REPORT 1/87

Accidents Investigation Branch

Department of Transport

Report on the accident to Bell 212 G–BJJR, In the North Sea 50 miles east of the Humber on 20 November 1984

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1/87	Bell 212 G–BJJR In the North Sea, 50 miles East of the Humber November 1984	

Department of Transport
Accidents Investigation Branch
Royal Aircraft Establishment
Farnborough
Hants GU14 6TD

9 February 1987

The Rt Honourable John Moore
Secretary of State for Transport

Sir

I have the honour to submit the report by Mr K P R Smart, Inspector of Accidents, on the circumstances of the accident to Bell 212 G–BJJR which occurred in the North Sea 50 miles East of the Humber on 20 November 1984.

I have the honour to be
Sir
Your obedient Servant

G C WILKINSON
Chief Inspector of Accidents

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Accidents Investigation Branch

Aircraft Accident Report No. 1/87 (EW/C896)

Registered Owner and Operator:		Bristow Helicopters Ltd
Aircraft:	*Type:*	Bell
	Model:	212
	Nationality:	United Kingdom
	Registration:	G–BJJR
Place of Accident:		In the North Sea 50 miles East of the Humber. Latitude 53° 51′ North Longitude 01° 13′ East
Date and Time:		20 November 1984 at 1919 hrs All times in this report are UTC

Synopsis

The accident occurred during a night approach to the exploration rig Cecile Provine and was reported to the Accidents Investigation Branch on 20 November 1984. The investigation was started the next day.

The helicopter departed from its base at North Denes near Great Yarmouth at 1757 hrs to carry out various transport tasks on several rigs in the southern North Sea. Its final task was to collect 7 passengers from the rig Cecile Provine and transport them back to Great Yarmouth. During the night approach to this rig, in reasonable weather conditions, the helicopter crashed into the sea 200 metres north of the rig and both crew members perished. Most of the wreckage was recovered from the sea bed in two diving operations during the next few weeks.

The report concludes that control of the helicopter was lost following a decay in rotor rpm while both engines were delivering full power. There was insufficient evidence to determine the cause of the rotor rpm decay.

1. Factual Information

1.1 History of the flight

On the day of the accident the helicopter, a Bell 212 G–BJJR, took off from North Denes airfield at 1757 hrs with the commander and cabin attendant on board to fly to various rigs in the southern North Sea to transport passengers and cargo between the rigs and eventually return several passengers to North Denes.

The first destination of the helicopter was the Leman 27H production platform, where it landed at 1813 hrs and made a rotors running turn round. It then carried out inter-rig transfers calling at the Leman 27H, J, C, A and F where it refuelled. During the refuelling slight spillage occurred because the fuel was not shut off in time. G–BJJR took off quite normally at 1844 hrs to fly to the exploration rig Cecile Provine where the intention was to pick up 7 passengers before returning to North Denes.

The helicopter climbed to 2000 feet for the transit and the commander reported the Decca position to his base at North Denes at 1844 hrs. At 1910 hrs the commander advised 13 nautical miles (nm) to run to the Cecile Provine and at 1917 hrs he reported leaving 2000 feet.

Several witnesses on the rig, including the intending passengers, saw the lights of the helicopter approaching the rig. The weather at the time was good with a 2000 feet cloudbase and good visibility. The wind was SW at 15-20 knots (kt). As the helicopter continued its approach to the rig some of the witnesses thought it was moving faster than normal and it seemed to be making an approach towards the derrick rather than towards the helideck. When only a few hundred yards from the rig the helicopter was seen to yaw or snake and sparks were seen in the vicinity of the engines or the base of the main rotor mast. The aircraft then rolled to the right, pitched nose down and crashed into the sea some 200 metres north of the rig.

Witnesses on the rig watched the helicopter sink and although floating wreckage, including a liferaft, came to the surface there was no sign of survivors. The search and rescue operation was begun at once in response to a distress call transmitted by the Cecile Provine, but by midnight it became clear that no survivors could be found and the operation was terminated.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	2	–	–
Serious	–	–	–
None	–	–	

1.3 **Damage to aircraft**

The helicopter was destroyed by the impact with the sea.

1.4 **Other damage**

There was no other damage.

1.5 **Personnel information**

Commander:	Male, aged 55 years
Licence:	Airline Transport Pilot's Licence (Helicopters) valid until 17 November 1988.
Aircraft ratings:	Westland S55 Series 3 Wessex 60 Series 1 Bell 206A Bell 47 Bell 212
Instrument rating:	26 October 1983, valid until 25 November 1984.
Last medical examination:	26 June 1984 valid until 26 December 1984. Corrective flying spectacles required to be worn.
Flying experience:	
Total hours as pilot:	10,091 hours
Total hours in command:	9,244 hours
Total hours on type:	2,066 hours
Total hours in last 28 days:	Day: 27 hours 45 minutes Night: 6 hours 50 minutes
Total hours in last 7 days:	Day: 3 hours 40 minutes Night: 2 hours 15 minutes
Rest period before duty on day of accident flight:	14 hours

1.6 **Aircraft information**

1.6.1 *Leading particulars*

Manufacturer:	Bell Helicopter Company
Type:	Bell 212
Date of Manufacture:	1980

Certificate of Airworthiness:	UK Transport Category (Passenger) valid until 7 January 1985
Certificate of Maintenance:	Issued 20 September 1984 and valid to 3699.45 hours or until 20 December 1984
Total airframe hours:	3,590 hours
Hours since last check:	16 hours 30 minutes
Maximum weight authorised:	11,200 lb
Estimated weight at time of accident:	8,756 lb
Estimated Centre of Gravity at time of accident:	138.6 inches aft of datum
CG range applicable:	133.0 to 142.4 inches aft of datum

1.6.2 General description

The Bell 212 is a twin engined utility helicopter powered by Pratt and Whitney PT6T engines. The teetering main rotor is of conventional design and is controlled via the Bell flybar/damper system. The collective and cyclic controls are each powered by tandem hydraulic actuators pressurised by the aircraft's two independent hydraulic systems. The tail rotor pitch control is powered from the No 1 hydraulic system but can be operated in the manual mode in the event of a No 1 hydraulic systems failure. G–BJJR was fitted with a Sperry SHZ–212 Integrated Flight Control system which operated in the roll, pitch and yaw axes. The autopilot has no control over the collective pitch system. Engagement and disengagement of the autopilot is achieved via the 'Helipilot' control panel located on the interseat console. There is no provision for an autopilot disconnect switch on the cyclic control.

Main rotor driving torque is displayed at each pilot's station by a combined indicator giving both total and individual engine torque in percentage terms. Since the main transmission cannot tolerate the maximum torque which can be produced by both engines, a torque limiter which cannot be overidden is fitted, restricting combined engine torque to a nominal 104% of transmission design capability.

The aircraft was equipped with a 'Decca' navigation system and a radar altimeter.

1.7 Meteorological information

1.7.1 Synoptic situation

Low pressure over Western Ireland was moving into North Wales overnight whilst the associated occluded front moved across the area.

1.7.2 *Forecast weather*

Surface wind:	200°/20-25 knots
Visibility:	8-12 kilometres
Cloud:	3-6 oktas stratocumulus base 4,000 feet tops 6,000 feet. Cloud thickening from the southwest.
Temperature:	+ 8° Celsius

1.7.3 *Actual weather conditions*

The 1720 hrs weather at the rig Cecile Provine was available to the commander before departure:

Surface wind:	SW/16-18 knots
Visibility:	5 nautical miles
Cloud:	5 oktas at 2,000 feet
Pressure:	1007 millibars
Temperature:	+ 10° Celsius

When in RTF communication with the rig Cecile Provine just before the accident the wind was passed to the commander as southwesterly 16-18 knots with a visibility of 5 nautical miles.

1.8 Aids to navigation

The aircraft was navigating between the Leman 27F and the Cecile Provine using Decca as the primary navigation aid. At 1857 hrs the aircraft reported its position as Decca co-ordinates B30, C59. At 1910 hrs the aircraft reported 13 nm to run to the Cecile Provine; this range was probably established using the helicopter's airborne radar. The rig non-directional radio beacon transmits on 553.5 with a morse callsign of CP.

1.9 Communications

The aircraft was communicating with its base at North Denes after take-off from the Leman 27F on frequency 120.45 MHz. Communication was satisfactory and at 1917 hrs the aircraft reported that with 6 nm to run to the Cecile Provine it was changing to the rig frequency of 123.45 MHz. The rig passed the surface wind and visibility and later warned the pilot that the port crane was unloading from a rig support vessel. The pilot acknowledged this call. No distress call was received from the helicopter on any frequency.

1.10 **Aerodrome information – Rig Cecile Provine** (Refer Appendix 1(a) and 1(b))

The rig Cecile Provine was equipped with a helideck, octagonal in shape, and 83 feet in diameter. The helideck was approximately 125 feet above the sea surface and had a clear approach from three sides.

The helideck was illuminated by deck edge lighting and the whole rig was lit to allow the normal work of the rig to continue after dark. The crane jibs were equipped with red obstruction lights at the extremity and the whole length of the jib was illuminated with strip lighting. Red obstruction lights were also provided on top of each jack-up leg.

1.11 **Flight recorders** (Refer Appendix 2)

The helicopter was fitted with a Fairchild A100 four track Cockpit Voice Recorder (CVR). This used plastic based magnetic tape as the recording medium and was of the normal endless loop type of recording with a duration of thirty minutes.

The track allocation was as follows:

Track 1 Captains microphone and headset signals
Track 2 Co-pilots microphone and headset signals
Track 3 Cockpit area microphone
Track 4 Main rotor rpm

The recorder was recovered from the helicopter wreckage and a satisfactory replay was obtained.

The replay of the CVR area microphone track in conjunction with the main rotor tachometer track revealed that until 20 seconds before the end of the recording the flight had been normal. There then followed a steady reduction in rotor rpm to a point where the low rotor rpm audio warning operated. During this time both engines had accelerated in an attempt to restore rotor rpm, resulting in a situation where full engine power was apparently insufficient to maintain rotor speed. The rotor rpm then started to behave erratically and there were sounds of severe vibration and or mechanical distress which persisted until the end of the recording.

Throughout the recording both main and tail rotor passing frequencies were monitored and their normal frequency relationship was maintained until the recording ended.

Details from the analysis of the recording are included at Appendix 2.

1.12 **Examination of the wreckage**

1.12.1 Wreckage distribution and recovery

The helicopter crashed in about 30 metres depth of water. The floating wreckage, including the forward part of the tail boom and a piece of main rotor afterbody was recovered by ships engaged in the search and rescue, but no accurate positions were established. A sidescan sonar plot of the sea bed in the impact area was made, and from this it was established that the bulk of the helicopter wreckage was contained in an area of about 100 metres diameter, 200 metres north of the rig.

The wreckage was salvaged in two diving sorties, and about 98% of the helicopter was recovered; the only significant item not found was the tail rotor. The wreckage was taken to the Accidents Investigation Branch at Farnborough for detailed examination.

1.12.2 *Structural damage* (refer Appendix 3)

The main structure of the helicopter had been severely disrupted during the impact with the sea. The nose section had fragmented and the pillars connecting the cabin floor assembly to the roof structure had failed at their top and bottom attachments. Both the cabin floor and the roof assemblies were disrupted around the main transmission support structure, and the fuel tanks beneath the cabin floor in the area of the transmission support had ruptured. All the doors except the rear right sliding door were relatively undamaged apart from their windows being shattered.

There was evidence of a main rotor blade strike on the tailboom at the stabilator. This strike had completely severed the tailboom after splitting the left stabilizer spanwise. The strike had occurred when the rotor disc was tilted back at 30° to the aircraft centreline. There is no evidence of any other rotor strike on the tail boom in the region aft of this strike.

There was evidence of a second main rotor strike on the left side of the tail boom 4 feet aft of the fuselage junction. The blade had struck between the two engine exhausts, destroyed the upper engine cowlings and right intake, and passed through the lower rear cabin structure to the region of the lower aft corner of the right sliding door.

The rear right door had evidence of mechanical damage, most severe towards the rear end. This part was the limit of a swathe of extreme disruption which had occurred just aft of the transmission support structure. The entire rear fuselage between the transmission support and the tail boom attachment including the engine deck and centre cowlings had been completely fragmented.

1.12.3 *Rotor damage*

The two rotor blades showed markedly different damage although both were still attached to the hub assembly. One blade showed no evidence of having struck the helicopter and the damage it had sustained was restricted to the tip; where about 3 inches of afterbody and one foot of trailing edge strip had been rolled upwards and directly inboard span wise, and a point 4 feet outboard of the blade root attachment where the whole blade structure had suffered a combined bending and shear failure again in a directly upward and inboard direction. The other blade had suffered massive mechanical damage as a result of striking the helicopter structure. The leading edge spar was curved directly forward about 30° from a point about 5 feet outboard of the root end over a length of about 6 feet. The afterbody had separated from the rear face of the spar from a point about 3½ feet outboard of the root and about half of the afterbody from outboard of this point was not recovered.

When the blade struck the aircraft it was dragged back about its main attachment and the drag strut forced a shear separation of the trailing edge strip from the inboard section of afterbody which remained attached to the spar. There were deposits of blue paint on the blade yoke similar to that on the engine cowlings. Outboard of the curve, the whole leading edge showed evidence of striking the aircraft structure and was particularly severely damaged at its outboard end. The tip balance weights of both blades were found to be installed and secure.

A detailed examination of the bonding failures between the spar and afterbody, and the afterbody and trailing edge strip, was conducted but no evidence of pre-impact bond failure was detected.

1.12.4 *Controls*

Detailed examination of the mechanical flying controls revealed no failures with characteristics other than pure overload as a result of structural deformation during the break-up of the aircraft. The controls at the rotor head had been very severely damaged, and it was not possible to be certain that any evidence of pre-existing failure had not been destroyed by the subsequent damage. Both blade pitch control arms had separated from the blade roots and one was not recovered; there was, however, no evidence of pre-separation fretting indicative of looseness at either attachment.

1.12.5 *Hydraulic systems*

All main rotor primary servos had suffered some degree of damage but on functional testing were all found to operate satisfactorily without significant leakage. Strip examination showed all seals to be in good condition. The tail rotor servo booster was found to be in a similar satisfactory condition.

Both hydraulic pumps were recovered and although the damage they had sustained, as a result of the accident and subsequent immersion in sea water, precluded functional testing, strip examination revealed no pre-existing faults in either.

The hydraulic filter units were both recovered and neither showed any significant particle contamination. Both filters were functionally checked and found to be fully serviceable. Samples of hydraulic fluid were taken from both filters. The analysis of these showed there to be 5% kerosene content in each. No feature was found to explain the presence of kerosene in these samples.

Examination of the hydraulic system pipework revealed no evidence of any pre-impact failures. The main hydraulic fluid reservoir was not recovered.

1.12.6 *Helipilot (Autopilot) system*

As recovered, the Helipilot system actuators were all found in extreme positions. The roll and pitch servos being fully retracted and the yaw servo fully extended. These positions equate to control commands of nose down, left roll and right yaw. The condition of the Helipilot computers precluded determination of their serviceability, nor was it possible to establish the modes engaged at the time of the accident.

1.12.7 *Engines*

Strip examination of both engines and their associated control systems revealed no evidence of pre-impact malfunctions or faults. It was not possible to functionally test the speed governor of either engine due to accident damage but engine performance was assured from data from the CVR. (See section 1.18.)

1.12.8 *Transmission*

Both the combining gearbox and the main transmission assembly had been disrupted as a result of impact forces. The combining gearbox engine attachments had failed as a result of the main rotor striking the engine cowlings. The main transmission had parted at the joint between the support and main cases with evidence of the main case moving to the left at separation. The input drive coupling showed evidence of disengagement whilst turning at speed.

The main rotor mast had failed in bending just below the rotor head, and there was evidence of almost equally severe contact of both teetering stops on the mast at that point.

The tail rotor drive shaft was not all recovered; sections were missing in the area of both rotor strikes on the tail boom. Examination showed there to be no evidence of distress in the sections recovered. The tail rotor mast had failed in bending at the point where the rotor attached and the rotor assembly was not recovered.

All transmission gearboxes were strip examined and no sign of pre-impact failure or distress was found in any of the gears or bearings. All auxiliary drives were found to be intact.

Examination of the rotor brake disc showed no evidence of abnormal heating.

1.13 **Medical and pathological aspects**

Autopsy examinations were carried out on the pilot and the crewman. No evidence was found to suggest a causative or contributory medical factor in this accident.

The pilot had sustained a broken right arm and fracture of all ribs on the right side of the body. However, the cause of death was a severe head injury due to impact with a light fitment fixed to a bar over the door.

The crewman's body was not recovered until a year after the accident. The cause of death appeared to be drowning as a result of multiple injuries.

1.14 **Fire**

There was no fire.

1.15 Survival aspects

1.15.1 Survivability

The accident was not survivable. Both occupants were found strapped to their seats but both seat structures had failed close to the floor.

1.15.2 Search and rescue

A "Mayday" call was broadcast by the rig Cecile Provine promptly after the crash. Appropriate search and rescue action was taken by Humber Coastguard which included the despatch of an RAF Search and Rescue helicopter, an RN frigate HMS Falmouth, and the Humber lifeboat. Shortly after the crash the rig standby vessel Oakleigh and the Anglia Service, a rig support vessel that was discharging cargo to the rig, were joined by another rig standby vessel Winkleigh. Several items of wreckage were recovered but there was no sign of survivors.

1.16 Tests and research

During the investigation the possibility of a partial disbonding of a main rotor blade afterbody section was examined in considerable detail.

The examination of the blade spars and those sections of afterbody recovered revealed no evidence of failure, but it was considered that any such failure would affect the blades aerodynamic characteristics and would be heard on the area microphone track of the cockpit voice recorder.

The helicopter operator offered to conduct a flight trial to test the validity of this hypothesis. The disturbance to the aerodynamic characteristics of the blade was simulated by adjusting the blade fixed trim tab to induce an out-of-track condition. The flight test involved a series of manoeuvres at different speeds and power settings and it was apparent from the pilot's comments that the vertical vibration experienced was much more severe than the noise generated by the out-of-track condition that was detected on the recording. However, a distinctive once per revolution sound was detected throughout the flight test sequence recording.

1.17 Additional information

1.17.1 Single pilot operation

The helicopter was being operated by a single pilot under instrument flight rules at night. The Bell 212 with the Sperry Helipilot is approved by the CAA for such operations. During the investigation a number of pilots skilled in single pilot operation commented on the difficulty of single pilot night approaches to jack up rigs like the Cecile Provine, especially when they were remote from other rig complexes. In such conditions the visual references available are sometimes confusing and the workload of the pilot is high.

Several night approaches to the Cecile Provine were flown to try to determine if there was any factor that could have either distracted the pilot or could have caused him to bank to the right suddenly. No factor could be identified that might have contributed to the accident, however, the visual problems of approaching a rig of this design at night, were well appreciated.

1.17.2 *Incidents involving Sperry Helipilot malfunction*

The operator had on record four incident reports associated with Sperry Helipilot malfunctions where handling difficulties were encountered. Two of these incidents occurred in 1982 one of which involved the accident aircraft G–BJJR. The two subsequent incidents occurred during 1985. Details are given below:

(i) Incident to Bell 212 G–BJJO on 5 January 1982: On lift-off the helicopter yawed violently left and right and could not be controlled with the rudder pedals. It was not practicable or safe to release the collective control to disengage the Helipilot yaw channel so the aircraft was landed immediately. Subsequent examination showed that the most probable cause was ingress of moisture into the nose compartment area that houses the Helipilot computers.

(ii) Incident to Bell 212 G–BJJR on 25 January 1982: Whilst in transit between North Denes and the Leman field the aircraft rolled to the left and right several times with sufficient violence to alarm the passengers. The Helipilot was disengaged and the flight was completed without further incident. Subsequent examinations of the system failed to find the cause of the malfunction.

(iii) Incident to Bell 212 5N–ALS on 21 September 1985: During the final stages of an approach to the Belle Isle Rig (Nigeria) the helicopter began to yaw left and right as power was applied. Because of the close proximity of the rig the pilot was unable to let go of the collective control to disengage the Helipilot, which he believed to be the cause of the yaw. The yawing continued in the hover and the helicopter was landed on the helideck. The Helipilot was then disengaged and a hover check confirmed that this was the source of the handling problem. Subsequent examination revealed that a terminal block matrix located in the nose avionics bay was suffering from ingress of moisture with associated corrosion.

(iv) Incident to Bell 212 5N–AOV on 23 September 1985: The helicopter was en-route from Pennington to Oloibiri (Nigeria) when on engagement of the Helipilot the aircraft began a divergent oscillation in all three axes. The motion of the helicopter was so violent that the pilot had difficulty in reaching the Helipilot control panel to disengage the system. After 3 or 4 seconds the system was disengaged and the motion ceased, the helicopter then made a precautionary landing. The control problem was confirmed with the system in the aircraft but thorough testing of the various components at the operator's engineering base failed to identify the source of malfunction.

In each of these incidents the pilots commented on the difficulty encountered in disengaging the helipilot system and suggested that the system might be modified to incorporate a cut-out switch on the cyclic control. Such modification action was discussed by the Operator and the Civil Aviation Authority in 1982 but at that time an acceptable installation could not be found.

British Civil Airworthiness Requirements Chapter G6–4 under the heading "Controls" states:

> "The pilot shall be provided with a control mounted on the cyclic control which, when operated, frees the rotorcraft from the control of the automatic system, unless it can be shown that any failure in the system which is Recurrent will only result in a Minor Effect".

1.18 Useful or effective investigation techniques

This was the first accident to a helicopter equipped with a cockpit voice recorder installation conforming to the requirements of CAA Spec 11 Issue 3.

In this installation, three of the four CVR tracks record audio signals; two record the Commander's and Co-pilot's microphone and headset signals and the third track records ambient flight deck noise from the cockpit area microphone. The fourth track records data in the form of a frequency shift keyed (FSK) signal proportional to main rotor speed. The source of this signal is the rotor tachometer generator supplying the pilot's instruments.

A computer programme was written for this accident which measured the main rotor speed during the CVR replay and provided a graphical plot of main rotor speed against elapsed time.

A digital read-out was provided which enabled the Inspectors to monitor main rotor speed whilst listening to the audio recording.

The background noise recorded from the area microphone was filtered such that blade passing frequencies within the engines could be detected and measured. A time history of engine gas generator speeds was then obtained which could be correlated with main rotor speed.

Test flights provided data enabling the torque to be derived from a combination of engine gas generator speeds and main rotor speed.

The results of this analysis are shown at Appendix 2.

2. Analysis

2.1 General

The recovery of all the wreckage from within a 100 metre radius of the main wreckage concentration together with the eye witness reports indicated that the helicopter was intact up to or very shortly before the time it struck the water. The deformation of the lower and forward area of the fuselage is consistent with it being slightly banked to the right, in a nose down attitude with moderate forward speed at the moment of impact.

The general impression gained from all eye witnesses was that the helicopter's approach to the rig was normal up to the point that they appreciated that, instead of descending to the helideck passing by the left side of the rig, it was descending behind the rig and appeared to be getting very close to the derrick which was its after-most part. There was almost universal agreement that the approach seemed to be faster than usual, although this may be explained by the fact that in passing behind the rig, the helicopter was tracking across the field of view of the witnesses rather than the more usual situation when it would have been descending almost directly towards them. There was also total agreement that the helicopter's flight became suddenly apparently out of control and that little if any control was regained before it struck the sea. It was a very dark night and until the helicopter came within the aura of the rig the witnesses would have been unable to appreciate any subtle perturbations of the flight path as all they could see was the aircraft's landing light.

2.2 Operational aspects

From the eyewitness evidence it could be postulated that the reason for the accident was pilot disorientation or incapacitation. However, there is no medical or pathological evidence to suggest that the pilot was incapacitated, nor was there any indication from the CVR record that the pilot was doing anything other than attempting to control the helicopter. Neither crew-member said anything that would suggest that either was medically incapacitated.

As this was a single pilot operation the possibility of pilot disorientation was fully investigated. There is little doubt that approaches to the Cecile Provine at night or in poor weather required a high skill level from the pilot. However, on the night in question the weather was fine and the pilot had the rig in sight early in the approach. He told the cabin attendant that he could see the port crane unloading the rig supply vessel. As it is extremely hazardous to approach over a working crane it can be assumed that the pilot had elected to make his approach along the starboard side of the rig. This would also have the advantage of an approach more nearly into wind, but have the disadvantage of having to look across the flight deck during the approach.

The CVR evidence gave the impression that the pilot had committed himself to an approach leaving the rig to port and it is at this point that some event, such as a change of collective or cyclic position, or perhaps a change in autopilot mode, precipitated a malfunction which caused the rotor rpm to droop. Without evidence from a flight data recorder it was not possible to determine whether any control inputs by the pilot either assisted in or detracted from maintaining control of the helicopter, but as he had the rig ahead of him providing a visual reference he should have had little trouble maintaining control of a serviceable aircraft. There is little doubt that control of the helicopter deteriorated rapidly from this point until the time when it rolled rapidly to the right and the accident became inevitable. Although a precise timescale is difficult to determine it is likely that until the helicopter rolled to the right the rotor rpm was well above the value below which control would be severely reduced. Furthermore, the CVR also provided evidence that the engines responded normally to try to restore the rotor to 100% rpm and in so doing increased their power output to the maximum available. This additional power should have resulted in a rapid climb or forward acceleration. As the eye witnesses saw neither a rapid climb nor an acceleration into fast forward flight it is most unlikely that a pilot input into the collective pitch system caused the rotor rpm decay but that some technical defect, or other event, dramatically increased the power absorbed by the rotor or transmission system and caused the rotor rpm to droop.

2.3 Rotor and transmission systems

The continuous noises heard for the last 5½ seconds of the cockpit voice recording are not identifiable but are clearly evidence of severe mechanical distress or rotor instability causing severe vibration. In view of the almost continuous rotor rpm decay over the preceeding 9 seconds without any sounds of mechanical distress, rotor instability appears to be more likely. The teetering type of rotor as fitted to this helicopter, characteristically becomes less stable as either rotor loading or rpm is reduced. However, it has been demonstrated to be quite satisfactory at rotor speeds down to about 88% and has been shown to be controllable at speeds as low as 78% with care.

Since the persistent decay in rotor speed and the loss of control are both unusual features, it appears reasonable that there is a causal link between the two. The implication of the loss of rotor rpm with full engine power being delivered is that either a high mechanical drag in the transmission system had developed suddenly or that the rotor had demanded more power than was available to it.

The examination of the transmission system showed that there was no evidence of any pre-impact failures. This was supported by the interpretation of the CVR area microphone track in which evidence of both main and tail rotor blade passing frequencies were determined up to the end of the recording. No bearing failure or other feature that could have absorbed power in the transmission was found.

Since there was no evidence of pre-impact failure or malfunction in the transmission system then it is reasonable to conclude that the power available must have been absorbed by the main rotor.

A high power demand by the rotor can arise for one of two reasons; either by a large blade pitch increase or as a result of blade damage.

A large blade pitch increase can occur as a result of either a pilot input of collective control, a collective servo runaway affecting both blades, or a disconnection of the control input to one or both blades leading to loss of control of the rotor. A symmetrical increase of blade pitch would lead to an increase in rotor thrust which if maintained over the period of persistent rotor droop would have led to a noticeable change in aircraft performance in either climb, forward acceleration or sustained high rate of turn. None of these features was observed by the witnesses. Disconnection of the control input to a blade would almost certainly result in severe rotor vibration and loss of control in forward flight, and whilst this would be consistent with what is observed in the last 5½ seconds of the recording it does not explain the previous 8 seconds of persistent rotor rpm decay without any apparent vibration.

The damage to the main rotor indicates that one of the blades suffered only failures consistent with water strike. The second blade had been severely damaged as a result of striking the helicopter structure. Of the two rotor strikes on that blade, the rearmost, on the tail-boom at the stabilizer is consistent with it occurring when the rotor and mast were still attached to the airframe but with the rotor flapped back about twice as far as the normally permitted maximum. Since there is no evidence of any other blade strike on the tail boom at a smaller flapping angle, particularly on the tail rotor driveshaft fairing, this implies that the rate of rotor flap back was exceedingly high. With a blade passing frequency of between 10 and 12 per second, it appears unlikely that the necessary rate or degree of flap back could be achieved by a control input, it is most probable therefore that this occurred during the impact sequence.

The other main rotor strike, which occurred at the junction of the tail boom with the rear fuselage, is only consistent with it having been made with the rotor detached from the helicopter and its axis of rotation displaced about 80° with respect to its normal orientation in the helicopter.

Combining the witness evidence that the rotor was seen to strike the tail boom at the moment the aircraft struck the water, with the damage features observed on the main rotor blades, it appears most likely that the rotor was flapped back as a result of the less damaged blade striking the water in the forward right quadrant of the disc and being crippled upwards near its root. The forces generated by almost simultaneous blade strikes on the water and tail boom would be likely to be sufficient to cause failure of the main rotor gearbox between the support casing and the epicyclic housing and induce violent teetering oscillation leading to failure of the mast at the rotor head.

The possibility of a single blade sustaining airborne damage as a result of failure or disbonding of the afterbody was considered. Such damage could have been overlaid and masked by the subsequent strikes on the helicopter structure. However, any airborne damage to one blade would have resulted in a once per revolution vibration (1R). This frequency is outside the lower limit of the voice recorder capability but it has been demonstrated during the flight test conducted by the operator that a significant 1R vibration causes amplititude modulation of a detectable frequency and this feature is not observed on the recording from G–BJJR. This evidence, combined with the symmetric contact by the main rotor head on the mast produced during the violent teetering oscillation, suggests that the possibility of gross damage to a single blade leading to main rotor instability and loss of control can be discounted.

2.4 Flying controls

The examination of the flying controls mechanical linkage revealed no evidence of any pre-impact failure between the pilot's controls and the output from the scissors assembly. It was apparent that the controls on the rotor head itself had suffered severe damage as a result of impacts with the upper structure of the helicopter after the mast had separated, and although no evidence of pre-impact failure was detected in this zone it must remain a possibility that evidence of such a failure may have been overlaid and destroyed.

Similarly, examination of the hydraulic system including the primary flying control servos revealed no evidence of pre-impact faults. The presence of 5% kerosene in the fluid samples is difficult to explain as post-accident ingress into closed containers. The absence of a reservoir sample precluded determination of whether this contamination was general throughout the system. It is, however, generally believed that this degree of contamination would at worst lead to a gradual degradation of seals in the system, and no evidence for this was found.

The position of the Helipilot servos is indicative that this system was operating up to a late stage in the flight. It was not possible to determine the mode in which the system was last operating, but in all modes it will basically attempt to restore the helicopter to its last stable state if an uncommanded deviation should occur. In this sense the positions of the roll and yaw servos appear reasonable. However, since the structural deformation of the forward fuselage is indicative of a nose down attitude at impact, the position of the pitch servo, giving a nose down command, is apparently contrary to what would be expected. The operator has suffered four reported Helipilot malfunctions (one occurring on G–BJJR) in which there were violent oscillating fluctuations of the servos in one or more axes. All these incidents had occurred in daylight but none the less caused serious control difficulties. Although the system has limited authority, an oscillating malfunction could lead to severe control difficulties and the absence of a Helipilot disconnect switch on either cyclic or collective control columns would make disengagement difficult whilst trying to maintain control at a low altitude.

The fact that the Bell 212 Sperry Helipilot installation does not include a dis-engagement switch on the cyclic control as normally required by British Civil Airworthiness Requirements suggests that the system was certificated on the basis that any failures would result in only a "Minor Effect". The four cases of Helipilot malfunction detailed in 1.17.2 show clearly that serious handling difficulties were encountered and graphically demonstrate the need for an autopilot dis-engagement switch on the cyclic control.

Nevertheless, when related to the accident to G–BJJR it is difficult to conceive of an autopilot malfunction that would generate such a large power requirement that it would result in a persistent decay in rotor rpm and culminate in a sudden and complete loss of control.

The absence of any evidence of failure in the rotor, transmission or flight control systems, despite exhaustive examinations, has led to an inability to determine the cause of the accident. The fact that most of the understanding of the accident sequence came from information derived from the cockpit voice recording, highlights the importance of this system. However, the investigation would have benefitted from more direct systems information such as would be provided by a dedicated flight data recorder. Crash protected data recording systems are currently under discussion for helicopter installation to complement the cockpit voice recorder.

Accidents, such as the one to G–BJJR, serve to stress the importance of expediting the requirement for flight data recorders to be fitted to helicopters engaged in public transport operations.

3. Conclusions

(a) *Findings*

(i) The helicopter had been maintained in accordance with an approved maintenance schedule and its Certificates of Airworthiness and Maintenance were valid at the time of the accident.

(ii) The crew were properly licenced and adequately experienced to conduct the flight.

(iii) The helicopter had been correctly loaded and its centre of gravity was within prescribed limits.

(iv) Weather was not a factor in the accident.

(v) Control of the helicopter was lost following a decay in rotor rpm while both engines were delivering full power.

(vi) The cause of the rotor rpm decay and the subsequent loss of control could not be determined.

(b) *Cause*

The cause of the accident could not be determined.

4. Safety Recommendations

It is recommended that:

4.1 The Civil Aviation Authority review the Sperry " Helipilot" installation in the Bell 212 to ensure its compliance with British Civil Airworthiness Requirements Chapter G6–4, in respect of an autopilot disconnect switch on the cyclic control.

4.2 The Civil Aviation Authority should require that helicopters operated in the transport category (Passenger) should be equipped with flight data recorders.

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