Air Accidents Investigation Branch

Department of Transport

Report on the accident to Bell 214 ST G-BKFN in the North Sea 14 miles North East of Fraserburgh, Scotland on 15 May 1986

LONDON
HER MAJESTY'S STATIONERY OFFICE

First published 1988

ISBN 0 11 550846 5

List of Aircraft Accidents Reports issued by AAIB in 1987/88

1/87	Bell 212 G-BJJR in the North Sea, 50 miles East of the Humber November 1984	April 1987
2/87	Lockheed TriStar G-BBAI at Leeds Bradford Airport May 1985	September 1987
3/87	Gulfstream Rockwell Turbo Commander EI-BGL at Jevington, Eastbourne November 1984	July 1987
4/87	Twin Otter G-BGPC at Laphroaig, Islay, Scotland June 1986	December 1987
5/87	Boeing Vertol (BV) 234 LR G-BISO in the East Shetland Basin of the North Sea May 1984	January 1988
6/87	Shorts SD3-60 EI-BEM 3.5 km from East Midlands Airport January 1986	January 1988
7/87	Twin Squirrel G-BKIH Swalcliffe, Nr Banbury, Oxfordshire April 1986	
8/87	Boeing 747-136 G-AWNB London (Heathrow) Airport November 1986	
9/87	Bell 214 G-BKFN in the North Sea, 14 miles North East of Frazerburgh, Scotland May 1986	
I/88	DH 89A Dragon-Rapide G-AGTM at Duxford Airfield, Cambridge June 1987	

BELL 214ST G-BKFN SHORTLY AFTER DITCHING
14 NAUTICAL MILES NORTH EAST OF FRASERBURGH

(Photograph courtesy of R.Tonge Esq.)

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

31 December 1987

The Right Honourable Paul Channon
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr K P R Smart, an Inspector of Accidents, on the circumstances of the accident to Bell 214 ST G-BKFN, which occurred in the North Sea 14 miles North East of Fraserburgh, Scotland on 15 May 1986.

I have the honour to be
Sir
Your obedient servant

D A COOPER
Chief Inspector of Accidents

Contents

Page

Air Accidents Investigation Branch

Aircraft Accident Report No 9/87

(EW/C967)

Registered Owner and Operator:		British Caledonian Helicopters Limited
Aircraft	Type:	Bell
	Model:	214 ST
	Nationality:	United Kingdom
	Registration:	G-BKFN
Place of accident:		In the North Sea 14 miles north east of Fraserburgh, Scotland Latitude 57° 52'N Longitude 01° 42'W
Date and time:		15 May 1986, 11.00 hours All times in this report are UTC.

Synopsis

The accident occurred during a flight from Sumburgh in the Shetland Isles to Aberdeen. A partial loss of collective control resulted in the crew being unable to maintain height and the helicopter was forced to ditch 14 miles north east of Fraserburgh, Scotland. The crew and passengers were able to evacuate safely and were picked up by a fishing vessel that was in the area. The helicopter was subsequently recovered and taken to the operator's base at Aberdeen.

The report concludes that the accident was caused by the fatigue failure of a locking plate on the collective hub assembly following the loss of torque loading on the collective hub retaining nut. This allowed the nut to lose engagement and resulted in the partial loss of collective control.

1. Factual Information

1.1 History of flight (refer Appendix 1)

On 15 May 1986, Bell 214 ST G-BKFN was scheduled to fly a routine, four sector personnel change flight for British Petroleum (BP) to the Magnus Oil Field, routing via Sumburgh on both the outbound and return journeys.

The flight, callsign "Caledonian 40 November" (40N) was entirely normal for the first three sectors. The helicopter departed Sumburgh for Aberdeen on the last sector at 09.55 hrs with the co-pilot as the handling pilot. The route to Aberdeen was below the Lower Air Traffic Service Advisory Route, White 5 (DW5) at 2500 feet and the estimated time of arrival (ETA) at Aberdeen was 1117 hrs. The helicopter passed the reporting point 'Beket' at 1026 hrs and was identified by Highland Radar (on 134.1 MHz) at 1030 hrs. Eleven minutes later it was instructed to cross the reporting point at a range of 50 nautical miles (nm), established from the Distance Measuring Equipment (DME) Aberdeen, at 2000 feet on Track Echo. This was acknowledged and a slow en-route descent was commenced.

As the co-pilot was about to level at 2000 feet, a sudden jolt was felt throughout the aircraft. With no instrument indications of any malfunction the commander took control, rapidly assessed that there had been some form of failure in the collective control system, and instructed the co-pilot to transmit a distress message.

At 1044 hrs a distress message was transmitted on the Highland Radar frequency. The message from the crew included the information that they had a control malfunction, were maintaining flight and reducing speed. They passed their position as on the 032° radial from Aberdeen at 47 nm DME. This was acknowledged by Highland Radar with a request to "squawk" 7700* and this was complied with.

On hearing the distress call a Bristow helicopter, callsign "53 Charlie" (53C), some 20 nm to the east of "40N" also inbound to Aberdeen, immediately turned and headed towards the distressed aircraft assisted by vectors from Highland Radar.

By cautiously moving the collective control the commander discovered that although he could lower the lever and increase the rate of descent, he was unable by raising the lever to increase collective pitch beyond the existing setting which was equivalent to a combined engine torque of about 40%. This was insufficient to maintain level flight and eventually it was found that an indicated airspeed (IAS) of 60-70 knots (kt) allowed the rate of descent to be minimised at 100-200 feet per minute.

*Standard international radar transponder distress code

At 1046 hrs "40N" passed its speed to Highland Radar as 70 kt and reported that the malfunction appeared to be in the collective control system with reduced collective pitch authority. The commander then stated his intention of landing at Longside Airfield if possible. At 1048 hrs Highland Radar maintained radar contact with "40N" at a range of 50 nm DME on Track Echo but "40N" then reported that they were losing height slowly and might not make the coast. A minute later the commander confirmed to Highland Radar that the problem appeared to be a "fixed pitch collective" and that the aircraft was descending through 1000 feet.

The passengers who had already been briefed on the situation were now instructed to don their lifejackets in preparation for a possible water landing.

At 1052 hrs "40N" reported descending below 700 feet and gave their position as on the 034° radial from Aberdeen at 47 nm DME. At the same time another Bristow helicopter inbound to Aberdeen on a similar track, callsign "72 Alpha" (72A), which had been orbiting 36 miles from Aberdeen awaiting instructions, was vectored towards "40N" and located it visually at a range of 8 miles.

At 1054 hrs, shortly after "40N" reported being down to 500 feet and heading for land, "53C" made visual contact and "72A" joined the distressed aircraft. Three minutes later "40N" reported that they were down to 200 feet and unlikely to make the coast which was still some 16 nm away.

At 1059 hrs an RAF Shackleton aircraft vectored to the scene reported that he had identified the distressed aircraft on his radar.

The co-pilot gave the passengers their final instructions, the commander completed the pre-ditching drills and turned the helicopter into wind and, at 1100 hrs, reported that they would be ditching in 30 seconds. The commander briefed the co-pilot that he intended to flare off the approach speed so that the water landing could be made at zero forward speed into the 10 kt north westerly wind slightly across the light swell. During the ditching sequence the co-pilot called out radio altimeter heights and a successful ditching was carried out.

At 1102 hrs "72A" reported that "40N" had ditched, was upright and that the passengers were evacuating successfully. Subsequently "72A" informed Highland Radar that they had diverted a nearby fishing vessel to pick up the survivors.

At 11.11 hrs all survivors were reported to be in life rafts and by 1118 hrs they were onboard the fishing vessel "Constant Friend" which then returned to Peterhead.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor/None	2	18	-

1.3 Damage to aircraft

The damage to the helicopter that initiated the control malfunction was restricted to the collective sleeve and hub assembly in the primary flying controls. Subsequently, the helicopter received minor damage during the ditching sequence. The forward compartments of the floatation bags on both sides of the helicopter were punctured, there was minor hydrodynamic wrinkling of the belly panels, and the transparency above the co-pilots head had shattered as the helicopter alighted on the water. The left hand crew door which was jettisoned after the ditching was not recovered. Additionally a number of electrical components were damaged as a result of seawater immersion.

1.4 Other damage

None.

1.5 Personnel information

Commander:	Male, aged 38
Licence:	Airline Transport Pilot's Licence (Helicopters) valid unitl 23 April 1988.
Helicopter type ratings:	Bell 214ST Sikorsky S61N
Instrument rating:	Renewed 11 April 1986
Medical certificate:	Class 1 valid until 1 June 1986
Certificate of test:	Bell 214ST 20 April 1986
Emergency and survival drill:	20 April 1986
Wet dingy drill:	13 January 1986

Flying experience:

Total all types:	5160 hours
Total helicopter:	5085 hours
Total Bell 214ST:	1658 hours
Total flying during previous 28 days:	32 hours

Duty time:	Off duty		9-12 May
	On duty	0900-1430	13 May
		0500-1245	14 May
		0430-	15 May

Co-pilot	Male, aged 41
Licence:	Airline Transport Pilot's Licence (Helicopters) valid until 16 June 1987
Helicopter type ratings:	Bell 47 Sikorsky S61N Bell 214ST
Instrument rating:	Renewed 4 August 1985
Medical certificate:	Class 1 valid until 1 October 1986
Certificate of test:	Bell 214ST 17 January 1986
Emergency and survival drills:	15 July 1985
Wet dinghy drill:	13 January 1986

Flying experience:

Total all types:	5700 hours
Total helicopter:	5656 hours
Total Bell 214ST:	503 hours
Total previous 28 days:	68 hours

Duty time:	Off duty		12 May
	On duty	0900-1645	13 May
		0900-1630	14 May
		0430-	15 May

1.6 Aircraft information

1.6.1 Leading particulars

Manufacturer	Bell Helicopter Textron
Type	Bell 214ST
Date of Manufacture	August 1982
Constructor's number	28109
Registered owner	British Caledonian Helicopters Ltd
Certificate of Airworthiness	UK Transport Category (Passenger) valid until 28 October 1986
Maintenance	A Certificate of Maintenance Review had been signed on 3 April 1986 valid for 4 months
Last 1250 hour inspection	5 May 1986 at 4660.05 airframe hours
Last 25 hour check	13 May 1986 at 4707.45 airframe hours
Total airframe hours at time of accident	4725.55 hours
Maximum weight authorised	17,500 lbs
Estimated weight at time of accident	16,344 lbs
Estimated Centre of Gravity (CG) at time of accident	Within Flight Manual Limits

1.6.2 Collective sleeve and hub assembly (Refer Appendix 2)

The collective sleeve and hub assembly is mounted on the main rotor mast below the rotor head. Its function is to transfer the pilot's collective control inputs to the main rotor blade pitch change links.

The assembly consists of two main components; the non-rotating collective sleeve and the rotating collective hub.

The hub is attached to the top of the collective sleeve by means of a thrust bearing. This consists of a matched set of five bearings, the bearing surfaces being etched with numbers and V marks to provide correct bearing installation. The inner race of the lowermost bearing rests on a shoulder on the sleeve and the inner race of the top bearing bears against the sleeve nut. The sleeve nut when tightened (on a left hand thread) to a torque of 350 to 450 foot pounds, securely clamps the complete stack of inner races. Between the maximum and minimum torque values, holes in the sleeve and nut become aligned during assembly to allow installation of a securing pin.

The bearing outer races are clamped between a spacer located beneath the flange at the top of the hub, and the hub nut at the bottom. The hub nut has a right hand thread and is tightened to a torque of 400 foot pounds. A locking plate and spacer assembly is attached to the underside of the hub by means of Allen screws such that the locking plate tangs engage with two adjacent castellations in the hub nut. During assembly, the hub nut torque may have to be increased to allow proper engagement of the serrations in the mating surfaces of the locking plate and spacer: however the maximum torque value should not exceed 500 foot pounds. Finally, the Allen screws are secured with locking wire.

There are two bearing seals; the upper one being recessed within the hub flange and the lower one being pressed into the hub nut. Grease is applied to the bearing assembly through two grease nipples in the hub, 180° apart.

The assembly instructions, which are contained in the Bell Component Repair and Overhaul Manual, call for corrosion preventive compound to be applied to the mating surfaces of hub and sleeve nuts prior to assembly.

1.6.3 Component history of scissors and sleeve assembly

The maintenance records for G-BKFN show that the scissors and sleeve assembly, part number 214-010-501-103, serial number A-25, was installed on the aircraft on 29 August 1985 at 3421.45 airframe hours, *ie* some 1300 hours before the accident.

During 1985 the manufacturer had identified a hydrogen embrittlement problem with the collective sleeve. This culminated with the issue in February 1986 of Alert Service Bulletin (ASB) No 214-86-33 which introduced a modified collective sleeve. This was effected on G-BKFN on 25 April1986 some 110 hours before the accident. Changing the sleeve entailed removing the hub; however, this was achieved simply by removing the sleeve nut and lifting the hub, complete with bearing set, seals and hub nut off the sleeve. It was not necessary to disturb the hub nut or the locking plate.

During a daily check on 7 May 1986, a quantity of black grease was seen to be discharging from the bearing area at the top of the collective sleeve. According to the relevant work card, the action taken was: "Pitch links disconnected at upper end. Drive plate disconnected from sleeve. Bearing checked for serviceability, purged and turned. Drive plate and pitch links reconnected". Following this a Duplicate Inspection was carried out.

1.6.4 Emergency exits (refer Appendix 3)

Normal access to the passenger compartment is via a hinged forward door and sliding aft door on either side of the fuselage. An emergency jettisonable (pop-out) plastic window is installed in each hinged door and the forward end of each sliding door.

A hinged door on either side of the forward fuselage permits access to the crew compartment and these may be jettisoned by pulling the appropriate door jettison handle.

The rearmost windows on each side of the cabin are designated "secondary exits". The Bell 214ST aircraft were supplied to British Caledonian Helicopters (BCHL) with standard, non-jettisonable rear windows. Following consultations with the manufacturer, a Minor Modification was embodied in 1983 which gave the rear seat occupants increased shoulder room. This resulted in new rear windows, the rear edges of which protruded outside the fuselage profile.

In October 1985, the CAA issued a Mandatory Direction to operators (applicable to all helicopters operated over water) under what was then Article 12/3 of the Air Navigation Order, stating that "All openings in passenger compartment agreed by the Authority as suitable for the purpose of underwater escape shall be so equipped as to be openable in an emergency". This Direction followed a series of meetings of the North Sea Helicopter Operators Technical Committee, of which BCHL and the CAA were participants. Although the rearmost windows did not comply with the requirements for Emergency Exits, BCHL were advised by the manufacturer that approximately 70 pounds force were required to push them out. Thus these windows became designated as "secondary exits", without additional modification, and were placarded with the instruction to "push hard in corners". No push-out trials were ever conducted however.

It should be noted that these windows do not lend themselves to the same pop-out design as the other windows, as the aerodynamic suction forces on this part of the fuselage are considerably higher. There would thus be an attendant risk of the windows detaching in flight.

The exits are individually identified by an Exit Emergency Lighting System (EXIS), powered by a self-contained water-activated alkaline battery.

1.6.5 Emergency floatation equipment (refer Appendix 3)

The emergency floatation equipment consists of three black coloured float bags, pneumatic bottles and plumbing for inflation, and an actuation mechanism. One float is mounted on the tailboom and one six compartment float is mounted on the left and right fuselage passenger step. The floats inflate automatically when the EMERG FLOATS switch on the collective switch box is ARMED and the water float switches are submerged. The Emergency Floats may be deployed manually by the EMERG FLOATS PULL handle if the electrical actuation system fails.

1.6.6 Safety equipment

The helicopter contained the following items of safety and survival equipment:

(i) Inflatable life rafts

Two RFD Aviation reversible Type 14R Mk 1 14-man Helirafts are mounted in the forward fairing on top of the cabin roof. The rafts are normally launched by manually pulling a 'D' ring located under the placarded breakaway cover, aft of the pilot's overhead console. This actuates a pneumatic system which causes the liferaft valises to be ejected from the compartment.

The rafts are tethered to the helicopter by one long mooring line and one short firing/mooring line which provides automatic/semi-automatic inflation on deployment. Alternative access to the rafts is by manually opening the external cabin roof stowages by rotating individual emergency latch handles on the rear lower face of the fairing. The decals indicating liferaft stowage and instructions for manual deployment are located adjacent to the handles in approximately 1/4 inch lettering. Each raft carries an Emergency Survival Pack.

The maintenance manual calls for a six monthly functional check of the liferaft deployment system. The stated method is to manually open the liferaft doors, secure them in the raised position, and to remove the valises. The pneumatic system is then operated and the satisfactory inflation of the ejector bags is checked. There is no specific instruction to return the handles (and hence latch

mechanism) to the closed position. Unless this is done the system design is such that the pneumatic actuator does not move the handle or latch.

(ii) Lifejackets

Both pilots were wearing the Beaufort Air Sea Equipment Ltd Mk 28 lifejacket.

The passengers were wearing RFD Aviation Mk 2 BA Helijackets.

(iii) Immersion suits

The commander was wearing an Albatross International Clothing Muskox immersion suit under a company flying overall. The co-pilot was wearing a Beaufort Ltd Mk 1 immersion suit under his company flying overall.

All the passengers were wearing Beaufort Ltd 'Transuits' supplied by British Petroleum.

1.7 Meteorological information

Synoptic situation

A depression North West of the Shetlands was moving away North Eastwards. A second depression centred 120 nm East of Edinburgh was moving Northwards. A light unstable Northerly airflow covered the relevant area.

Forecast

A North Sea Rig Area Forecast issued by the Meteorological Office for the period 0500 to 1300 was used by the crew for flight planning.

Wind: 500 ft - variable 10kt, 190°/20 kts in East at first, temperature +6C

2000 ft - variable 10 kt 200°/20 kts in East at first, temperature +6C

Visibility: 25 Km but 8 Km in showers

Cloud: 3 oktas cumulus base 2500 ft top 7000 ft becoming in showers 7 oktas cumulus base 1500 ft top 13000 ft.

1.8 Aids to navigation

The aircraft was fully equipped for Instrument Flight Rules (IFR) operations in the North Sea. The Global Navigation System (GNS) 500 Series 3 Omega was being

used to position the aircraft along Track Echo on DW5 while an Automatic direction finder (ADF) was tuned to Scotstown Head beacon on 383 KHz.

1.9 Communications

On passing the 'Beket' reporting point at 1026 hrs the aircraft contacted Highland Radar on 134.1 MHz and remained on that frequency until it ditched.

Immediately after the distress message, on instructions from Highland Radar, the aircraft transponder was selected to Squawk 7700. Communication with the Shackleton S.A.R. aircraft and the accompanying Bristow helicopters was maintained on 134.1 MHz and the Search and Rescue (S.A.R.) helicopter from Lossiemouth joined the frequency at 1112 hrs.

1.10 Aerodrome and approved facilities

Not relevant.

1.11 Flight recorders

The helicopter was fitted with a Fairchild A100 four track Cockpit Voice Recorder (CVR). This used plastic based magnetic tape as a recording medium and was of the endless loop type of recording with a duration of 30 minutes.

The track allocation was as follows :-

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

The CVR equipment was serviceable and a satisfactory replay was obtained.

1.12 Wreckage and impact information

1.12.1 Salvage

After the successful evacuation of the crew and passengers the helicopter remained afloat and during the late afternoon G-BKFN was lifted on to the oil supply vessel "Seaforth Emperor". The forward compartment of each fuselage floatation bag had deflated; as the aircraft was lowered onto the deck, these were deliberately ripped open to release the accumulation of sea water. Freshwater was then played on the aircraft in an attempt to minimise the effects of sea water immersion.

The aircraft was off-loaded at Peterhead, from where it was taken by road to British Caledonian's hangar at Aberdeen and liberally treated with dewatering fluid to prevent corrosion.

1.12.2 Subsequent detailed examination

The aircraft was initially examined at the operator's maintenance facility at Aberdeen. Components from the collective hub and sleeve assembly together with the liferaft housing doors and liferaft deployment cable were removed for further examination at AAIB's facility at Farnborough and later at Bell Helicopter Textron, Fort Worth.

1.12.2.1 Main rotor controls

It was quickly established that the primary cause of the collective pitch control problem was that the collective hub nut had become unscrewed from the hub. Both tangs of the locking plate that retained the nut had fractured and were not recovered. The remainder of the locking plate and spacer assembly had been retained on the hub by the two Allen screws. (Refer Appendix 4(a)).

The nut had fallen out of the lower end of the hub and was lying on the rubber gaiter located beneath the hub assembly. In this condition the hub could not transmit the thrust (vertical) loads arising out of the pilot's inputs: i.e. an increase pitch demand would pull the collective sleeve plus the bearing stack downwards out of the hub, thereby leaving the hub behind. The total range of vertical movement of the sleeve was less than the height of the bearing stack, thus the bearings (the inner races of which had remained secured by the sleeve nut) had not been pulled completely clear of the hub.

The inside of the hub had suffered some light grooving and scoring, which was indicative of the bearing outer races having been spinning within the hub.

Evidence of rotation was also visible on the outer faces of the bearings, as were small areas where fretting had occurred between the bearings and hub.

An area of cadmium plating on the shoulder of the collective sleeve had been worn away. Inspections of collective sleeves from other aircraft showed this to be typical and was in fact due to light contact between the non-rotating shoulder and the skirt of the grease seal in the rotating hub nut. It was observed that the frictional force so generated applied a torque to the nut in an unscrewing direction. A similar removal of cadmium plating had occurred on the sleeve nut, with the seal at the top of the hub being responsible. The seal had in fact become displaced slightly, such that part of its circumference protruded below the flange. In this condition, the upper bearing could not seat squarely on the flange, although when the hub and bearing were subsequently reassembled, the seal readily adopted its correct position.

Some thread damage on the hub nut had occurred due to the thread crests contacting the inner edge of the locking plate when the nut was unwinding. Also a strand of locking wire securing the Allen screws was broken, the appearance of this, plus a mark on the remaining strand strongly suggesting that this was caused through contact with the nut threads. Some light "chatter marks" on the threads tended to support this view. It was clear that considerable slippage had occurred between the bottom bearing outer race and the face of the nut, as a step of approximately 0.003 inches had been worn in the latter.

Dimensional checks were made on the nut and bearings, together with concentricity checks on the bearings. All measurements conformed to the drawing requirements.

No other defect was found in the rotor controls.

1.12.2.2 Locking plate assembly

The locking plate assembly comprising the upper and lower locking plates, was subjected to a metallurgical examination.

Rub marks on the flanks of the serrations showed that when the Allen screws had been tightened down, and the serrations of the upper and lower locking plates were forced into engagement, the tangs were pushed against the edges of the castellations in the nut in a direction which applied an unscrewing torque to the nut. Fretting marks were visible on the edges of the two adjacent castellations with which the tangs had been engaged. These showed that the tangs had been positioned about halfway down the depth of the castellations.

A total of seven cracks and fractures were observed on the locking plate, and these are detailed in the diagram at Appendix 4(b). Fatigue origins were identified in the fillet radii of the sides of the tangs that had been in contact with the edges of the castellations at assembly. Fatigue and/or overstress was identified in most of the remaining fractures, the origins being predominantly in the bottoms of the serrations.

A curious feature was the presence of a number of small (0.011 to 0.018 inches diameter) balls of metal in the bottom of the grooves inboard of the slot. Some had left indentations in the crests of the serrations in the mating part.

The hardness of the locking plate was measured as Rockwell 'C' 37, and was thus within the drawing requirements of between 36 and 40.5.

1.12.2.3 Liferaft deployment system (refer Appendix 5)

It was found that the linkage connected to the crew actuation handle had been operated, and the gas bottles had discharged. However, it was discovered that the door latch operating cable had failed down-stream of the gas operated actuator. The failure had occurred within the steel tube where the cable splits into two, allowing the broken end to pull out of the tube. A slider is located within the tube, with two cables emerging from it on the downstream side, and the single cable (the other end of which is attached to the gas actuator rod) emerging from the upstream side. The latter cable had failed approximately 0.5 inches from the slider. The failure seemed to be associated with a change of stiffness where the cable had been treated with a flux-like compound close to its brazed attachment to the slider. A metallurgical examination of the cable revealed that the failure was due to overload.

The liferaft compartment doors did not appear to have suffered any distortion. However, the panel that covers the central portion of the compartment had been considerably distorted as a result of pressure generated by the ejector bags. There were a few fragments of a plastic material found within the compartment, these were subsequently identified as being from a liferaft valise. The right hand ejector bag was found to have a small slit in it which most probably was caused by a sharp edge of broken valise material.

It was observed that the liferaft compartment door handles were very stiff in operation. When the latch operating mechanism was disconnected, there was little discernible difference; it was thus clear that the source of friction lay within the handle spigots. The latch linkage is connected to a bellcrank on the rear of the handle spigot by means of a flat-headed pin. On the left hand door, inadequate clearance between the pin and a false skin inside the door had resulted in fouling between the two, as evidenced by an area of exposed metal on the skin where the paint had been scraped away. However, the amount of friction this would have contributed to the system was assessed as small compared to that due to the handle spigots.

1.12.2.4 Crew doors

The captain had been unable to jettison the right hand crew door despite pulling hard on the T-handle. As found, the door was jammed in a half open state due to a buckled door stay. This is in fact a gas-filled strut, and it was considered probable that it became buckled after the ditching due to the action of a wave pushing the door rapidly towards the closed direction.

1.12.2.5 Emergency floatation equipment

The emergency floatgear had functioned satisfactorily, although as noted at Section 1.12.1, the forward compartment of each fuselage float had deflated. It was clear that the left hand float bag had suffered a puncture as a result of abrasion on a stringer that mounts the aerodynamic fairing forward of the float bag pack. The fairing, which is made of glassfibre had been crushed and fragmented as the front part of the float bag was pushed forwards out of its stowage during the inflation process. As part of the fairing fell away, this had exposed the mounting stringer which has tab-like protuberances along its length, through which pass the fairing attachment screws. (Refer Appendix 6). The impressions of the tabs could be clearly seen in the bag material.

Although some abrasion damage was visible on the right hand fuselage floation bag, it had not resulted in a puncture. It was thus not obvious what had led to the deflation. It is possible however that the material may have been cut by a fragment of glassfibre fairing (none of which remained on the right hand side.) or perhaps by the bottom corner of the crew door, the cut being subsequently exploited when the bag was deliberately ripped open during the salvage.

The aft fairings on the fuselage floatation backs had also been crushed and partially fragmented by the inflating bags, although not to such an extreme as those at the front. They had not caused any apparent damage to the bags.

The aft floatation bags had remained fully inflated until they were deliberately deflated after the aircraft had been recovered to Aberdeen.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Not applicable.

1.15 **Survival aspects**

1.15.1 Evacuation

As the helicopter ditched the commander closed the throttles and pulled the 'manual' floatation release handle. The floatation bags inflated correctly and the aircraft floated upright in a stable position on the water but slowly turning to the left. When the aircraft was pointing downwind the engines were stopped, and first the co-pilot and then the commander attempted to release the liferafts from their external stowages by pulling the "D" ring in the cockpit roof. All their attempts were unsuccessful.

The passengers were instructed to push out their emergency windows and although they had been briefed to remain seated after jettisoning them, as water entered the aircraft, up to a reported depth of 12 inches in the rear of the cabin, some passengers on the right hand side started to leave the aircraft and jump into the sea. The passengers in the last seat row on either side of the aircraft were unable to "push out" their adjacent secondary escape windows and had to use other exits.

As the aircraft moved downwind the commander saw the first passengers drift out towards the rotor disc and he was forced to apply the rotor brake, which caused the aircraft to rotate a further 180° back onto its initial heading into wind. One pasenger reported that on exiting on the right hand side he slipped off the floatation bag and found himself drifting towards the still rotating tail rotor. He dived under the tailboom and eventually surfaced on the left hand side of the aircraft where he swam around to the liferaft. Ten passengers in all entered the sea via the right hand main door.

The co-pilot jettisoned the left crew door but the commander was unable to jettison his door, however, he was able to open it using the normal handle. When the commander left the cockpit he opened the exterior liferaft stowage on the righthand side, deployed the liferaft, and pulled the manual inflation line. On the left side however the co-pilot was unable to get to the liferaft stowage as a number of passengers were already standing on the floatation bag. He therefore directed a passenger to the liferaft stowage release handle above the cabin roof. This powerfully built passenger had great difficulty in turning the handle but finally when on the point of giving up, turned it, and released the liferaft from its stowage allowing it to inflate automatically. All eight passengers and the co-pilot who exited on the left side were able to step into the liferaft over the floatation bags. After recovering the one passenger in the water on that side the co-pilot released the mooring line from the aircraft.

On the right hand side the commander boarded the liferaft, cut it loose from the aircraft, and with the help of three passengers already onboard paddled over to pick up the remaining survivors who had drifted away about thirty yards. Five of the six survivors remaining in the water were assisted into the liferaft via the boarding ramps and the sixth was helped in over the side. Although no injuries were reported, a number of passengers complained that their immersion suits had leaked.

The helicopter remained in a stable position with the rotor blades athwartships even though the forward cell of each main floatation bag was punctured.

1.15.2 Search and rescue

Immediately following the transmission of the distress message a Bristow helicopter callsign "53C", 20 nm to the east, turned to intercept "40N" which was under Highland Radar control. The other helicopter callsign "72A" 36 nm north east of

Aberdeen was instructed to orbit by Aberdeen Air Traffic control (ATC) to await developments.

When"72A" was vectored to the scene at 1051 hours it gained visual contact one minute later. "53C" gained visual contact at 1100 hours and both helicopters remained with "40N" until the survivors were safely on board the fishing vessel the 'Constant Friend'.

An RAF Shackleton aircraft diverted to the scene by the Northern Rescue Co-ordination Centre quickly identified "40N"from its emergency squawk and overflew the ditched helicopter at 1107. An RAF SAR Sea King took off from Lossiemouth at 1101 and arrived on the scene at 1120 hours. Two RAF SAR Wessex helicopters dispatched from Leuchars at 1107 and 1117 hours respectively were recalled when all survivors had been picked up.

The Shackleton aircraft did not have VHF/FM Marine band radio and was thus unable to speak to fishing vessels seen in the vicinity to request assistance. "72A" which was suitably equipped initially failed to get a response on Channel 16 FM, the Marine distress and calling frequency, and had to fly very close to a nearby fishing vessel to gain its attention. Once communication had been established, the 'Constant Friend' responded expeditiously and all the survivors were transferred from the liferafts and taken to Peterhead.

The Frazerburgh lifeboat was launched at 1109 hours and was initially given a ditching position, also broadcast by Wick Radio, some 25 nm to the east of the actual ditching position. It was later recalled when it became clear that the passengers and crew had been picked up.

1.16 Tests and research

1.16.1 Tests on the collective hub assembly

(a) A trial assembly of the hub assembly from G-BKFN was carried out at the manufacturer's facility at Fort Worth, Texas. (A new nut had to be used, due to the thread damage on the one from G-BKFN). The bearing set was assembled into the hub and the nut torque loaded to 50 foot pounds to ensure proper seating of the bearings, seal and spacer. A reference mark was made on the hub and nut, and the latter was then torque loaded to 400 foot pounds. The circumferential distance between the reference marks was noted, and the nut was then torque loaded to 500 foot pounds (*ie* the maximum value permitted when fitting the locking plate), the amount of nut rotation again being noted. The assembly was left for a few minutes before being check tightened at 500 foot pounds: no further movement of the nut occurred.

The axial movement that corresponded to the nut rotation could thus be calculated. The results are noted below.

Axial movement of nut through one revolution (*ie* thread pitch):	0.064 inches
Axial movement between 50 and 400 foot pounds:	0.0040 inches
Axial movement between 400 and 500 foot pounds:	0.0008 inches

The axial movement is made up of compression of the bearing set plus extension of the hub, the amounts being inversely proportional to the loaded annulus areas (assuming identical values of Young's Modulus for the bearing and hub material). These were:

Hub:	Approximately 0.0007 inches extension
Bearing set:	Approximately 0.0033 inches compression

Thus the bearing set was compressed by a theoretical maximum of approximately 3 thousands of an inch over its depth of 2.5 inches. In reality the amount would be considerably less as no allowance has been made for thread distortion.

(b) Within a few days of the accident to G-BKFN, the manufacturer carried out a trial assembly, on a bench, of a hub and bearing. After the nut was torqued up, the assembly was left overnight. The following morning the nut rotated approximately 0.75 inches (measured at the circumference) when it was check tightened. The reason for the torque loss was not established, although it was assumed that a bedding down process had occurred.

1.16.2 Torque-tension (compression) relationship

Textbooks on industrial fasteners show that the relationship between torque and tension takes the following form:

$$T = \frac{KDW}{12}$$

where T = torque in foot pounds

D = bolt diameter in inches

W = tension in pounds force

K is a friction factor which depends on the bolt/nut material and is also modified by thread form and length of thread engagement. Typical values for K are as follows:-

Material	K
Lubricated steel	0.11
Cadium plated steel	0.15
Plain steel	0.20
Stainless steel	0.30

Most of the applied torque is absored by friction (*ie* thread friction and bearing friction) with only a small amount, in the region of 10% accounting for the tension (or compression) produced.

The above relationship when applied to the collective hub assembly, where the nut diameter (measured at the threads) is 5.75 inches, produces a compressive force in the bearing set of approximately 4200 pounds for K = 0.2 or 7600 pounds for K = 0.11 when the applied torque is 400 foot pounds.

It is noteworthy that a compressive force of 7600 pounds would compress the bearing set by approximately 0.0003 inches, *ie* approximately one tenth of the "apparent" value calculated in Section 1.16.1(a), which, as noted, made no allowance for thread distortion.

1.16.3 Grease analysis

Following the accident, a grease sample from the collective hub of G-BKFN was analysed by plasma emission spectrometry along with samples taken from the remaining three aircraft in the fleet. The hubs are greased at 25 flying hour intervals. The times that the samples were taken relative to the previous greasing are not all known. The results are given below.

Quantities given in milligrammes per kilogram (mg/kg)

	Aeroshell 22c Samples				
Element	**unused**	**G-BKFN**	**G-BKJD**	**G-BMDU**	**G-BKFP**
Iron (Fe)	162	5320	275	341	207
Manganese (Mn)	7	39	4	5	6
Zinc (Zn)	3	72	23	470	97
Copper (Cu)	4	250	65	712	164
Cadmium (Cd)	0	3500	26	88	13
Nickel (Nc)	2	218	3	5	3
Chromium (Cr)	0	596	0	0	0

Fine metallic particles were discovered in the sample from the accident aircraft G-BKFN and to a lesser extent in the sample from G-BMDU. Subsequently the hub nut on G-BMDU was found to be hand tight only.

1.16.4 Liferaft compartment doors: deployment cable pull-off loads

After the accident, British Caledonian measured the cable loads required to open the liferaft compartment doors on the remaining three aircraft in the fleet. A spring balance was applied to the cable downstream of the gas operated actuator, and the loads were as follows:-

G-BKFP	95-100	pounds
G-BKJD	180	pounds
G-BMDU	180	pounds

The cables were replaced with new, lubricated items and the loads reduced to 90-100 pounds in all cases.

A similar test was carried out on the doors plus cable assembly from G-BKFN. A force of 220 pounds was insufficient to move the mechanism.

The latch mechanism was disconnected so that the cable was acting only on the door handles. A force of approximately 150 pounds was required to operate the right handle with the left one disconnected and 70 pounds force was required to move the left handle with the right one disconnected.

The door handle spigots were removed and were found to be coated with a white powdery compound. Chemical analysis revealed this to be a product of corrosion. No evidence of any lubricating compound was found.

With regard to the problem of one of the linkage pins fouling on the false skin of the liferaft compartment door, as observed on G-BKFN, a similar condition was observed on another aircraft during a visit to the manufacturers. Door operation was not noticeably impeded however. The manufacturer stated that there should normally be a 0.077 inch clearance between the pin and skin.

1.16.5 Secondary escape windows

At their engineering base on May 17 1986, two days after the accident, British Caledonian Helicopters demonstrated ejection of the lefthand side secondary esacape window on G-BKFN. Two subjects were seated in the last row on the left side of the helicopter and the one nearest to the window attempted unsuccessfully to push it out by hand, the sealing strip keeping the window firmly in place. Finally by kicking at the lower section of the plastic window a piece broke off and it was then a simple matter to push out the remainder.

1.16.6 Crew door release mechanism

During discussions with AAIB, the manufacturers stated that they considered that the captain's difficulty with the crew door stemmed from a build up of dirt in the mechanism through lack of exercise. In support of this they stated that they had measured the pull-off load at the pilot's handle as 120 pounds. After lubrication and reassembly, the loads reduced to 50 pounds. The load did not alter markedly, regardless of whether the frangible plastic plate was fitted over the external jettison handle.

1.16.7 Liferaft deployment system pressure regulator

The purpose of the pressure regulator is to control the inlet pressure to the gas operated actuator to approximately 400 pounds per square inch (psi), the pressure from the gas bottles being approximately 2000 psi. Pressure regulation is achieved by an internal valve, the position of which is controlled by balancing the inlet pressure acting on a small piston against the outlet (regulated) pressure acting on a larger piston. BCHL had found that by applying shop air, at approximately 110 psi to the actuator, a force of some 80 pounds resulted. This relationship suggested that a pressure of 400 psi ought to give a force of approximately 300 pounds, which would have been unlikely to have been sufficient to break the cable. Accordingly, BCHL engaged the assistance of a local firm to test the regulator. They reported that with an inlet pressure of 2000 psi, the outlet pressure was the same. Clearly, had this situation existed on the aircraft, then a snatch load of approximately 1500 pounds would have been applied to the cable.

It was therefore decided to test the regulator at an approved organisation, in accordance with the manufacturer's acceptance test specification. A spare regulator from stores was also tested in order to provide a comparison. It was found that both regulators performed in an identical manner, with the outlet pressures being approximately 360 psi for an inlet pressure of 2100 psi. The values did not change regardless of whether the outlet pipe was vented or closed off. The regulator from G-BKFN was subsequently disassembled and examined for evidence of corrosion, or any other feature that may have impeded movement of the piston upon which the regulator function depends. None was found.

1.17 Other information

1.17.1 Similar occurrences

(a) In October 1978, a Norwegian registered Bell 214B1 (a single engined predecessor of the 214ST, with the same rotor control components) suffered a loss of collective control whilst in the hover prior to landing. A heavy landing ensued which caused damage to the landing gear. The collective hub nut had become unscrewed and the locking plate assembly had disappeared following the failure of the two attachment screws. The manufacturer was informed and they advised the operator to increase the assembly torque of the collective hub nut from 250 foot pounds to 450-500 foot pounds. In the absence of a repetitive torque check the operator then instigated its own 100 hour torque check inspection, later relaxing the period to 300 hours. In 1981 the component repair and overhaul manual was revised to include the higher assembly torque.

(b) In 1979, a military Bell 214B suffered a loss of collective control while landing at a helipad in southern Oman. The collective hub nut had become unscrewed and the locking plate had fractured in a similar manner to that of G-BKFN.

(c) On April 16 1984, the manufacturer issued Alert Service Bulletin No. 214ST-04-19, which called for inspection of the locking plate assembly for correct installation, and introduced revised attachment screws. The narrative described how collective control of a 214ST was lost with the aircraft on the ground. The collective hub nut had completely unscrewed and the locking plate screws had failed in fatigue due to the locking plate assembly being installed in reverse position, *ie* with the locking plate being sandwiched between the spacer and hub. Mounted thus, the locking plate tangs would have contacted the bases of the castellations in the hub nut, thereby placing a bending load on the screws.

The date and location of the incident were not given.

(d) Following the accident to G-BKFN, the operator checked the collective hub nuts on their remaining aircraft and as noted at Section 1.16.3, one was found to be only hand tight. The locking plate tangs were still present however, although one of them was found to be cracked. A metallurgical examination revealed that this was a fatigue crack, with the origin at a casting defect in the fillet radius.

1.17.2 Previous occurrences to G-BKFN

In August 1985 the aircraft made an emergency landing following the in-flight failure of a main rotor blade drag brace. All the dynamic components were changed before the aircraft flew again. Thus none of the rotor system components discussed in this Report were exposed to the drag brace incident.

1.17.3 Additional problems with the hub assembly

Following the accident the manufacturers issued Alert Service Bulletin 214ST-86-36, part of which called for a 250 hour disassembly and inspection of the hub and bearing components. BCHL have experienced several problems during these inspections: on one occasion the sleeve nut was found to be only hand tight (although the locking screw was still in position) and all five bearing inner races had clearly been spinning on the sleeve. However it had been more common to discover excessive torque loadings when disassembling, with up to 900 foot pounds failing to move the sleeve nut. One assembly was despatched to the manufacturers, as BCHL could not undo the sleeve nut: the manufacturers subsequently had to cut the nut, reporting that it "sprang open (when the cut was made) indicating a considerable pre-load". There was no apparent cause for the excessive torque loading.

BCHL reported that high torque loadings have even been experienced on assemblies that have just been put back together, *ie* prior to re-installation on the aircraft.

The manufacturer stated that no other operator has reported similar problems.

1.17.4 Report of the Helicopter Airworthiness Review Panel (HARP) of the Airworthiness Requirements Board (ARB).

In December 1982 the Chairman of the Civil Aviation Authority (CAA) wrote to the Chairman of the ARB. He suggested that there was a need to review Helicopter Certification standards to ensure that they fully reflected the state of the art in terms of design philosophies, manufacturing techniques and the availability of new materials. In response the Board set up the Helicopter Airworthiness Review Panel (HARP) and in April 1984 its report was submitted to the CAA. The Report contains a section on Helicopter ditching which it considered to be of particular concern to the British helicopter industry operating as it does for long distances near the sea.

It identifies that the frequency of forced landings (and hence, in over water operations, of ditchings) is such that a high probability of survival is essential. To achieve this, the Report goes on to say that the helicopter must have adequate buoyancy, stability, practicable means of escape and effective liferaft equipment. Recommendation No 9 of 15, proposed that draft requirements covering ditching be published at an early date to encourage technical consideration. The draft requirements were published shortly after the issue of the HARP Report.

Analysis

2.1 The flight path

The evidence suggests that co-incidental with the helicopter levelling out at 2000 feet a failure occurred in the collective control system. The commander rapidly and correctly assessed the problem and the co-pilot transmitted a distress message on 134.1 MHz advising Highland Radar of their predicament and passed an accurate position report. As the helicopter continued to fly towards the coast the crew attempted to assess the situation further and found that it was impossible to increase the collective pitch beyond the existing setting. The net result was that the helicopter continued to descend at 1-200 feet per minute at an IAS of 65-70 kts.

The commander originally intended to make a "run-on" landing at Longside airfield near Peterhead but as he was unable to achieve level flight the helicopter was later turned towards the nearest point of land. It was thought that level flight might have been possible at low altitude but when down to 200 feet and still 16 nm from Fraserburgh a ditching became inevitable.

2.2 Ditching

It is clear that the crew made a skilful ditching under limited power and that proper passenger briefings had been carried out. Once on the water the helicopter was found to be stable with the floatation equipment deployed. Although the forward cell of both main floatation bags punctured the helicopter remained upright until it was recovered later the same day.

The HARP Report (see 1.17.4) emphasises that to achieve a high probability of survival the helicopter must have adequate boyancy, stability, practicable means of escape and effective liferaft equipment. In this ditching, buoyancy and stability were good, although not seriously tested in the prevailing conditions. On the other hand, difficulties were experienced in escape and in liferaft deployment which highlighted deficiencies in the overall escape and survival system. It would seem appropriate that the Civil Aviation Authority review the current ditching requirements in the light of this accident.

2.3 Evacuation and survival

Initial attempts to deploy the liferafts failed, for the reasons stated in 1.12.2.3, despite repeated attempts to release them by pulling the "D" ring release handle.

When the order to jettison the emergency exits was given, the primary emergency windows in the cabin doors were pushed out. However, the secondary windows on each side of the rear cabin, labelled "Escape Window", could not be ejected despite the use of considerable force.

On touchdown on the sea a large quantity of water entered the cabin up to a depth of about 12 inches in the rear cabin. This unexpected entry of water probably hastened the departure of survivors on that side who thought that the helicopter was sinking and immediately vacated the aircraft. Current survival training with its emphasis on the likelihood of helicopters overturning soon after ditching may also have been a factor in their decision to enter the sea without instructions. Consequently the survivors who entered the water first drifted out towards the still rotating blades, forcing the commander to apply the rotor brake. This would have assisted the helicopter to rotate further until it finally came to rest pointing into wind with the blades athwartships.

Although the commander was unable to jettison his crew door, he was able to open it by using the normal handle. Once outside the helicopter and standing on the floatation bag he had no difficulty releasing and deploying the starboard liferaft. The co-pilot however could not reach the secondary liferaft release handle on the left side due to the number of survivors standing on the floatation bag and he had to direct the nearest survivor to its location and operation. In this respect the external identification of the stowage and the explanatory legend on operation of the release handle is considered to be inadequate both in size and colour coding. The passenger who tried to open the left liferaft stowage was initially unable to do so as the door handle mechanism had apparently seized. After repeated attempts, and when he was almost on the point of giving up, the handle rotated and the liferaft was deployed and automatically inflated. Had the helicopter overturned it is unlikely that the liferafts would have been available. It would seem prudent that the Airworthiness Authorities involved (CAA and FAA) should consider automatic deployment of liferafts in this circumstance.

The effectiveness of the reversible RFD Helirafts was clearly demonstrated as although each liferaft inflated a different way up it was instantly useable.

Despite recent improvements in passenger immersion suit design and attempts to maintain them to an adequate standard, a number of the passengers complained of water entering their suits. In this instance the loss of insulation due to water ingress did not cause significant body heat loss as the survivors were only in the sea, at a temperature of 8°C, for a short while.

2.4 Search and rescue

The distress call from "40N" was heard by the commander of "53C" who turned to intercept with commendable speed as he clearly understood the meaning of the distress message. The immediate acknowledgement by Highland Radar and instruction to Squawk 7700 was important as will be seen later.

The crew's decision to continue towards land for as long as possible was reasonable in the circumstances in view of the low rate of descent. This progress towards land, albeit slowly losing height, may have misled Highland Radar into believing that the helicopter was under full control and the significance of the distress message may not have been fully appreciated. Consequently an offer from Aberdeen Approach to send "72A" back to the scene was not accepted until some time after the distress call. Similarly when the Maritime Rescue Co-ordination Centre (MRCC) finally alerted the SAR helicopter from Lossiemouth it made an expeditious response to get airborne at 1101 hours but was unable to reach the scene until after the survivors had been picked up.

Fortunately two Bristow helicopters were in the area and one reached and one made visual contact with "40N" before the ditching took place at 1100 hours. It was equally fortuitous that an RAF Shackleton aircraft identified the emergency squawk at a considerable distance and overflew the scene at 1106 hours.

The Fraserburgh lifeboat was not requested until 1109 hours and was then launched with the speed and efficiency that one has come to expect from the RNLI. The error in the ditching position initially passed to the RNLI highlights the need, especially in a multi-agency search and rescue service, to ensure that vital information is always transmitted clearly and accurately. A detailed analysis of the communications during the incident suggested that some confusion existed about the ditching position which was only 14 nm from land and had been identified on radar.

2.5 Primary control failure

2.5.1 Effect of failure

It was clear from the early stages of the investigation that the cause of the loss of collective control was that the collective hub nut had become unscrewed from the hub. The moment the threads came out of engagement, the hub would have adopted a position on the mast consistent with a low main rotor blade collective pitch angle, the blades being driven to this equilibrium position under the action of centrifugal and aerodynamic forces. At the time this occurred, the aircraft was in a cruise descent; thus the blade pitch angle would have been relatively close to the equilibrium position. The jolt felt by the occupants of the aircraft was undoubtedly due to the sufdden, albeit small, lift loss as the blades adopted the new pitch angle, It is fortunate that the event did not occur when a high collective pitch angle was being demanded, for example during take-off from an oil platform. The lift loss would clearly have been far more dramatic, possibly with dire consequences for the aircraft and its occupants.

Once the nut and hub had become disconnected, an increase collective pitch demand would have moved the collective sleeve down the mast, pulling the bearing stack further out of the hub. Lowering the collective lever would have pushed the bearing stack back into the hub until the upper-most bearing contacted the flange at the top of the hub. The hub, and hence pitch links would have then moved to reduce collective pitch. However, this limited control of collective pitch below the equilibrium position would have been of no value to the captain in his predicament.

2.5.2 Failure mechanism

The nut became unscrewed following the failure, in fatigue, of the locking plate tangs. The metallurgical examination of the locking plate concluded that the fatigue failure was the result of oscillatory stresses superimposed on top of an assembly stress. This implies that some relative movement, however small, must have occurred between the nut and hub. Clearly, with an assembly torque of between 400 and 500 feet pounds, no movement can occur. It therefore must be concluded that a torque loss must be a necessary precursor to the fatiguing process. With no assembly torque, the bearing outer races would then, of course, no longer be clamped between the flange at the top, and the face of the nut at the bottom. Rolling friction between the inner and outer races would then encourage the latter to slip (rotationally) relative to the inside of the hub and the nut. Examination of the bearing nut and hub bore revealed that this had in fact occurred with a step of approximately three thousandths of an inch being ground into the face of the nut. The contact forces between the bearing and nut would vary as the collective sleeve moved up and down the mast in response to the pilot's demands. It is considered that the frictional forces thus generated on the nut were the major factor in the fatiguing mechanism of the locking plate tangs.

Once the tangs had become detached, the same, variable frictional forces would act to cause the nut to become unscrewed. In addition, there would have been a constant frictional force between the skirt of the grease seal and the shoulder on the collective sleeve. It was not possible to gain an assessment of the elapsed time between the detachment of the tangs and the nut becoming fully unscrewed.

The reasons behind the loss of assembly torque on the nut are less easily explained. However, it is probable that a clue lies in the high rigidity of the hub and bearing assembly. Even with the nut torque loaded, deflections are very small, with the bearing stack compressed by something of the order of a thousandth of an inch. Indeed torque-tension relationships defined in handbooks on industrial fasteners suggest that the deflection may have been considerably less. Also a variable is introduced by the friction factor between the mating parts, depending on the amount of corrosion preventive compound applied during assembly, or perhaps the degree to which the cadmium plating (which confers a low co-efficient of friction to mating parts so treated) may have been removed during assembly. Thus, thread binding or bearing friction hang-ups would give a high reading on the torque wrench for a comparatively low deflection (compression) of the bearing stack. Any small contaminant particles trapped between bearings, nut, spacer or flange, could, after migrating free, cause the bearing set to "settle" with consequent loss of clamping between the flange and the nut.

Following the accident to G-BKFN, the manufacturer conducted a trial assembly of a collective hub and observed that torque loss occurred overnight without the assembly even being installed on an aircraft. The reason was not positively established, although a bedding down process was assumed to have occurred. It is reasonable to assume that a similar process is even more likely to occur in the high vibration environment of a helicopter. Thus, with the benefit of hindsight there is reason to suppose that a post-installation torque check may have prevented the torque loss from occurring. Since the accident, BCHL have observed loss of torque on both the hub and sleeve nuts, *ie* involving outer and inner bearing races respectively.

During the course of the investigation, a number of earlier incidents came to light which involved the unscrewing of the collective nut and consequent loss of collective control. The manufacturer's response was predominantly concerned with the integrity of the locking plate and its attachment to the hub. However, the locking plate is only designed to retain the nut , as opposed to maintaining the torque. Only after an incident to a Bell 214 in Norway was any attention given to the nut itself. On this occasion collective control was lost whilst the aircraft was in the hover close to the ground. There were no injuries and only minimal damage, thus the incident received no public attention. The manufacturer advised the operator to increase the hub nut torque, although no service bulletin was issued, and the component repair and overhaul manual was not amended to reflect the increased torque value until three years after the incident. The operator instigated its own periodic torque check inspection as a result of the accident. Had the manufacturer issued a Service Bulletin calling for similar action to be taken across the Bell 214 fleet then the accident to G-BKFN may have been avoided.

It was found that grease samples taken from the hub of G-BKFN after the accident contained high concentrations of iron, copper, cadmium, nickel and chromium.

Slippage of the bearing races relative to the hub (or sleeve) would clearly cause particles of cadmium plating, hub, bearing, spacer and bearing cage material to be released into the grease. Samples were taken for analysis from the remainder of the BCHL 214 fleet and high concentrations of iron, zinc, cadmium and copper were found in the sample from the aircraft whose hub nut was found to be only hand tight; some wear would thus be expected to have occurred. It is thus possible that a regular grease sampling programme, similar to spectrometric oil analyses carried out on engines and gearboxes might provide early warning of torque loss and consequent wear. Such a programme could prove complementary to, or even replace, the labour intensive torque check inspection introduced by an Alert Service Bulletin following the G-BKFN accident.

In summary therefore, once a loss of assembly torque occurs, forces are generated which act on the nut in an unscrewing direction. This is effectively a dormant part of the failure sequence, the assembly subsequently relying for its integrity upon the fatigue resistance of the locking plate. It thus seems logical to recommend that the manufacturer introduces a left hand thread on the hub nut so that in the event of a loss of torque loading, there would be a tendency for the nut to tighten. A revised, strengthened locking plate assembly would also seem to be prudent.

Since the accident, BCHL has experienced some problems with the hub assembly during inspections, *eg* inexplicably high torque values on the hub and sleeve nuts. Such torque loadings were considerably in excess of that which be accounted for by torque wrenches being out of calibration and were close to, or even exceeded that which could be physically applied by the maintenance personnel. No reason for this was established, although it is possible that the remnants of the corrosion preventive compounds are squeezed out under assembly forces with a consequent loss of lubrication effect. However these events serve to illustrate that there are certain aspects of the design and behaviour of the hub assembly that are not fully understood. It is therefore further recommended that the overall design be reviewed by the manufacturer to identify possible additional areas of modification.

2.6 Emergency equipment

2.6.1 Liferaft deployment system

Examination revealed that an overload failure had occurred in the single cable that connected the gas operated actuator to the separate door operating cables. The cable pull-off loads were significantly higher on G-BKFN than on the other B214ST's in BCHL's fleet, and this was due to corrosion in the door handle spigots. In addition, one of the latch linkage pins was found to be fouling on the inside of a false skin on a door. Such a feature is clearly undesirable, although in this instance, the amount of friction it contributed to the system was assessed as small.

The fact that the cable failed suggests that the gas operated actuator applied a force considerably in excess of the 300 pounds or so that would result from a correctly functioning pressure regulator. The results of an unsupervised test on the unit conducted by BCHL indicated that the full 2000 psi reservoir pressure may have been ported to the actuator. However, the performance was satisfactory when the regulator was subjected to the manufacturer's test schedule, and no significant corrosion was found on a subsequent strip examination. Nevertheless, in view of the cable failure, it seems likely that one of the following alternatives occurred:

(a) A degree of "stiction" existed within the regulating valve, causing at least a momentary overpressure condition within the actuator.

(b) The way in which the regulator operates could result in a pressure pulse before the stable, regulated pressure is achieved, and it was this pulse that was responsible for the cable failure.

The fact remains however, that the cable failure would have been less likely to occur had the door operating mechanism been free to move. Furthermore, it is considered that a significant improvement in the design of the system would be achieved by replacing the single element in the latch operating cables with independent cables.

The manner in which the system is functionally checked also deserves scrutiny. Clearly, in performing such a check, it is desirable to operate as many of the system components as possible. The maintenance manual currently instructs that the doors be opened and tied in the raised position, the liferaft valises removed and the pneumatic system operated. However, unless the door handles are returned to the locked position the gas operated actuator will not move the door handles or latch mechanism; only the cables themselves will be moved.

It is therefore recommended that consideration be given to a periodic functional check of the deployment system in its entirety. Clearly if this were to be adopted, some form of netting or cradle would be required in order to catch the valises as they are ejected.

2.6.2 Crew door jettison mechanism

The right hand crew door could not be jettisoned, the handle being apparently seized. This did not, however, materially affect the evacuation. The manufacturers performed tests on the jettison mechanism and concluded that the presence of a frangible plastic strip over the externally mounted jettison handle made little significant difference to the pull-off loads. They reported that in their opinion, a build-up of dirt or corrosion in the mechanism through lack of exercise may have been responsible for the apparent seizure. Unfortunately it was not possible to verify this on G-BKFN, as the mechanism was sprayed with corrosion preventive as soon as the aircraft was recovered to Aberdeen and when examined the handle was free to move. The co-pilot's door, however operated satisfactorily; it thus seems reasonable to conclude that the jettison mechanism was less stiff than that of the right hand door, given that the frangible plastic strip would be expected to exert nominally equal opposing forces to each crew member's efforts. A logical recommendation arising out of this is that a periodic disassembly/lubrication requirement be added to the maintenance manual.

2.6.3 Emergency floatation equipment

The emergency floatation equipment operated satisfactorily although the forward compartment of each fuselage floatation bag became deflated. On the left hand side, evidence was found which indicated that the bag had been punctured as a result of abrasion on a stringer that mounts a glassfibre fairing forward of the float pack. It was not clear what had caused the puncture in the right hand bag, although it is possible that fragments of the glassfibre fairing were responsible. A redesigned stringer combined with a crushable, as opposed to frangible fairing, could alleviate this problem.

One of the passengers entered the sea inadvertently as a result of slipping off the floatation bag, and subsequently found himself drifting towards the still turning tail rotor. The addition of a non slip surface to the float bag material could have prevented exposing the passenger to this hazard. A further comment on the float bag material is that its black colour would not have helped to visually locate the aircraft in the event of a capsize. A high visibility material, such as that already fitted to some helicopter types, would be an advantage in this circumstance.

The shortcomings of the emergency floatation equipment and, to perhaps a greater extent, the liferaft deployment system, were of comparatively minor significance in the benign weather conditions that existed on the day of the accident. However, in more adverse conditions it is probable that the ditching/evacuation processes would have been considerably impeded, with potentially fatal consequences for the passengers and crew. If the aircraft manufacturers had conducted a trial ditching, it is likely that many of the shortcomings would have been identified prior to the type being put into service. It is therefore recommended that future helicopter types be subjected to ditching trials as part of the certification procedure.

3 # Conclusions

(a) Findings

(i) The helicopter had been maintained in accordance with the approved maintenance schedule and its Certificate of Airworthiness was valid.

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

(iii) The helicopter suffered a partial loss of collective control when the collective hub retaining nut became disengaged in flight.

(iv) The crew made a skilful landing in the sea with only partial collective control available.

(v) The forward compartment of the flotation gear ruptured after ditching, on the left hand side this was due to abrasion on the floatation bag fairing attachment structure.

(vi) The liferaft deployment system failed to operate when a cable failed as a result of high frictional forces within the system.

(vii) The rear cabin "Escape Windows" were unable to be pushed out because of the resistance offered by the window sealing strip.

(viii) The Commander was unable to jettison the right hand crew door as result of stiffness in the operating mechanism

(ix) The liferaft stowages and the external instructions for deployment were inadequately highlighted.

(x) Many of the difficulties and equipment failures experienced during the ditching sequences could have been revealed during certification if a ditching trial had been carried out.

(xi) The disengagement of the collective hub nut was a result of an earlier loss of nut torque and fatigue failures of the nut locking plate.

(xii) This and the other failures cited in the collective sleeve assembly indicate the possibility that the flight loading spectrum may be more severe than is currently believed.

(xiii) The Shackleton search and rescue aircraft was not equipped with VHF/FM Marine Band radio and was therefore unable to contact fishing vessels seen in the vicinity of the ditching.

(b) **Cause**

The accident was caused by the partial loss of collective pitch control following the disengagement of the collective hub retaining nut in flight.

A contributory factor was the unsatisfactory design of the collective hub nut locking plate assembly.

4 Safety recommendations

It is recommended that:

4.1 The manufacturer review the flight loading conditions experienced by the collective sleeve and hub assembly.

4.2 The manufacturer consider modifying the collective hub and nut assembly to incorporate a left hand thread and an improved method of nut retention.

4.3 The United Kingdom Civil Aviation Authority should require that helicopter manufacturers demonstrate ditching, liferaft demployment and evacuation during the certification process.

4.4 The Bell 214ST Maintenance Manual should be amended to include periodic lubrication/inspections of the door jettison and liferaft deployment mechanisms. The latter should also be subjected to a periodic functional check which exercises the entire system.

K P R SMART
Inspector of Accidents

Air Accidents Investigation Branch
Department of Transport
December 1987